Analysing impact of oxygen and water exposure on roll-coated organic solar cell performance using impedance spectroscopy

In this work we study the degradation of roll-coated flexible inverted organic solar cells in different atmospheres. We demonstrate that impedance spectroscopy is a powerful tool for elucidating degradation mechanisms; it is used here to distinguish the different degradation mechanisms due to water and oxygen. Identical cells were exposed to different accelerated degradation environments using water only, oxygen only, and both water and oxygen simultaneously, all of them enhanced with UV light. The photocurrent is dramatically reduced in the oxygen-degraded samples. Impedance measurements indicate that this phenomenon is attributed to defects introduced by absorption of oxygen, which results in an increase of the acceptor impurity (NA) at the cathode interface obtained from a Mott-Schottky analysis. Simultaneously, at the anode interface where PEDOT:PSS is not shielded by the substrate, the nature of degradation differs for the water and oxygen degraded samples. While oxygen + UV light decreases the conductivity of the PEDOT:PSS layer, water + UV light changes the PEDOT:PSS work function inducing a depletion region at the anode.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Organic Energy Materials, Universidad Rey Juan Carlos, National Physical Laboratory
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Main Research Area: Technical/natural sciences

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Organic solar cells, Degradation, Impedance spectroscopy, Roll coated OPV

DOIs:
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Source: FindIt
Source-ID: 2393266280
A Novel Algorithm for Lifetime Extrapolation, Prediction, and Estimation of Emerging PV Technologies

Accurate determination of the lifetime of novel hybrid and organic solar cells is often rather challenging due to the very dynamic behavior of such cells over time and ageing curves with shapes of varying nature. Therefore, in order to accurately and reproducibly determine the lifetime of photovoltaic devices with such a behavior, a novel elaboration algorithm is developed, which enables automatic smoothing, filtering, and extrapolation of the real lifetime data and reproducible determination of the lifetime parameters defined in the International Summit on OPV Stability guiding standards. The algorithm is also capable of predicting the lifetime of devices, not tested until the end of sample life, given that there is sufficient number of measured data points to perform reliable extrapolation of ageing curves (to a limited time frame). The algorithm is discussed in detail and a range of examples for different lifetime data are presented.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, University of Padova
Authors: Rizzo, A. (Ekstern), Cester, A. (Ekstern), Madsen, M. V. (Intern), Krebs, F. C. (Intern), Gevorgyan, S. A. (Intern)
Number of pages: 9
Publication date: 2018
Main Research Area: Technical/natural sciences

High stability of benzotriazole and benzodithiophene containing medium band-gap polymer solar cell

The improvement of polymer solar cell stability is a challenge for the scientists and has significant implications commercially. In this study, we investigated the stability of a novel P-SBTBDT active material applied in an inverted type solar cell. Detailed stability experiments comprising shelf life, laboratory weathering and outdoor testing were carried out according to ISOS testing guidelines. Shelf life showed that P-SBTBDT solar cells were very stable after 840 h with encapsulation. Although accelerated weathering aging tests are a very harsh, the devices remained stable after the burn-in phase with T50 from 700 to 840 h, with some P-SBTBDT solar cells did not reach T50 in the time span of the test. Degradation tests on the P-SBTBDT solar cells which were carried out under natural solar light indicated that T40 was reached after 840 h. The results of dark, light, damp and dry stability tests showed that most of the degradation was provoked by failure of the encapsulation. The experiments indicated that P-SBTBDT solar cells are sensitive to light and oxygen but are strikingly stable under humid conditions. Further developments for minimizing the degradation effects using UV-filters and better encapsulation are some of the necessary improvements in further research.

General information
State: Published
Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Organic Energy Materials, Department of Energy Conversion and Storage, Middle East Technical University, Yildiz Technical University, TUBITAK
Pages: 433-444
Publication date: 2018
Main Research Area: Technical/natural sciences
Mechanical stability of roll-to-roll printed solar cells under cyclic bending and torsion

The ability of printed organic solar cells (OSC) to survive repeated mechanical deformation is critical to large-scale implementation. This paper reports an investigation into the mechanical stability of OSCs through bending and torsion testing of whole printed modules. Two types of modules are used that differ slightly in thickness as well as on the basis of the electrode materials: silver nanowires or carbon-based inks. Each type of module is subjected to two different mechanical modes of deformation, bending and torsion, of several thousand cycles per module using a purpose-built robotic device. Analysis of the distribution of stress in the devices performed by finite-element modeling predicts the locations of failure. Failure upon bending originates at the laser-cut edges of the modules from shear at the clamp/module interface leading to crazing of the plastic barrier encapsulant foils. This crazing leads to eventual delamination due first to decohesion of the active layer at the edge of the modules and later to deadhesion between the PEDOT-PSS (electrode) and P3HT:PCBM (semiconductor) layers. The torsion mode imposes greater stresses than the bending mode and thus leads to failure at fewer strain cycles. Failure during torsion occurs through crack propagation initiated at stress concentrations on the edges of the module that were imposed by their rectangular geometry and ultimately leads to bifurcation of the entire module. Rather than the differences in electrode materials, the differences in survivability between the two types of modules are attributed mostly to the thickness of the substrate materials used, with the thinner substrate used in the carbon-based modules (~160 µm) failing at fewer strain cycles than the substrate used in the silver-nanowire-based modules (~190 µm). Taken together, the results suggest ways in which the lifetimes of devices can be extended by the layouts of modules and choices of materials.
METHOD AND APPARATUS FOR CHARACTERIZATION OF A SOLAR CELL

The present disclosure relates to a method for characterization of a solar cell, comprising the steps of: providing an optical probe light; modulating the optical probe light with a modulation frequency of between 100 kHz and 50 MHz, thereby obtaining a modulated probe light; scanning the modulated probe light such that said modulated probe light is incident on at least a part of the surface of the solar cell, and such that the part of the solar cell exposed to the modulated probe light converts the modulated probe light to an electrical signal; detecting and analyzing said electrical signal; and estimating variations in the solar cell, thereby electrically characterizing the solar cell.

The disclosure further relates to a solar cell characterization apparatus for characterization of a solar cell, comprising: a light source for generating an optical probe light; a modulation unit, configured to produce modulated probe light by modulating the optical probe light with a modulation frequency of between 100 kHz and 50 MHz; a light scanning unit for scanning the modulated probe light such that said modulated probe light is incident on at least a part of the surface of the solar cell; and a signal analyzer, configured to detect and analyze electrical signals produced by the solar cell as a response to exposure of the modulated probe light.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Krebs, F. C. (Intern)
Publication date: 16 Mar 2017

Publication information
IPC: H02S 50/ 15 A I
Patent number: WO2017042248
Date: 18/03/2017
Priority date: 08/09/2015
Analysis of electrical and thermal stress effects on PCBM:P3HT solar cells by photocurrent and impedance spectroscopy modeling

We investigated the effects of electrical stress and thermal storage by means of photocurrent, Impedance Spectroscopy and Open Circuit Voltage Decay models. The electrical stress damages only the active layer, by reducing the generation rate, the polaron separation probability and the carrier lifetime. The thermal stress also degrades the anode interface. This reflects on the appearance of an inflection in the I-V photocurrent shape close to the operative region.

Application of Photocurrent Model on Polymer Solar Cells Under Forward Bias Stress

We performed a constant current stress at forward bias on organic heterojunction solar cells. We measured current voltage curves in both dark and light at each stress step to calculate the photocurrent. An existing model applied to photocurrent experimental data allows the estimation of several parameters such as generation, recombination, dissociation rate, and nearly zero field voltage within the active layer as a function of the stress time. The analysis of extrapolated parameters shows that the stress mainly affects the recombination rate of the polaron charge transfer states.
Carbazole-based copolymers via direct arylation polymerization (DArP) for Suzuki-convergent polymer solar cell performance

Although direct arylation polymerization (DArP) has recently emerged as an alternative to traditional cross-coupling methods like Suzuki polymerization, the evaluation of DArP polymers in practical applications like polymer solar cells (PSCs) is limited. Because even the presence of minute quantities of defects can dramatically influence the solar cell performance, DArP polymers offer critical insight alongside other structural and optoelectronic comparisons. Even via traditional methods, carbazole-based donors are frequently prone to homocoupling defects, which has been shown to - along with β-defects - compromise performance. Through defect minimization with the bulky and affordable neodecanoic acid (NDA) mixture, we report the synthesis of DArP poly[(9-(heptadecan-9-yl)-9H-carbazole)-alt-(4,7-di(thiophen-2-yl)benzo[c][1,2,5]thiadiazole)] (PCDTBT) that outperforms Suzuki PCDTBT with similar molecular weights. Expanding beyond this model system, carbazole-based polymers featuring 2,5-diethylhexyl-3,6-di(thiophen-2-yl)-2,5-dihydropyrrolo[3,4-c]pyrrole-1,4-dione (DPP), 4,10-bis(diethylhexyl)-thieno[2',3':5,6]pyrido[3,4-g]thieno[3,2-c]isoquinoline-5,11-dione (TPTI), 5-octyl-1,3-di(thiophen-2-yl)-4H-thieno[3,4-c]pyrrole-4,6(5H)-dione (DT-TPD), and 2,5-bis(2,3-dihydrothieno[3,4-b][1,4]dioxin-5-yl)pyridine (EDOT-Pyr) are generated. Polymers are characterized by 1H NMR, cyclic voltammetry, UV-Vis, GIXRD, SCLC hole mobilities, and are implemented into polymer solar cells fabricated in air under ambient humidity. We demonstrate that DArP polymers perform comparably to Suzuki in practical applications.

General information
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Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, University of Southern California
Authors: Gobalasingham, N. S. (Ekstern), Ekiz, S. (Ekstern), Pankow, R. M. (Ekstern), Livi, F. (Intern), Bundgaard, E. (Intern), Thompson, B. C. (Ekstern)
Pages: 4393-4402
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Scopus rating (2017): SNIP 1.034 SJR 1.778
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 5.3 SJR 2.086 SNIP 1.052
BFI (2015): BFI-level 1
Conjugated Polymers Via Direct Arylation Polymerization in Continuous Flow: Minimizing the Cost and Batch-to-Batch Variations for High-Throughput Energy Conversion

Continuous flow methods are utilized in conjunction with direct arylation polymerization (DArP) for the scaled synthesis of the roll-to-roll compatible polymer, poly[(2,5-bis(2-hexyldecyloxy)phenylene)-alt-(4,7-di(thiophen-2-yl)benzo[c][1,2,5]thiadiazole)] (PPDTBT). PPDTBT is based on simple, inexpensive, and scalable monomers using thienyl-flanked benzothiadiazole as the acceptor, which is the first β-protected substrate to be used in continuous flow via DArP, enabling critical evaluation of the suitability of this emerging synthetic method for minimizing defects and for the scaled synthesis of high-performance materials. To demonstrate the usefulness of the method, DArP-prepared PPDTBT via continuous flow synthesis is employed for the preparation of indium tin oxide (ITO)-free and flexible roll-coated solar cells to achieve a power conversion efficiency of 3.5% for 1 cm² devices, which is comparable to the performance of PPDTBT polymerized through Stille cross coupling. These efforts demonstrate the distinct advantages of the continuous flow protocol with DArP avoiding use of toxic tin chemicals, reducing the associated costs of polymer upscaling, and minimizing batch-to-batch variations for high-quality material.

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Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, University of Southern California, Technical University of Denmark
Authors: Gobalasingham, N. S. (Ekstern), Carlé, J. E. (Intern), Krebs, F. C. (Intern), Thompson, B. C. (Ekstern), Bundgaard, E. (Intern), Helgesen, M. (Intern)
Number of pages: 7
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.19 SJR 1.711 SNIP 0.937
To address sustainability challenges, photovoltaics (PV) are regarded as a promising renewable energy technology. Decreasing PV module costs and increasing residential electricity prices have made self-consumption of PV-generated electricity financially more attractive than exporting to the grid. Organic photovoltaics (OPV) are an emerging thin-film PV technology that shows promise of greatly improving the environmental and economic performances of PV technologies.

Previous studies have estimated the current and future costs of OPV technologies, but the attractiveness of investing in OPV systems has not been evaluated under real market conditions, especially under PV self-consumption schemes. In this study, we investigate the self-consumption of electricity generation from conventional and organic PV systems installed at residential houses in two different countries, Denmark and Greece, under current PV regulatory frameworks. We then focus on modelling and assessing the cost-competitiveness of organic PV technologies based on cost estimations for existing pilot-scale (kW-range), and projected scale-up (100MW) and industrial-scale (100GW) manufacturing capacity levels. Our generic results applying to all PV technologies show that PV systems installed at residential houses in Greece perform economically better than those in Denmark do in terms of self-sufficiency and gross electricity bill savings (i.e. excluding PV costs). Using the two country cases, which present very different settings, we characterise and discuss the influence of three key parameters of the economic performance of PV systems, namely the
PV regulatory scheme, the solar irradiation level and the temporal match between the electricity consumption and solar irradiation profiles. Focusing on organic PV systems developed in an industrial-scale cost setting (1.53€/Wp), we find that they deliver significant electricity bill savings for residential houses in Greece (38%) under current conditions, while they may not be sufficiently attractive for residential houses in Denmark (6.5%) due to mainly the different PV regulatory schemes. Based on these findings, we therefore recommend investors interested in renewable energy technologies to pursue scaling up the manufacturing capacity of OPV technologies, as well as assess a large number of countries to identify and prioritise financially attractive settings for PV self-consumption.
Development of outdoor luminescence imaging for drone-based PV array inspection

This work has the goal to perform outdoor defect detection imaging that will be used in a fast, accurate and automatic drone-based survey system for PV power plants. The imaging development focuses on techniques that do not require electrical contact, permitting automatic drone inspections to be perform quicker and with less manpower. The final inspection method will combine several techniques such as, infrared (IR), electroluminescence (EL), photoluminescence (PL), and visual imaging. Solar plant inspection in the future can be restricted only by imaging speed requirements, allowing an entire new perspective in large-scale PV inspection.

General information

State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, Department of Photonics Engineering, Diode Lasers and LED Systems, Coding and Visual Communication, Skive Kommune, Kenergy, SiCon • Silicon and PV consulting, Aalborg University, Sky-Watch A/S
Number of pages: 2
Publication date: 2017

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Publisher: IEEE

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Main Research Area: Technical/natural sciences

Relations

Projects:
Development of outdoor luminescence imaging for drone-based PV array inspection
Source: FindIt
Source-ID: 2355411135
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

Development of outdoor luminescence imaging for drone-based PV array inspection
This work has the goal to examined experimentally PV module imaging methods under natural light conditions, that will be used in a fast, accurate and automatic drone-based inspection system for PV power plants.
**General information**

State: Published

Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, Department of Photonics Engineering, Diode Lasers and LED Systems, Coding and Visual Communication, Skive Kommune, Kenergy, SiCon • Silicon and PV consulting, Aalborg University, Sky-Watch A/S


Number of pages: 1

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Main Research Area: Technical/natural sciences

Electronic versions:

program_20172.pdf

**Resume:**

More frequently high refractive index dielectric matrix are used in thin film photovoltaics as transporting layers with good optical proprieties. Doping such matrix with plasmonic resonant scatterers is a promising way to further increase energy conversion efficiencies by trapping incoming light in ultrathin solar cells. Colloidal plasmonic oligomers are obtained following a cost-effective selfassembly strategy and incorporated in organic based cells produced using spincoating techniques in ambient air conditions. An interesting increase is observed of both external quantum efficiency (EQE) and short-circuit current for solar cells loaded with plasmonic oligomers compared with reference organic cells. Theoretical calculations demonstrate that the wavelength dependent EQE enhancement is a resonant process due to the increased scattering efficiency in plasmonic antennas allowed by a chemically controlled 1 nm nanogap. The nanogap antennas are linked at a controlled distance of a few nanometers by Dithiothreitol molecules. The spacing molecules ensure a minimum distance that plays a fundamental role in the formation of intensity hot spots in the nanogap as well as large and redshifted scattering peaks. This OPV device, realized in ambient air condition, exhibited an efficiency 14% higher than the reference one showing a relevant enhancement in the red part of the EQE measurements.

**Environmental impacts of electricity self-consumption from organic photovoltaic battery systems at industrial facilities in Denmark**

Organic photovoltaics (OPV) show promise of greatly improving the environmental and economic performance of PV compared to conventional silicon. Life cycle assessment studies have assessed the environmental impacts of OPV, but not under a self-consumption scheme for industrial facilities. We investigate the life cycle environmental impacts of electricity self-consumption from an OPV system coupled with a sodium/nickel chloride battery at an iron/metal industry in Denmark. Results show that an OPV system without storage could decrease the carbon footprint of the industry; installation of the battery increases climate change and human toxicity impacts. We discuss sensitive modelling parameters and provide recommendations.
High definition in-situ electro-optical characterization for Roll to Roll printed electronics

Resume: Printed electronics is emerging as a new, large scale and cost effective technology that will be disruptive in fields such as energy harvesting, consumer electronics and medical sensors. The performance of printed organic electronic devices relies principally on the carrier mobility and molecular packing of the polymer semiconductor material. Unfortunately, the analysis of such materials is generally performed with destructive techniques, which are hard to make compatible with in situ measurements, and pose a great obstacle for the mass production of printed electronics devices. A rapid, in situ, non-destructive and low-cost testing method is needed. In this study, we demonstrate that nonlinear optical microscopy is a promising technique to achieve this goal. Using ultrashort laser pulses we stimulate two-photon absorption in a roll coated polymer semiconductor and map the resulting two-photon induced photoluminescence (TPPL) and second harmonic response. We anticipate that this non-linear optical method will substantially contribute to the understanding of printed electronic devices and demonstrate it as a promising novel tool for non-destructive and facile testing of materials during printing of the device and at any moment during its lifespan. This will help the production and development of high quality printed technologies where the semiconductor material can be accessed by infrared light, such as solar cells, displays and sensors.

General information
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Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Pastorelli, F. (Intern)
Number of pages: 1
Publication date: 2017
Event:
Main Research Area: Technical/natural sciences
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Bibliographical note
SYMPOSIUM L: New materials for organic electronics: from synthesis to processing, characterization and device physics (abstract L. 1.6)
Source: PublicationPreSubmission
Source-ID: 134441444
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2017

Highly Conformal Ni Micromesh as a Current Collecting Front Electrode for Reduced Cost Si Solar Cell

Despite relatively high manufacturing cost, crystalline-Si solar cell continues to hold promising future due to its high energy conversion efficiency and long life. As regards cost, one pertinent issue is the top electrode metallization of textured cell surface, which typically involves screen printing of silver paste. The associated disadvantages call for alternative methods that can lower the cost without compromising the solar cell efficiency. In the present work, a highly interconnected one-dimensional (1D) metal wire network has been employed as front electrode on conventional Si wafers. Here, for the first time, we report an innovative solution based crackle templating method for conformal metal wire network patterning over large textured surfaces. Laser beam induced current mapping showed uniform photocurrent collection by the electrodes without any shadow losses. With electroless deposition of Ni wire network on corrugated solar cell, a short circuit current of 33.28 mA/cm² was obtained in comparison to 20.53 mA/cm² without the network electrode. On comparing the efficiency with the conventional cells with screen printed electrodes, a 20% increment in efficiency has been observed. Importantly, the estimated manufacturing cost is at least two orders lower.

General information
In situ electrical and thermal monitoring of printed electronics by two-photon mapping

Printed electronics is emerging as a new, large scale and cost effective technology that will be disruptive in fields such as energy harvesting, consumer electronics and medical sensors. The performance of printed electronic devices relies principally on the carrier mobility and molecular packing of the polymer semiconductor material. Unfortunately, the analysis of such materials is generally performed with destructive techniques, which are hard to make compatible with in situ measurements, and pose a great obstacle for the mass production of printed electronics devices. A rapid, in situ, non-destructive and low-cost testing method is needed. In this study, we demonstrate that nonlinear optical microscopy is a promising technique to achieve this goal. Using ultrashort laser pulses we stimulate two-photon absorption in a roll coated
polymer semiconductor and map the resulting two-photon induced photoluminescence and second harmonic response. We show that, in our experimental conditions, it is possible to relate the total amount of photoluminescence detected to important material properties such as the charge carrier density and the molecular packing of the printed polymer material, all with a spatial resolution of 400 nm. Importantly, this technique can be extended to the real time mapping of the polymer semiconductor film, even during the printing process, in which the high printing speed poses the need for equally high acquisition rates.

**General information**

State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, ICFO - Institute of Photonic Sciences
Authors: Pastorelli, F. (Intern), Accanto, N. (Ekstern), Jørgensen, M. (Intern), van Hulst, N. F. (Ekstern), Krebs, F. C. (Intern)
Number of pages: 6
Publication date: 2017
Main Research Area: Technical/natural sciences

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Scopus rating (2017): SNIP 1.245 SJR 1.533
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.63 SJR 1.692 SNIP 1.354
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.034 SNIP 1.597 CiteScore 5.3
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.163 SNIP 1.554 CiteScore 4.75
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.998 SNIP 1.57 CiteScore 4.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.531 SNIP 0.962 CiteScore 2.44
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Original language: English
Electronic versions: s41598_017_03891_7.pdf
DOIs: 10.1038/s41598-017-03891-7
Source: FindIt
Source-ID: 2371468520
Publication: Research - peer-review › Journal article – Annual report year: 2017

**Improving, characterizing and predicting the lifetime of organic photovoltaics: Topical Review**

This review summarizes the recent progress in the stability and lifetime of organic photovoltaics (OPVs). In particular, recently proposed solutions to failure mechanisms in different layers of the device stack are discussed comprising both structural and chemical modifications. Upscaling is additionally discussed from the perspective of stability presenting the challenges associated with device packaging and edge protection. An important part of device stability studies is the
characterization, and this review provides a short overview of the most advanced techniques for stability characterization reported recently. Lifetime testing and determination is another challenge in the field of organic solar cells and the final sections of this review discuss the testing protocols as well as the generic marker for device lifetime and the methodology for comparing all the lifetime landmarks in one common diagram. These tools were used to determine the baselines for OPV lifetime tested under different ageing conditions. Finally, the current status of lifetime for organic solar cells is presented and predictions are made for progress in the near future.

**General information**

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Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
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- Web of Science (2018): Indexed yes
- BFI (2017): BFI-level 1
- Scopus rating (2017): SNIP 1.011 SJR 0.717
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): CiteScore 2.07 SJR 1.135 SNIP 1.122
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 1
- Scopus rating (2015): SJR 0.886 SNIP 1.25 CiteScore 2.1
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 1
- Scopus rating (2014): SJR 1.096 SNIP 1.408 CiteScore 2.53
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 1
- Scopus rating (2013): SJR 1.194 SNIP 1.452 CiteScore 2.6
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 1.279 SNIP 1.414 CiteScore 2.31
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 1.266 SNIP 1.399 CiteScore 2.36
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 1.292 SNIP 1.28
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 1.269 SNIP 1.327
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 1.427 SNIP 1.549
- Web of Science (2008): Indexed yes
Indoor measurement of angle resolved light absorption by antireflective glass in solar panels

In this work, we present measurements of angle resolved light absorption of antireflective (AR) glass of PV samples, performed indoors using a collimated high radiance broadband light source. This indoor method proved to be viable and offered a significant simplification compared to outdoor measurements with trackers. The experimental results showed optical responses that are stable and suitable for indoor characterization of solar cells. We find the characteristic optical response of six different antireflective glasses, and based on such measurements, we perform PVsyst simulations and present the monthly DC energy production estimates across four distinct latitudinal locations with six different glass types. The results indicated that the AR glasses present different optical effects at the angles intervals between 0 – 45° and 60 – 90° and that the Diffuse AR glass can improve monthly yields by as much as 2% relatively to a bare cell.

General information
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Organisations: Department of Photonics Engineering, Diode Lasers and LED Systems, Photovoltaic Materials and Systems, Organic Energy Materials, Department of Micro- and Nanotechnology, Silicon Microtechnology, Experimental Surface and Nanomaterials Physics
Number of pages: 4
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Host publication information
Title of host publication: Proceedings of the 33rd European Photovoltaic Solar Energy Conference and Exhibition
Main Research Area: Technical/natural sciences
Antireflective glass, Angle of Incidence, Incidence Angle Modifier, Simulation
Electronic versions:
Poster

Relations
Projects:
Indoor measurement of angle resolved light absorption by antireflective glass in solar panels
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017
**Indoor Measurement of Angle Resolved Light Absorption by Black Silicon**

Angle resolved optical spectroscopy of photovoltaic (PV) samples gives crucial information on PV panels under realistic working conditions. Here, we introduce measurements of angle resolved light absorption by PV cells, performed indoors using a collimated high radiance broadband light source. Our indoor method offers a significant simplification as compared to measurements by solar trackers. As a proof-of-concept demonstration, we show characterization of black silicon solar cells. The experimental results showed stable and reliable optical responses that makes our setup suitable for indoor, angle resolved characterization of solar cells.

**General information**

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Title of host publication: Proceedings of the international 2017 IEEE Photovoltaic Specialists Conference
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Indoor_Measurement_of_Angle_Resolved_Absorption_of_Black_Silicon_CommentsAddressed_BI_Mek_PP_Final_1_.pdf
Source: PublicationPreSubmission
Source-ID: 139805541
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

**In-line, roll-to-roll morphology analysis of organic solar cell active layers**

We present the first comparative in situ small and wide angle X-ray scattering study of two polymers that are relevant for organic photovoltaics, during coating on a flexible substrate. From the obtained measurements we identified several differences between the drying of the two polymers. The polymer optimized for roll-to-roll coating attained its final morphological packing nearly instantly after deposition, and had the shortest drying profile. We therefore conclude that fast-drying polymers which are influenced less by drying temperature or substrate inhomogeneities are better suited for roll-to-roll coating, and that fundamentally, the kinetics of drying dominate the process in the case of roll-to-roll slot-die coating.

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Inside or Outside? Linking Outdoor and Indoor Lifetime Tests of ITO-Free Organic Photovoltaic Devices for Greenhouse Applications

We present results from an installation of fully roll-to-roll printed and coated polymer solar cell modules in a greenhouse environment over the course of roughly 2 years (650 days). We explored two different device architectures based on either fully carbon-based electrodes or silver nanowire (AgNW)-based electrodes and two different barrier materials. We followed the ISOS protocols while studying the devices in three different greenhouse conditions in the Netherlands and compared to reference devices mounted outdoors in Denmark tested according to ISOS-O-1 and ISOS-O-2. We studied each condition and type in multiples to obtain acceptable statistics and found that the AgNW-based devices performed best in terms of stability.

General information
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Authors: Benatto, G. A. D. R. (Intern), Corazza, M. (Intern), Roth, B. (Intern), Schütte, F. (Ekstern), Rengenstein, M. (Ekstern), Gevorgyan, S. (Intern), Krebs, F. C. (Intern)
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Life-Cycle Assessment of Solar Charger with Integrated Organic Photovoltaics

Organic photovoltaics (OPV) applied in a commercial product comprising a solar charged power bank is subjected to a life cycle assessment (LCA) study. Regular power banks harvest electricity from the grid only. The solar power bank (called HeLi-on) is however, a power bank that includes a portable OPV panel, enabling the possibility to be charged from the sun, and not only from the grid. In this paper, two well-established power bank products using amorphous silicon solar panels (a-Si PV) and a regular power bank without any portable solar panel is compared to HeLi-on. The environmental impact of the products is quantified with the aim of indicate where eco-design improvements would make a difference and to point out performance of a portable solar panel depending on the context of use (Denmark and China), realistic disposal scenarios and the recycling relevance particularly concerning metals content.
Luminescence Imaging Strategies for Drone-Based PV Array Inspection

The goal of this work is to develop outdoor defect detection imaging and understand fully its challenges and limitations. The imaging is based on luminescence strategies that will be used for fast and accurate UAV-based inspection system for PV power plants. We studied electroluminescence (EL) acquisition under natural light conditions during several times of the day, under high sun irradiation, to unveil the sunlight noise characteristics towards an InGaAs detector. In order to bring more freedom to a drone-based inspection, we also show the preliminary results of a laser-line based photoluminescence (PL) strategy as a viable method for an outdoor module PL imaging system.

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Model of Organic Solar Cell Photocurrent Including the Effect of Charge Accumulation at Interfaces and Non-Uniform Carrier Generation

We developed an improved model to fit the photocurrent density versus voltage in organic solar cells. The model has been validated by fitting data from P3HT:PCBM solar cells. Our model quantitatively accounts for the band bending near the electrodes caused by charge accumulation in the active layer. The model explains the position of the built-in and the zero-field voltage, the value of the internal electric field, the impact of electrode materials, and the appearance of multiple inflections. In addition, the model can be used to monitor the cell condition during accelerated lifetests.

New Light Source Setup for Angle Resolved Light Absorption measurement of PV sample

Here, we introduce measurements of angle resolved light absorption by PV cells, using broadband laser driven white light source with a bright, stable, broad spectral range and well collimated light.
Overcoming the Scaling Lag for Polymer Solar Cells

There is a long stretch between a laboratory discovery and a practical demonstration. For a potentially useful energy technology, many further strides must be taken before a societally meaningful scale is reached. In this work we have, based on many past experiences, brought the fully roll-to-roll printed polymer solar cell to a realistic scale across the entire value chain. The materials synthesis, the manufacture, the installation, the failure modes, and the operation have all been covered and addressed. We demonstrate outdoor operation for 2 years through a large-scale, grid-tied, high-voltage system and show that thin plastic foil can be operated as an energy-producing technology. Critical to the demonstration was the identification of the drying method during printing, and we show how this development relates to the scaling lag (the period between the point in time for a laboratory demonstration and the point in time for scaled manufacture) and allows for closure of the scaling gap.

Printed organic smart devices characterized by nonlinear optical

In this study, we demonstrate that nonlinear optical microscopy is a promising technique to characterize organic printed electronics. Using ultrashort laser pulses we stimulate two-photon absorption in a roll coated polymer semiconductor and map the resulting two-photon induced photoluminescence (TPPL) and second harmonic response. First, we show that the different nonlinear optical signals can be used to discriminate between the polymer semiconductor material and embedded metal nanoparticles which constitute the electrode in a real device. Next we demonstrate that the TPPL quenches when applying a current between source and drain; this decrease can be used to determine the electrical characteristic of the device [1]. Finally, we show that the TPPL increases with higher temperature in the 20 - 120 °C range, closely following the supported current characteristics of the semiconductor. With this technique, we can recognize different nanomaterials and we propose that the TPPL is a good indicator to map and monitor the charge carrier density and the molecular packing of the printed polymer material. Importantly, simple calculations based on the signal levels, suggest that this technique can be extended to the real time mapping of the polymer semiconductor film, even during the printing process, in which the high printing speed poses the need for equally high acquisition rates.
Printed organic smart devices characterized by ultra-short laser pulses

Resume: In this study, we demonstrate that nonlinear optical microscopy is a promising technique to characterize organic printed electronics. Using ultrashort laser pulses we stimulate two-photon absorption in a roll coated polymer semiconductor and map the resulting two-photon induced photoluminescence (TPPL) and second harmonic response. First, we show that the different nonlinear optical signals can be used to discriminate between the polymer semiconductor material and embedded nanoparticles which constitute the electrode in a real device. Next we demonstrate that the TPPL quenches when applying a current between source and drain; this decrease can be used to determine the electrical characteristic of the device. Finally, we show that the TPPL increases with higher temperature in the 20 - 120 °C range, closely following the supported current characteristics of the semiconductor. We propose that the TPPL is a good indicator to map and monitor the charge carrier density and the molecular packing of the printed polymer material. Importantly, simple calculations based on the signal levels, suggest that this technique can be extended to the real time mapping of the polymer semiconductor film, even during the printing process, in which the high printing speed poses the need for equally high acquisition rates.

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Authors: Pastorelli, F. (Intern)
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Quantification of solar cell failure signatures based on statistical analysis of electroluminescence images

We propose a method to identify and quantify the extent of solar cell cracks, shunting, or damaged cell interconnects, present in crystalline silicon photovoltaic (PV) modules by statistical analysis of the electroluminescence (EL) intensity distributions of individual cells within the module. From the EL intensity distributions (ELID) of each cell, we calculated summary statistics such as standard deviation, median, skewness and kurtosis, and analyzed how they correlate with the type of the solar cell degradation.

We found that the dispersion of the ELID increases with the size and severity of the solar cell cracks, correlating with an increase in standard deviation and decrease in kurtosis. For shunted cells, we found that the ELID median is strongly correlated with the extent of cell shunting. Last, cells with damaged interconnect ribbons show current crowding and increased series resistance regions, characterized by increased dispersion and skewness of the ELID. These cell-level diagnostic parameters can be used to quantify the level of mismatch between the solar cells in the module, which can represent the extent of the module degradation, due to transportation, installation, or field operation. The method can be easily automated for quality control by module manufacturers or installers, or can be used as a diagnostic tool by plant operators and diagnostic service providers.

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Organisations: Department of Photonics Engineering, Photovoltaic Materials and Systems, Organic Energy Materials, Aalborg University, National Renewable Energy Laboratory
Authors: Spataru, S. (Ekstern), Parikh, H. (Ekstern), Benatto, G. A. D. R. (Intern), Hacke, P. (Ekstern), Sera, D. (Ekstern), Poulsen, P. B. (Intern)
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SUN HUB – ENERGY HUB FOR OUTDOOR TABLES
Solar cells integrated into products are attracting more and more attention especially due to the dramatically declining cost of solar cells. Furthermore, we are getting more dependent on portable units like mobile phones, tablets and PCs which has to be charged to be of any use. Especially on festivals where people camps for several days it can be hard to have your portable units charged. In this this work we report a solar powered hub, as an add-on to a table in the urban environment for charging mobile phones and tablets and other handheld devices through USBs, charging laptops through AC connections, providing opportunity to stream music via Bluetooth and play it from a handheld device to the table and lastly to provide LED lighting on the table during the dark hours. 3 prototypes of the system was built and tested at the Roskilde Festival 2017. Electrical logger units were built into the 3 Sun Hubs to monitor the overall energy system and the consumption of each functionality in the table.

Synthesis of conjugated polymers with complex architecture for photovoltaic applications
A common approach to bulk heterojunction solar cells involves a “trial and error” approach in finding optimal kinetically unstable morphologies. An alternative approach assumes the utilization of complex polymer architectures, such as donor–acceptor block copolymers. Because of a covalent preorganization of the donor and acceptor components, these materials may form desirable morphologies at thermodynamic equilibrium. This chapter reviews synthetic approaches to such architectures and shows the first photovoltaic results.
Toward a drone-based EL and PL inspection tool for PV power plants

On-site inspection of PV systems has been historically performed through visual inspection, infrared (IR) thermography, and electrical measurements. Recent advances and cost reductions in unmanned aerial vehicle (UAV) technology have led to adoption of UAVs equipped with thermal cameras for inspection of PV plants, which survey power plants in a fraction of the time and cost than walk through IR imaging. IR imaging however, is limited only to detection of certain fault types that result in elevated temperatures. Techniques such as electro-(EL) and photo-(PL) luminescence imaging offer a higher level of image detail and qualitative insight compared to IR thermography. Furthermore, detection and identification of incipient or severe faults in PV panels is more straightforward. This project proposes for the first time a fast and accurate automatic drone-based inspection method for large PV plants that combines IR, EL, PL imaging, and visual images (VI), called DronEL. The overarching goal is to correlate these images with known PV failures such as hotspots, cell cracks, and potential induced degradation. The DronEL project is carried out by a number of academic and commercial partners including Denmark’s Technical University (DTU), Aalborg University (AAU), Sky-watch, SiCon and Kenergy.

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Using ISOS consensus test protocols for development of quantitative life test models in ageing of organic solar cells

As Organic Photovoltaic (OPV) development matures, the demand grows for rapid characterisation of degradation and application of Quantitative Accelerated Life Tests (QALT) models to predict and improve reliability. To date, most accelerated testing on OPVs has been conducted using ISOS consensus standards. This paper identifies some of the problems in using and interpreting the results for predicting ageing based upon ISOS consensus standard test data. Design of Experiments (DOE) in conjunction with data from ISOS consensus standards are used as the basis for developing life test models for OPV modules. This is used to study their temperature-humidity and light-induced degradation, which enables failure rates during accelerated testing to be assessed against the typical outdoor operational conditions. The life test models are used to assess the relative severity of the ISOS standards and the impact of geographic and seasonal climatic changes on OPV degradation.

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Authors: Kettle, J. (Ekstern), Stoichkov, V. (Ekstern), Kumar, D. (Ekstern), Corazza, M. (Intern), Gevorgyan, S. A. (Intern), Krebs, F. C. (Intern)
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Web of Science (2008): Indexed yes
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Web of Science (2007): Indexed yes
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Web of Science (2006): Indexed yes
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Web of Science (2005): Indexed yes
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Organic solar cells, OPV, Stability of OPVs

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Voltage and Thermally Driven Roll-to-Roll Organic Printed Transistor Made in Ambient Air Conditions
Resume: Organic thin film transistors offer great potential for use in flexible electronics. Much of this potential lies in the solution processability of the organic polymers enabling both roll coating and printing on flexible substrates and thus greatly reducing the material and fabrication costs. We present flexible organic power transistors prepared by fast (20 m min⁻¹) roll-to-roll flexographic printing of the drain and source electrode structures, with an interspace below 50 μm, directly on polyester foil[1]. The devices have top gate architecture and were completed by slotdie coating of the organic semiconductor poly3hexylthiophene and the dielectric material polyvinylphenol before the gate was applied by screen printing. All the processing was realized in ambient air on a PET flexible substrate. We explore the footprint and the practically accessible geometry of such devices with a special view toward being able to drive large currents while handling the thermal aspects in operation together with other organic printed electronics technologies such as large area organic photovoltaics (OPV) and large area electrochromic displays (EC). We find especially that an elevated operational temperature is beneficial with respect to both transconductance and on/off ratio. We achieve high currents of up to 45 mA at a temperature of 80 °C. Finally, we observe a significant temperature dependence of the performance, which can be explored further in sensing applications.

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Analysis of diverse direct arylation polymerization (DArP) conditions toward the efficient synthesis of polymers converging with stille polymers in organic solar cells
Despite the emergence of direct arylation polymerization (DArP) as an alternative method to traditional cross-coupling routes like Stille polymerization, the exploration of DArP polymers in practical applications like polymer solar cells (PSCs) is limited. DArP polymers tend to have a reputation for being marginally inferior to Stille counterparts due to the increased presence of defects that result from unwanted side reactions in direct arylation, such as unselective C-H bond activation and homocoupling. We report ten DArP protocols across the three major classes of DArP to generate poly[(2,5-bis(2-hexyldecyloxy)phenylene)-alt-(4,7-di(thiophen-2-yl)benzo[c][1,2,5]thiadiazole)] (PPDTBT). Through evaluation of the method and resulting photophysical and electronic properties, we show not all DArP methods are suitable for generating device-quality alternating copolymers. When DArP PPDTBT was synthesized in superheated THF with Cs2CO3, neodecanoic acid, and P(o-anisyl)3, it generated polymers of exceptional quality that performed comparably to Stille counterparts in both roll coated ITO-free and spin-coated ITO devices.

General information
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Organisations: Functional organic materials, Department of Energy Conversion and Storage, University of Southern California
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A stability study of polymer solar cells using conjugated polymers with different donor or acceptor side chain patterns

Improvement of the power conversion efficiency and long term stability remains to be of crucial importance for the further development of polymer solar cells (PSCs). Herein, a donor-acceptor copolymer based on 4,8-di(thiophene-2′-yl)benzo[1,2-b:4,5-b']dithiophene (DTBDT) and 4,7-di(thiophene-2′-yl)benzo[c][1,2,5]thiadiazole (DTBT), specifically selected because of its suitability for roll-coating in the ambient environment, is investigated in terms of operational stability via partial exchange (5 or 10%) of the alkyl side chain on either the donor or the acceptor monomer with a 2-hydroxyethyl or 2-phenylethyl group. It is shown that the exchange of the hexyl chain on the DTBT moiety has a negative impact on the stability of the polymer as well as on the performance of the resulting PSCs. On the other hand, partial exchange of the 2-hexyldecyl side chain of the BDT unit by a 2-hydroxyethyl group results in an improved photochemical stability of the polymer film and a higher efficiency of 5.6% for the spin-coated PSC. The stability of roll-coated devices also slightly increases with the incorporation of 10% of either the 2-hydroxyethyl or 2-phenylethyl side chain.

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Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, Hasselt University, Vrije Universiteit Brussel
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Baselines for Lifetime of Organic Solar Cells
The process of accurately gauging lifetime improvements in organic photovoltaics (OPVs) or other similar emerging technologies, such as perovskites solar cells is still a major challenge. The presented work is part of a larger effort of developing a worldwide database of lifetimes that can help establishing reference baselines of stability performance for OPVs and other emerging PV technologies, which can then be utilized for pass-fail testing standards and predicting tools. The study constitutes scanning of literature articles related to stability data of OPVs, reported until mid-2015 and collecting the reported data into a database. A generic lifetime marker is utilized for rating the stability of various reported devices.
The collected data is combined with an earlier developed and reported database, which was based on articles reported until mid-2013. The extended database is utilized for establishing the baselines of lifetime for OPVs tested under different conditions. The work also provides the recent progress in stability of unencapsulated OPVs with different architectures, as well as presents the updated diagram of the reported record lifetimes of OPVs. The presented work is another step forward towards the development of pass-fail testing standards and lifetime prediction tools for emerging PV technologies.

Characterization and modeling of organic (P3HT:PCBM) solar cells as a function of bias and illumination
We investigated the response of roll coated organic solar cells at different bias voltages and illumination levels to implement a detailed impedance model. The technique used for the investigation is based on the combination of standard...
DC characterization with the impedance spectroscopy at different bias and illumination intensity conditions. We analyzed both fresh and intentionally degraded cells. The impedance spectra show different peaks evolutions, depending on the degradation of the cells. Moreover, the same trend appears by measuring the cell at different illumination levels. To describe the cell impedance behaviors we suggest an electrical model based on distributed elements. By fitting the model to experimental data, we extrapolate the parameters related to electron transport, recombination and accumulation. The main differences between fresh and degraded samples are underlined. (C) 2016 Elsevier B.V. All rights reserved.

Renewable energies are a critical and necessary technological development deeply connected to human evolution and even survival. The extraordinary technological development of the past century brought tremendous changes to the planet which, despite the scepticism of some, are indubitably affecting the natural ecosystem and maybe even the destiny of Earth. Human evolution does not mean only advanced technological development, but also deeper consciousness and responsibility for the next generations to come. Everything on Earth exists because of the Sun: heat, wind, life... everything. Therefore, solar energy is one of the answers for renewable energy. In this thesis, the research has been conducted on polymer solar cells. In particular, the thesis deals with the extensive study of device lifetime, characterized with several methods: from bare benchmarking of the lifetimes, to more advanced characterizations of different device properties and materials under degradation. The devices were mostly produced using roll-to-roll processing, which is compatible with an upscaled production, essential for commercialization. Therefore, a fast characterization of a large number of samples has been a general goal of this thesis, which has been driving the choice of both the measurement techniques and also the methods for data handling. This included the development of both novel hardware and software. The possibility of fast screening a large number of devices can in fact lead to a faster improvement of the technology, due to the large amount of experimental data that would become available in a relatively short time. Real time in-situ data analysis, during the fabrication, is possibly the ultimate type of fast screening technique. In-situ X-ray diffraction analysis is a good example of a fast screening technique, that has been presented in this thesis. The challenge of standardizing the report of lifetime was addressed, with the development of novel methods for intercomparing the lifetime of a large amount of data. In particular, the comparison of the lifetime extracted under accelerated and outdoor conditions allowed for the generation of a tool for lifetime prediction. The lifetime extracted from outdoor conditions was found to be in between the one extracted from moderate conditions (shelf test and high temperature storage) and harsher conditions (light soaking and damp heat test). In-depth characterization techniques were also employed in order to study the effect of degradation on the device structure and its interfaces. This was done by exploiting different techniques that measured different properties of the device: mechanical, imaging, and electrical. Mechanical characterization of roll-to-roll processed samples allowed the detection of a mechanically weak interface between PEDOT:PSS and ZnO, which could be improved by applying a combination of humidity and high temperature. Moreover, impedance spectroscopy combined with modelling enabled identifying the degradation of the ZnO / active layer interface. Finally, imaging of cross sections of an ITO-free roll-to-roll processed device was performed successfully using transmission electron microscopy. The cross sections were prepared both with focused-ion-beam and ultramicrotomy, which gave the possibility for effectively comparing these two techniques. Moreover, the sectioning of the solar cells with a diamond blade, in the ultramicrotomy, opened the possibility for a fast cross sections preparation. An optimal lifetime characterization, producing relevant data for the whole OPV field, both on the macroscopic and on the microscopic level, in a fast and automatic way, is possibly the perfect lifetime characterization. The extensive characterization of lifetime performed in this thesis was done with the attempt to approach to such an optimal characterization, providing valuable results to study the effect of degradation and also providing effective tools for increasing the lifetime data exchange within the OPV research field.

General information
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Comparative Indoor and Outdoor Degradation of Organic Photovoltaic Cells via Inter-laboratory Collaboration

We report on the degradation of organic photovoltaic (OPV) cells in both indoor and outdoor environments. Eight different research groups contributed state of the art OPV cells to be studied at Pomona College. Power conversion efficiency and fill factor were determined from IV curves collected at regular intervals over six to eight months. Similarly prepared devices were measured indoors, outdoors, and after dark storage. Device architectures are compared. Cells kept indoors performed better than outdoors due to the lack of temperature and humidity extremes. Encapsulated cells performed better due to the minimal oxidation. Some devices showed steady aging but many failed catastrophically due to corrosion of electrodes not active device layers. Degradation of cells kept in dark storage was minimal over periods up to one year.

General information

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Scopus rating (2013): SJR 0.913 SNIP 1.08 CiteScore 3.1
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Comparison of the electron work function, hole concentration and exciton diffusion length for P3HT and PT prepared by thermal or acid cleavage

The electron work function, hole concentration and diffusion length were compared for poly(3-hexylthiophene) polymer (P3HT) that is commonly used for construction of solar cells, and two types of native polythiophene (PT) samples which are prospective candidates for this purpose. The polythiophene samples were prepared from 2 different precursors by thermal or chemical treatment at room temperature. Cyclic voltammetry and work function measurements were used for estimating the concentration of holes. The measured data were evaluated assuming the validity of band theory based on the tight-binding model. Published data on the valence bandwidth were used for calculating the value of the overlap integral which is related to the hole effective mass. Energy band diagrams were constructed for all 3 materials. Finally, the exciton diffusion length, which is a critical parameter for the application of conjugated polymer materials in solar cells, was measured by a modified surface photovoltage method. The approach allowed us to identify the differences in the material properties related to the processing method. Morphology of the samples determined by AFM was another tool showing these differences. It is stated that a native polythiophene prepared by treatment with acids is a prospective material for solar cells and shows a similar quality as that produced by a thermal process. © 2015 Elsevier Ltd. All rights reserved.

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Authors: Tousek, J. (Ekstern), Touskova, J. (Ekstern), Ludvík, J. (Ekstern), Liška, A. (Ekstern), Remes, Z. (Ekstern), Kylian, O. (Ekstern), Kousal, J. (Ekstern), Chomutová, R. (Ekstern), Heckler, I. M. (Intern), Bundgaard, E. (Intern), Krebs, F. C. (Intern)
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Scopus rating (2017): SNIP 0.923 SJR 0.492
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.544 SNIP 0.976 CiteScore 1.67
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.612 SNIP 0.969 CiteScore 1.7
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.675 SNIP 0.987 CiteScore 1.7
Comparison of ultramicrotomy and focused-ion-beam for the preparation of TEM and STEM cross section of organic solar cells

The challenge of preparing cross sections of organic photovoltaics (OPV) suitable for transmission electron microscopy (TEM) and scanning TEM (STEM) is addressed. The samples were polymer solar cells fabricated using roll-to-roll (R2R) processing methods on a flexible polyethylene terephthalate (PET) substrate. Focused ion beam (FIB) and ultramicrotomy were used to prepare the cross sections. The differences between the samples prepared by ultramicrotomy and FIB are addressed, focusing on the advantages and disadvantages of each technique. The sample prepared by ultramicrotomy yielded good resolution, enabling further studies of phase separation of P3HT:PCBM by means of energy filtered TEM (EFTEM). The sample prepared by FIB shows good structure preservation, but reduced resolution due to non-optimal thicknesses achieved after treatment. Degradation studies of samples prepared by ultramicrotomy are further discussed, which reveal particular effects of the ISOS-L-3 aging test (85 °C, 50% R.H., 0.7 Sun) onto the sample, especially pronounced in the silver layer.
Conjugated Polymers for Energy Production: Finding Suitable Candidates for Low Cost Solar Cells

This dissertation is aimed at developing materials for flexible, large area, ITO-free polymer solar cells (PSCs) fully printed under ambient conditions. A large screening of conjugated polymers, both novel and well-known materials, has been carried out in order to find suitable candidates for scalable PSCs fully printed under ambient conditions [Adv. Energy Mater. 2015, 5, 1402186]. PPDTBT resulted to be the conjugated polymer with the best photovoltaic performance within the 104 synthesized macromolecules. Therefore, further studies have been done on such material. The impact of side chain position on the physical and electrical properties of PPDTBT backbone have been evaluated, finding that anchoring a branched alkoxy chain to benzene leads to PCE as high as 3.6%, a considerably high performance for flexible ITO-free PSCs (area of approx. 1 cm²) [Macromolecules 2015, 48, 3481–3492]. Direct arylation (DAr) and direct arylation polymerization (DArP) have been applied to the preparation of PPDTBT, making this polymer readily available in only 4 synthetic steps and thus easily transferable to a large scale-production setup. DArP avoids organometallic species and therefore is an appealing polymerization method for industrial production of polymers. Several DArP protocols have been employed for the synthesis of PPDTBT leading to polymers with high structural regularity and photovoltaic performances comparable with the same materials synthesized via Stille cross-coupling polymerization. The reactivity of DArP has been further studied and applied to the synthesis of fluorinated copolymers featuring thiophene, which are largely used materials for organic electronics. In particular, by moving the bromine functionality from one monomer to the other, a big impact on the reactivity has been observed. When a thiophene-based donor monomer was brominated and copolymerized with 1,2,4,5-tetrafluorobenzene, hydrodehalogenation side reactions were suppressed, leading to the synthesis of the new PTPTP4 defects-free copolymer [J. Polym. Sci.Part A: Polym. Chem. 2015, 53, 2598–2605].
Editorial for the special issue life cycle, environmental, ecology and impact analysis of solar technology

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Technical University of Cartagena, Star Science
Authors: Espinosa, N. (Ekstern), Krebs, F. C. (Intern), Lampert, C. M. (Ekstern)
Number of pages: 1
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Main Research Area: Technical/natural sciences

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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.532 SJR 1.459
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.182 SNIP 2.577 CiteScore 5.16
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Effects of current stress and thermal storage on polymeric heterojunction P3HT:PCBM solar cell

We subjected P3HT:PCBM solar cells to electrical constant current stress and thermal storage. We employed the impedance spectroscopy technique combined to conventional DC measurements for device characterization during all stresses. We identified and separated different contributions affecting the open circuit voltage and short circuit current. Several mechanisms are behind these changes during the stresses; in particular, we underlined the exciton recombination rate and the variation of the built-in voltage.

General information

State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, University of Padova
Number of pages: 6
Publication date: 2016

Host publication information
Title of host publication: 2016 International Reliability Physics Symposium (IRPS)
Publisher: IEEE
ISBN (Print): 978-1-4673-9138-2
ISSN: 1541-7026
Main Research Area: Technical/natural sciences
Stress, Solar cell, Heterojunctions, Current, Thermal stability
DOIs: 10.1109/IRPS.2016.7574523
Source: FindIt
Source-ID: 2346008884
Publication: Research - peer-review › Article in proceedings – Annual report year: 2016
Flexible ITO-free organic solar cells applying aqueous solution-processed V2O5 hole transport layer: An outdoor stability study

Solution processable semiconductor oxides have opened a new paradigm for the enhancement of the lifetime of thin film solar cells. Their fabrication by low-cost and environmentally friendly solution-processable methods makes them ideal barrier (hole and electron) transport layers. In this work, we fabricate flexible ITO-free organic solar cells (OPV) by printing methods applying an aqueous solution-processed V2O5 as the hole transport layer (HTL) and compared them to devices applying PEDOT:PSS. The transparent conducting electrode was PET/Ag/PEDOT/ZnO, and the OPV configuration was PET/Ag/PEDOT/ZnO/P3HT:PC60BM/HTL/Ag. Outdoor stability analyses carried out for more than 900 h revealed higher stability for devices fabricated with the aqueous solution-processed V2O5.
photovoltaics and compared to traditional printed silver electrodes based on micron sized silver flakes using life cycle analysis and environmental impact analysis methods. The life cycle analysis of AgNWs confirms that they provide an avenue to low-impact semitransparent electrodes. We find that the benefit of AgNWs in terms of embodied energy is less pronounced than generally assumed but that the toxicological and environmental benefits are significant.

**General information**
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Espinosa Martinez, N. (Intern), Søndergaard, R. R. (Intern), Jørgensen, M. (Intern), Krebs, F. C. (Intern)
Number of pages: 8
Pages: 893–899
Publication date: 2016
Main Research Area: Technical/natural sciences

**Publication information**
Journal: ChemSusChem (Print)
Volume: 9
Issue number: 8
ISSN (Print): 1864-5631
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 1.235 SJR 2.538
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 6.7 SJR 2.505 SNIP 1.311
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.53 SNIP 1.424 CiteScore 7.33
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.864 SNIP 1.663 CiteScore 7.97
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.561 SNIP 1.46 CiteScore 6.79
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 3.054 SNIP 1.553 CiteScore 6.72
ISI indexed (2012): ISI indexed yes
Scopus rating (2011): SJR 2.759 SNIP 1.497 CiteScore 5.53
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 1.959 SNIP 1.143
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 0.979 SNIP 0.718
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.297 SNIP 0.508
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.281 SNIP 0.49
Scopus rating (2006): SJR 0.242 SNIP 0.37
Scopus rating (2005): SJR 0.195 SNIP 0.287
Scopus rating (2004): SJR 0.214 SNIP 0.272
Scopus rating (2003): SJR 0.276 SNIP 0.417
Scopus rating (2002): SJR 0.3 SNIP 0.584
Scopus rating (2001): SJR 0.29 SNIP 0.496
Scopus rating (2000): SJR 0.425 SNIP 0.571
Flow synthesis - the answer to reproducible high-performance conjugated polymers on the scale that R2R processing demands

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Helgesen, M. (Intern)
Publication date: 2016

Publication information
Media of output: Video
Original language: English
Publisher: DTU Energy
Main Research Area: Technical/natural sciences
Links:
https://youtu.be/S1KSjEnRJgM

Bibliographical note
Invited talk
Publication: Research - peer-review › Sound/Visual production (digital) – Annual report year: 2016

High Current Printed Transistor

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Pastorelli, F. (Intern), Schmidt, T. M. (Intern), Hösel, M. (Intern), Søndergaard, R. R. (Intern), Jørgensen, M. (Intern), Krebs, F. C. (Intern)
Number of pages: 1
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Publication date: 2016

Host publication information
Title of host publication: Book of Abstracts. General Assembly of the Marie Curie Alumni Association 2016
Publisher: Marie Curie Alumni Association
Main Research Area: Technical/natural sciences
Conference: General Assembly of the Marie Curie Alumni Association, Venice, Italy, 04/03/2016 - 04/03/2016
Electronic versions:
High_Current_Printed_Transistor.pdf
Source: PublicationPreSubmission
Source-ID: 127807214
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2016

High Current Printed Transistor: Roll-to-Roll Manufacture and Thermal Behavior

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Pastorelli, F. (Intern), Schmidt, T. M. (Intern), Hösel, M. (Intern), Søndergaard, R. R. (Intern), Jørgensen, M. (Intern), Krebs, F. C. (Intern)
Number of pages: 1
Publication date: 2016
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Main Research Area: Technical/natural sciences
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High Current Temperature Sensitive RolltoRoll Printed Transistor

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Pastorelli, F. (Intern)
Number of pages: 1
Publication date: 2016
Event: Abstract from 2016 MRS Fall Meeting & Exhibit, Boston, MA, United States.
Main Research Area: Technical/natural sciences
Electronic versions:
High_Current_Temperature.pdf

Bibliographical note
Symposium PM4 : Novel Materials, Fabrication Routes and Devices for Environmental Monitoring
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2016

In situ X-ray scattering of perovskite solar cell active layers roll-to-roll coated on flexible substrates
In an effort to understand recent results showing differences between the power conversion efficiencies of lead halide (CH$_3$NH$_3$PbI$_3-x$Cl$_x$) solar cells on glass versus flexible substrates, this study investigates the influence that substrate and processing methods have on morphological and crystallographic development. Using our in situ slot-die micro roll-to-roll coater setup, we measured small and wide angle X-ray scattering in grazing incidence while the material dried, enabling us to follow the crystallization from just after the deposition and up to 25 minutes later. The data showed differing crystallographic developments between the substrates, especially seen through the behaviour of a crystalline precursor which survived longer on the flexible substrates than on glass. Additionally, the common degradation product PbI$_2$ was absent on the thickest flexible substrate. This leads us to conjecture that the flexible substrates absorb part of the solvent, thereby delaying evaporation and changing the solvent environment around the perovskite. As a further test, we produced solar cells with the same substrates and confirmed that the ones made on flexible substrates performed worse than those made on glass, but that when including an ITO layer in the stack it seemed to act as a buffer, whereby the solar cell performance was improved.

General information
State: Published
Number of pages: 6
Pages: 5083-5088
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information
Journal: CrystEngComm
Volume: 18
Issue number: 27
ISSN (Print): 1466-8033
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 0.823 SJR 0.998
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.37 SJR 1.053 SNIP 0.904
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Improving the Operational Stability of PBDTTTz-4 Polymer Solar Cells Modules by Electrode Modification

PBDTTTz-4 is employed in the ambient manufacturing of fully Roll-to-Roll organic solar cell modules. Modules are manufactured using a novel silver nanowire electrode or a previously reported carbon electrode. The average PCE of carbon modules (3.07%) and AgNW modules (1.46%) shows that PBDTTTz-4 is a good candidate for upscaling. Stability measurements following the ISOS standards are used to compare the lifetime of the different modules. In all tests but one, the carbon modules are less stable. The higher stability of AgNW is attributed to the removal of the PEDOT:PSS in the front electrode. Finally during indoor light tests, a new degradation phenomenon is observed where bubbles are formed inside the modules contrary to previous reports of bubble formation by thermal expansion of trapped gas inside the barrier.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Number of pages: 7
Published: 2016
Main Research Area: Technical/natural sciences
Incineration of organic solar cells: Efficient end of life management by quantitative silver recovery

Recovery of silver from the electrodes of roll-to-roll processed organic solar cells after incineration has been performed quantitatively by extraction with nitric acid. This procedure is more than 10 times faster than previous reports and the amount of acid needed for the extraction is reduced by a factor of 100-150. LCA studies show that the resulting environmental impacts from silver extraction of incinerated ashes are more favourable on almost all standard factors compared to extraction from shredded organic solar cells. The lessened environmental impacts by efficient recovery fully justify the use of Ag as an electrode in scaled production of organic solar cells.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, University of Applied Sciences and Arts Northwestern Switzerland
Authors: Søndergaard, R. R. (Intern), Zimmermann, Y. S. (Ekstern), Espinosa Martinez, N. (Intern), Lenz, M. (Ekstern), Krebs, F. C. (Intern)
Number of pages: 5
Pages: 857-861
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information
Journal: Energy & Environmental Science
Volume: 9
Issue number: 3
ISSN (Print): 1754-5692
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 4.819 SJR 14.59
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 7.769 SNIP 4.001 CiteScore 19.28
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.019 SNIP 2.996 CiteScore 14.81
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 5.868 SNIP 2.599 CiteScore 11.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 3.737 SNIP 2.505 CiteScore 9.96
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 3.87 SNIP 2.42
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 2.111 SNIP 1.15
Original language: English
In-situ, long-term operational stability of organic photovoltaics for off-grid applications in Africa
This paper presents a field-trial of organic photovoltaic (OPV) technology used within a practical application for rural electrification in Rwanda. Fourteen, large area, flexible, ITO-free, roll-to-roll processed OPV modules, encapsulated with low-cost materials, were installed on corrugated steel roofs at two sites in a rural village in Southern Rwanda and subject to continuous monitoring. This field-trial exposed modules to very high levels of insolation, in particular in the UV, high temperatures and heavy rainfall. Results show that the modules exhibit practical lifetimes (to degrade by 20% of their initial capacity) of between 2 and 5 months, a value 5-6 times lower than control modules kept both in the dark and outdoors in Roskilde, Denmark. Degradation was primarily the result of extensive delamination caused by failure of the non-UV stable encapsulation, which led to decay in the FF, Voc and Isc of the module.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imperial College London, MeshPower Limited
Number of pages: 10
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Publication date: 2016
Main Research Area: Technical/natural sciences

Publication information
Journal: Solar Energy Materials and Solar Cells
Volume: 149
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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.532 SJR 1.459
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Introduction to the Issue on Organic Nanophotonics

The papers in this special issue focus on the topic of organic nanophotonics. Since early works in the 1980s, significant advances have been made in organic materials with semiconducting and photonic properties due to the development of materials/device technologies on the nanoscale. The most impressive outcomes include organic light-emitting devices (OLEDs) that are now competing with the well-established liquid crystal display technology in the mobile and television markets. In addition, organic solar cells (OSCs) offer the potential to create new paradigms for ultrathin and lightweight plastic solar modules in the coming flexible electronics era. Further developments are ongoing across a broad range of organic nanophotonics topics including organic laser devices, organic phototransistors, organic plasmonic devices, etc. This issue introduces recent cutting-edge research from the fast-breaking area of organic nanophotonics. The subject in this special issue includes organic lasers, OLEDs, organic photovoltaics, organic phototransistors, microcavities, and related materials. In particular, most papers included in this special issue offer insights into technology innovations including flexible optoelectronics. We trust that readers will benefit from the timely and in-depth research presented in this special issue and get an insight into future nanophotonics directions with organic and related materials.

General information

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Kyungpook National University, University of Oxford, Beijing Jiaotong University, Monash University
Laser beam induced current mapping (LBIC) of solar cells

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Jørgensen, M. (Intern)
Publication date: 2016

Publication Information
Media of output: Video
Original language: English
Publisher: DTU Energy
Main Research Area: Technical/natural sciences
Links:
https://youtu.be/gH4vyC-CUsg

Bibliographical note
Invited talk
Publication: Research - peer-review › Sound/Visual production (digital) – Annual report year: 2016

Lifetime of organic photovoltaics: Status and predictions

The results of a meta-analysis conducted on organic photovoltaics (OPV) lifetime data reported in the literature is presented through the compilation of an extensive OPV lifetime database based on a large number of articles, followed by analysis of the large body of data. We fully reveal the progress of reported OPV lifetimes. Furthermore, a generic lifetime marker has been defined, which helps with gauging and comparing the performance of different architectures and materials from the perspective of device stability. Based on the analysis, conclusions are drawn on the bottlenecks for stability of device configurations and packaging techniques, as well as the current level of OPV lifetimes reported under different aging conditions. The work is summarized by discussing the development of a tool for OPV lifetime prediction and the development of more stable technologies. An online platform is introduced that will aid the process of generating statistical data on OPV lifetimes and further refinement of the lifetime prediction tool.

General information
State: Published

Lifetime of Organic Photovoltaics: Status and Predictions

The results of a meta-analysis conducted on organic photovoltaics (OPV) lifetime data reported in the literature is presented through the compilation of an extensive OPV lifetime database based on a large number of articles, followed by analysis of the large body of data. We fully reveal the progress of reported OPV lifetimes. Furthermore, a generic lifetime marker has been defined, which helps with gauging and comparing the performance of different architectures and materials from the perspective of device stability. Based on the analysis, conclusions are drawn on the bottlenecks for stability of device configurations and packaging techniques, as well as the current level of OPV lifetimes reported under different aging conditions. The work is summarized by discussing the development of a tool for OPV lifetime prediction and the development of more stable technologies. An online platform is introduced that will aid the process of generating statistical data on OPV lifetimes and further refinement of the lifetime prediction tool.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Number of pages: 17
Publication date: 2016
Main Research Area: Technical/natural sciences

Manufacture, installation and decommissioning of organic solar cell parks

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials
Authors: Sandergaard, R. R. (Intern)
Publication date: 2016

Publication information
Media of output: Video
Original language: English
Publisher: DTU Energy
Main Research Area: Technical/natural sciences
Links:
https://youtu.be/JMcAN88OeQs

Bibliographical note
Mechanical Properties of a Library of Low-Band-Gap Polymers

The mechanical properties of low-band-gap polymers are important for the long-term survivability of roll to roll processed organic electronic devices. Such devices, e.g., solar cells, displays, and thin-film transistors, must survive the rigors of roll-to-roll coating and also thermal and mechanical forces in the outdoor environment and in stretchable and ultraflexible form factors. This paper measures the stiffness (tensile modulus), ductility (crack-onset strain), or both of a combinatorial library of 51 low-band-gap polymers. The purpose of this study is to systematically screen a library of low-band-gap polymers to better understand the connection between molecular structures and mechanical properties in order to design conjugated polymers that permit mechanical robustness and even extreme deformability. While one of the principal conclusions of these experiments is that the structure of an isolated molecule only partially determines the mechanical properties another important codeterminant is the packing structure some general trends can be identified. (1) Fused rings tend to increase the modulus and decrease the ductility. (2) Branched side chains have the opposite effect. Despite the rigidity of the molecular structure, the most deformable films can be surprisingly compliant (modulus >= 150 MPa) and ductile (crack-onset strain).
Novel high band gap pendant-borylated carbazole polymers with deep HOMO levels through direct $^+\text{N}=\text{B}^-$ interaction for organic photovoltaics

In this communication, we investigate the direct and still conjugated intramolecular $^+\text{N}=\text{B}^-$ interactions in novel high band gap borylated carbazole containing polymers, namely, poly(3,6-(N-di(2,4,6-trimethyl)-phenylboryl-carbazole)-alt-4,8-di(5-(2-ethylhexyl)thiophene-2-yl)benzo[1,2-b:4,5-b']dithiophene) (P(3,6-BCBDT)) and poly(3,6-(N-di(2,4,6-trimethyl)phenylboryl-carbazole)-alt-3,3''-didodecyl-2,2':5',2':5'',2''-quaterthiophene) (P(3,6-BCQT)), which result in ambipolarity, high electron affinity, and deep HOMO levels. The quasi-donor-acceptor nature of the two polymers was confirmed by UV-Vis absorption, electro-chemical property studies, and computer modelling. Band gaps of 2.07 eV for P(3,6-BCBDT) and 2.23 eV for P(3,6-BCQT) were obtained. P(3,6-BCQT) afforded a power conversion efficiency of 1.44%, with a $J_{sc}$ of 4.82 mA cm$^{-2}$, a $V_{oc}$ of 0.79 V and a FF of 37%, and P(3,6-BCBDT) performed better with an efficiency of 3.82%, with a $J_{sc}$ of 8.31 mA cm$^{-2}$, a $V_{oc}$ of 1.0 V based on its low lying HOMO level, and a FF of 45%.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Aalborg University, Chinese Academy of Sciences
Number of pages: 9
Pages: 4393-4401
Publication date: 2016
Main Research Area: Technical/natural sciences

Publication Information
Journal: Journal of Materials Chemistry C
Volume: 4
Issue number: 20
ISSN (Print): 2050-7526
Operational stability of large scale OPV modules: interfaces, materials selection and stack design

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Roth, B. (Intern), Krebs, F. C. (Intern), Søndergaard, R. R. (Intern)
Number of pages: 135
Publication date: 2016

Publication information
Place of publication: Roskilde, Denmark
Publisher: Department of Energy Conversion and Storage, Technical University of Denmark
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Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
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Relations
Projects:
Operational stability of large scale OPV modules: interfaces, materials selection and stack design
Publication: Research › Ph.D. thesis – Annual report year: 2016

Outdoor fate and environmental impact of polymer solar cells through leaching and emission to rainwater and soil
The emission of silver and zinc to the aqueous environment (rain, fog, dew) from polymer solar cells installed outdoors is presented. Studies included pristine solar cells and solar cells subjected to mechanical damage under natural weather conditions in Denmark. We find the emission of silver and zinc to the environment through precipitated water for damaged solar cells, and also observed failure and emission from an initially undamaged device in an experiment that endured for 6 months. In the case of the damaged cells, we found that the drinking water limits for Ag were only exceeded on a few single days. We also progressed our studies to include end-of-life management. To assess the implications of improper practices (uncontrolled disposal, landfilling) at the end-of-life, we buried different OPV types in intact and damaged forms in soil columns. In the case of high Ag emission (shredded cells), the potential for migration was confirmed, even though the soil was found to exhibit sequestration of silver. We conclude that recycling of Ag at the end-of-life is mandatory from an environmental point of view.

General information
Polymer materials for roll coated solar cells: strategies to improve performance and stability

Solar cells are among the renewable energy technologies with a large potential in terms of solar energy availability. The solar cells based on conjugated polymers belong to the third generation of this technology and their attractive features include a fast and cheap solution-processed production. At DTU Energy the focus is the roll-to-roll coating process of these materials in order to reach large area devices, as the processability and scalability of the technology is an important factor. The process ability using roll-coating techniques and the stability of the used materials can be crucial. Therefore this project focuses on the synthesis of conjugated polymers and their application in roll-coated polymer solar cells. The first part of this project aims at using a screening strategy to find suitable polymer candidates for well performing solution processed polymer solar cells. A large number of polymers was screened by applying them in roll-coated solar cells and their performance, stability and number of synthetic steps was compared, to find promising candidates. In the end seven polymers with a sufficient efficiency were found to behave in a higher or in similar manner as poly(3-hexyli thiophene). Further polymers were prepared based on well-performing benzothiadiazole and thiophene based polymers with different incorporation ratios of these monomers. The incorporation ratio has different effects on the polymer properties and the performance and stability of the corresponding roll-coated devices. The best efficiency was achieved with a polymer by using an incorporation of four thiophenes in the repeating unit. The second part of the work aims at using a known strategy to improve the solar cells stability. Three of the polymers from the polymer screening were therefore partly modified with stabilizing side chains, 2-phenetyl and 2-ethanol, respectively, to influence especially the device stability but also the performance. For most modifications a decrease of the solar cell efficiency was observed. The incorporation of 10% of these side chains show improvements of the stability of devices in a minor degree with a variation in the photo- and thermal stability. In addition to the use of different side chains, the impact of different positioning of one side chain was investigated, showing that the incorporation onto the acceptor or donorunit of the polymer showed a degradation or improvement of the resulting properties. In addition, the approach of side chain removable on polythiophene was compared in terms of optical properties and morphologies of two polymers with different (thermal or acidic) cleavage processes. It was found that their properties were not the same and therefore different results from the corresponding solar cells can be expected.
Portable and wireless IV-curve tracer for >5 kV organic photovoltaic modules
The practical design of a wirelessly controlled portable IV-curve tracer based on a capacitive load is described. The design is optimized for the measurement of solar cell modules presenting a high open circuit voltage of up to 6 kV and a low short circuit current below 100 mA. The portable IV-tracer allows for on-site/in-situ characterization of large modules under real operating conditions and enables fast detection of potential failure of anomalies in electrical behavior. Currently available electronic loads only handle voltages up to around 1 kV. To overcome cost and safety issues related to high voltage applications, the design is based on low cost components, battery-based isolated supply and wireless communication. A prototype has been implemented and field tested for characterization of different organic photovoltaic modules (OPV) made according to the infinity concept with a large number of serially connected single junctions (~7,450 single junctions) presenting open circuit voltages up to 5.6 kV.
Printable luminescent down shifter for enhancing efficiency and stability of organic photovoltaics
The proof of concept of using luminescent down shifting (LDS) layers as alternative UV filters for P3HT:PCBM OPVs is demonstrated using a lanthanide-based metal complex. The results are verified using a combination of indoor light soaking, with single cell devices, and outdoor performance monitoring, using a 16-cell monolithically connected OPV module. By applying the LDS layer, a ~5% relative enhancement in photocurrent is observed for both sets of devices. More significantly, indoor light soaking tests on single cell devices without encapsulation showed an 850% enhancement in the measured half-life (T50%). The OPV modules were encapsulated and tested for outdoor stability over a 70 day period in the Negev desert, Israel. The modules made with the LDS filter are shown to match the stability of those made with a commercial UV filter and outperform the modules with no filter applied, with a 51% enhancement in the measured stability (T75%). Significantly, the work provides clear experimental evidence that the LDS layer can act as a UV filter in OPVs without compromising the efficiency of the solar cell, thus providing an added benefit over commercial UV filters.
Role of Stress Factors on the Adhesion of Interfaces in R2R Fabricated Organic Photovoltaics

The role of the common stress factors such as high temperature, humidity, and UV irradiation on interface adhesion of roll-to-roll fabricated organic photovoltaic (OPV) devices is investigated. The samples range from bare front electrodes to complete devices. It is shown that applying single stress or combinations of stresses onto the samples variably affect the adhesion properties of the different interfaces in the OPV device. It is revealed that while the exposure of the complete devices to the stresses results in the loss of photovoltaic performance, some interfaces in the devices present improved adhesion properties. Depth profiling analysis on the fractured samples reveals interdiffusion of layers in the structure, which results in the increase of adhesion and change of the debond path. It is shown that through diffusion and intermixing of internal interfaces coupled stresses can increase the adhesion of OPV interfaces by over tenfold. The results are additionally compared to the photovoltaic performance of the complete devices.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Stanford University
Authors: Corazza, M. (Intern), Rolston, N. (Ekstern), Dauskardt, R. H. (Ekstern), Beliatis, M. (Intern), Krebs, F. C. (Intern), Gevorgyan, S. (Intern)
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Roll coated large area ITO- and vacuum-free all organic solar cells from diketopyrrolopyrrole based non-fullerene acceptors with molecular geometry effects

In this paper, we investigate three diketopyrrolopyrrole (DPP) based small molecular non-fullerene acceptors, namely Ph(DPP)₃, Ph(DPP)₂, and PhMe(DPP)₂, focusing on molecular geometry effects on the frontier orbital level, light absorption, molecular configuration, electron mobility, thin film morphology, and photovoltaic performance of both spin-coated ITO based and roll coated large area, ITO- and vacuum-free organic solar cells (OSCs). For spin-coated devices based on P3HT as the donor polymer the solar cells gave power conversion efficiencies (PCEs) in the following order for (P3HT:PhMe(DPP)₂, 0.65%) > (P3HT:Ph(DPP)₂, 0.48%) > (P3HT:Ph(DPP)₃, 0.31%). All devices present an open circuit voltage (Vₒₒ) higher than 1.0 V. For the roll-coated devices, the PCEs were found to fall in another order and with lower values (P3HT:Ph(DPP)₂, 0.54%) > (P3HT:Ph(DPP)₃, 0.43%) > (P3HT:PhMe(DPP)₂, 0.04%) and the highest Vₒₒ was 0.82 V. Our preliminary results highlight the influence of geometry, structure and processing on the performance of non-fullerene acceptors.

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Scopus rating (2016): CiteScore 3.06 SJR 0.889 SNIP 0.757
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ISI indexed (2013): ISI indexed yes
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Roll-coating fabrication of flexible organic solar cells: comparison of fullerene and fullerene-free systems
Flexible organic solar cells (OSCs) based on a blend of low-bandgap polymer donor PTB7-TH and nonfullerene small molecule acceptor IEIC were fabricated via a roll-coating process under ambient atmosphere. Both an indium tin oxide (ITO)-free substrate and a flexible ITO substrate were employed in these inverted OSCs. OSCs with flexible ITO and ITO-free substrates exhibited power conversion efficiencies (PCEs) up to 2.26% and 1.79%, respectively, which were comparable to those of the reference devices based on fullerene acceptors under the same conditions. This is the first example for all roll-coating fabrication procedures for flexible OSCs based on non-fullerene acceptors with the PCE exceeding 2%. The fullerene-free OSCs exhibited better dark storage stability than the fullerene-based control devices.

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Source-ID: 119867021
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Roll-to-Roll Printed Electronics for Standalone Smart Windows
Roll-to-roll printed silver nanowires for increased stability of flexible ITO-free organic solar cell modules
We report the use of roll-to-roll printed silver nanowire networks as front electrodes for fully roll-to-roll processed flexible indium-tin-oxide (ITO) free OPV modules. We prepared devices with two types of back electrodes, a simple PEDOT:PSS back electrode and a PEDOT:PSS back electrode with a printed silver grid in order to simultaneously explore the influence of the back electrode structure on the operational stability of the modules that did not include any UV-protection. We subjected the devices to stability testing under a number of protocols recommended by the international summit on OPV stability (ISOS). We explored accelerated ISOS-D-2, ISOS-D-3, ISOS-L-2, ISOS-L-3, ISOS-O-1 and ISOS-O-2 testing protocols and compared the performance to previous reports employing the same testing protocols on devices with PEDOT:PSS instead of the silver nanowires in the front electrode. We find significantly increased operational stability across all ISOS testing protocols over the course of the study and conclude that replacement of PEDOT:PSS in the front electrode with silver nanowires increase operational stability by up to 1000%. The duration of the tests were in the range of 140–360 days. The comparison of front and back electrode stability in this study shows that the modules with silver nanowire front electrodes together with a composite back electrode comprising PEDOT:PSS and a silver grid present the best operational stability.
Screening of materials for OPV - finding the perfect candidate(s)

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Authors: Bundgaard, E. (Intern)
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Self-Assembled Plasmonic Nanoparticles for Organic Photovoltaics

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Authors: Pastorelli, F. (Intern)
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Slot-Die-Coated V_2O_5 as Hole Transport Layer for Flexible Organic Solar Cells and Optoelectronic Devices
Vanadium pentoxide has been proposed as a good alternative hole transport layer for improving device lifetime of organic photovoltaics. The article presents a study on the optimization of slot-die-coated vanadium oxide films produced with a roll coating machine with the aim of achieving scalable organic solar cells and photo-detectors with improved performance. The effect of different diluents on the electrical properties of the vanadium oxide films is investigated, and methodologies
for efficient interfacing of the anode are studied. Furthermore, the lifetime of the cells with incorporated vanadium oxide is investigated employing different encapsulation methods. Finally, an application of the manufactured scalable devices in proximity sensors is demonstrated using a 3D-printed scaffold.

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Scopus rating (2014): SJR 6.668 SNIP 2.942 CiteScore 15.27
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 6.006 SNIP 2.949 CiteScore 13.24
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 5.575 SNIP 2.181 CiteScore 9.64
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Web of Science (2011): Indexed yes
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The Influence of Conjugated Polymer Side Chain Manipulation on the Efficiency and Stability of Polymer Solar Cells
The stability of polymer solar cells (PSCs) can be influenced by the introduction of particular moieties on the conjugated polymer side chains. In this study, two series of donor-acceptor copolymers, based on bis(thienyl)dialkoxybenzene donor and benzo[c][1,2,5]thiadiazole (BT) or thiazolo[5,4-d]thiazole (TzTz) acceptor units, were selected toward effective device scalability by roll-coating. The influence of the partial exchange (5% or 10%) of the solubilizing 2-hexyldecylolxy by alternative 2-phenylethoxy groups on efficiency and stability was investigated. With an increasing 2-phenylethoxy ratio, a decrease in solar cell efficiency was observed for the BT-based series, whereas the efficiencies for the devices based on the TzTz polymers remained approximately the same. The photochemical degradation rate for PSCs based on the TzTz polymers decreased with an increasing 2-phenylethoxy ratio. Lifetime studies under constant sun irradiance showed a diminishing initial degradation rate for the BT-based devices upon including the alternative side chains, whereas the (more stable) TzTz-based devices degraded at a faster rate from the start of the experiment upon partly exchanging the side chains. No clear trends in the degradation behavior, linked to the copolymer structural changes, could be established at this point, evidencing the complex interplay of events determining PSCs’ lifetime.
The Organic Power Transistor: Roll-to-Roll Manufacture, Thermal Behavior, and Power Handling When Driving Printed Electronics

We present flexible organic power transistors prepared by fast (20mmin$^{-1}$) roll-to-roll (R2R) flexographic printing[1] of the drain (D) and source (S) electrode structures directly on polyester foil. The devices have top gate architecture and were completed by spin coating or slot-die coating of the organic semiconductor poly-3-hexylthiophene (P3HT) and the dielectric material polyvinylphenol (PVP) before the gate (G) was applied by either screen printing or evaporation of silver. We explore the footprint and the practically accessible geometry of such devices with a special view toward being able to drive large currents while handling the thermal aspects in operation together with other organic printed electronics technologies such as large area organic photovoltaics (OPV)[2] and large area electrochromic displays (EC).[3] We find especially that an elevated operational temperature is beneficial with respect to both transconductance and on/off ratio. We achieve high currents of up to 45mA at a temperature of 80 C with an on/off ratio of 100 which is sufficient to drive large area organic electronics such as an EC device powered by OPV devices that we also demonstrate. Finally, we observe a significant temperature dependence of the performance which can be explored further in sensing applications.
Voltage and Thermally Driven High Current Roll-to-Roll Printed Transistors

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Which Electrode Materials to Select for More Environmentally Friendly Organic Photovoltaics?

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Authors: Espinosa Martinez, N. (Intern), Laurent, A. (Intern), Benatto, G. A. D. R. (Intern), Hösel, M. (Intern), Krebs, F. C. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.07 SJR 0.834 SNIP 1.125
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.806 SNIP 1.028 CiteScore 1.82
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 0.802 SNIP 1.055 CiteScore 1.66
Web of Science (2014): Indexed yes
Air-processed organic tandem solar cells on glass: toward competitive operating lifetimes

Photovoltaic devices based on organic semiconductors (OPVs) hold great promise as a cost-effective renewable energy platform because they can be processed from solution and deposited on flexible plastics using roll-to-roll processing. Despite important progress and reported power conversion efficiencies of more than 10% the rather limited stability of this type of devices raises concerns towards future commercialization. The tandem concept allows for both absorbing a broader range of the solar spectrum and reducing thermalization losses. We designed an organic tandem solar cell with an inverted device geometry comprising environmentally stable active and charge-selecting layers. Under continuous white light irradiation, we demonstrate an extrapolated, operating lifetime in excess of one decade. We elucidate that for the current generation of organic tandem cells one critical requirement for long operating lifetimes consists of periodic UV light treatment. These results suggest that new material approaches towards UV-resilient active and interfacial layers may enable efficient organic tandem solar cells with lifetimes competitive with traditional inorganic photovoltaics.

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Authors: Adams, J. (Ekstern), Spyropoulos, G. D. (Ekstern), Salvador, M. (Ekstern), Li, N. (Ekstern), Strohm, S. (Ekstern), Lucera, L. (Ekstern), Langner, S. (Ekstern), Machui, F. (Ekstern), Zhang, H. (Ekstern), Ameri, T. (Ekstern), Voigt, M. M.
A model for the impact of the nanostructure size on its gas sensing properties

The size of a metal oxide nanostructure plays a key role in its performance as a gas sensor. ZnO nanostructures with different morphologies including nanowires at different diameters and nanodisks at different thicknesses were synthesized hydrothermally. Gas sensors based on individual nanostructures with different sizes were fabricated and their sensing properties were compared and investigated. Nanowires with smaller diameter size and higher surface to volume ratio showed enhanced gas sensing performance. Also, as the nanodisk thickness gets closer to the thickness of the ZnO depletion layer, the sensitivity increases significantly due to the semi complete depletion of the nanostructure. Our results were explained using a modified general formula for a ZnO ethanol sensor. The formula was established based on the chemical reaction between ethanol molecules and oxygen ions and considering the effect of the surface to volume ratio as well as the depletion region of the nanostructure. This work can be simply generalized for other metal oxides to enhance their performance as gas sensors.
An isoindigo containing donor-acceptor polymer: synthesis and photovoltaic properties of all-solution-processed ITO- and vacuum-free large area roll-coated single junction and tandem solar cells

In this work, the design, synthesis, and characterization of a donor-acceptor polymer from dithieno[3,2-b:2',3'-d]pyrrole and isoindigo (i-ID) are presented. The synthesized polymer has been applied in large area ITO-free organic photovoltaics, both as spin coated and roll coated devices; the latter as both single junction and multi junction organic photovoltaic (OPV) architectures.

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Bipolar polaron pair recombination in P3HT/PCBM solar cells

The unique properties of organic semiconductors make them versatile base materials for many applications ranging from light emitting diodes to transistors. The low spin-orbit coupling typical for carbon-based materials and the resulting long spin lifetimes give rise to a large in uence of the electron spin on charge transport which can be exploited in spintronic devices or to improve solar cell ef ciencies. Magnetic resonance techniques are particularly helpful to elucidate the microscopic structure of paramagnetic states in semiconductors as well as the transport processes they are involved in. However, in organic devices the nature of the dominant spin-dependent processes is still subject to considerable debate. Using multi-frequency pulsed electrically detected magnetic resonance (pEDMR), we show that the spin-dependent response of P3HT/PCBM solar cells at low temperatures is governed by bipolar polaron pair recombination involving the positive and negative polarons in P3HT and PCBM, respectively, thus excluding a unipolar bipolaron formation as the main contribution to the spin-dependent charge transfer in this temperature regime. Moreover the polaron-polaron coupling strength and the recombination times of polaron pairs with parallel and antiparallel spins are determined. Our results demonstrate that the pEDMR pulse sequences recently developed for inorganic semiconductor devices can very successfully be transferred to the study of spin and charge transport in organic semiconductors, in particular when the dierent polarons can be distinguished spectrally.
Bipolar polaron pair recombination in polymer/fullerene solar cells

We present a study of the rate-limiting spin-dependent charge-transfer processes in different polymer/fullerene bulk-heterojunction solar cells at 10 K. Observing central spin-locking signals in pulsed electrically detected magnetic resonance and an inversion of Rabi oscillations in multifrequency electron-double-resonance spectroscopy, we find that the spin response of both spin-coated and printed P3HT/PCBM and spin-coated PCDTBT/PCBM solar cells at low temperatures is governed by bipolar polaron pair recombination and quantitatively determine the polaron-polaron coupling strength with double electron-electron resonance experiments. Furthermore spin Hahn echo decay and inversion recovery measurements are performed to measure spin coherence and recombination times of the polaron pairs, respectively.

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Authors: Kupijai, A. J. (Ekstern), Behringer, K. M. (Ekstern), Schaeble, F. G. (Ekstern), Galfe, N. E. (Ekstern), Corazza, M. (Intern), Gevorgyan, S. A. (Intern), Krebs, F. C. (Intern), Stutzmann, M. (Ekstern), Brandt, M. S. (Ekstern)
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Scopus rating (2016): CiteScore 3.16 SJR 2.339 SNIP 1.151
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Scopus rating (2015): SJR 2.377 SNIP 1.13 CiteScore 2.8
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 2.762 SNIP 1.316 CiteScore 3.3
Web of Science (2014): Indexed yes
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Scopus rating (2012): SJR 3.173 SNIP 1.378 CiteScore 3.57
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 3.318 SNIP 1.447
Web of Science (2010): Indexed yes
Web of Science (2009): Indexed yes
Scopus rating (2008): SJR 2.923 SNIP 1.516
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.892 SNIP 1.588
Comparative Indoor and Outdoor Degradation of Organic Photovoltaic Cells via Inter-laboratory Collaboration

We report on the degradation of organic photovoltaic (OPV) cells in both indoor and outdoor environments. Eight different research groups contributed state-of-the-art OPV cells to be studied at Pomona College. Power conversion efficiency, fill factor, and IV curves were collected at regular intervals over six to eight months. Similarly prepared devices were measured indoors, outdoors, and after dark storage. Device architectures are compared. Cells kept indoors performed better than outdoors due to the lack of temperature and humidity extremes. Encapsulated cells performed better due to the minimal oxidation. Some devices showed steady aging but many failed catastrophically due to corrosion of electrodes not active device layers. Degradation of cells kept in dark storage was minimal over periods up to one year.

General information

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Pomona College, Technische Universität Dresden, IMEC, Holst Center, Institut für Solarenergieforschung, Ilmenau University of Technology, Centre d’Investigació en Nanociència i Nanotecnologia, Heliatek GmbH
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Conference: 42nd IEEE Photovoltaic Specialists Conference, New Orleans, United States, 14/06/2015 - 14/06/2015
DOIs:
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Source: FindIt
Source-ID: 276914242
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015
Development and Manufacture of Polymer-based Electrochromic Devices

The field of organic electrochromics is reviewed here, with particular focus on how the "electrochromic" as a functional material can be brought from the current level of accurate laboratory synthesis and characterization to the device and application level through a number of suited roll-to-roll methods compatible with upscaling and manufacture. The successful approaches to operational devices are presented in detail, as well as areas where future research would have a high impact and accelerate the development such as highly conducting and transparent substrates, electrolytes adapted for multilayer application and morphologically stable conjugated polymers.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Clayton State University
Authors: Jensen, J. (Intern), Hösel, M. (Intern), Dyer, A. L. (Ekstern), Krebs, F. C. (Intern)
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Scopus rating (2015): CiteScore 11.93
Web of Science (2015): Indexed yes
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Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 10.6
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 10.41
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 9.47
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
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Development of Lab-to-Fab Production Equipment Across Several Length Scales for Printed Energy Technologies, Including Solar Cells

We describe and review how the scaling of printed energy technologies not only requires scaling of the input materials but also the machinery used in the processes. The general consensus that ultrafast processing of technologies with large energy capacity can only be realized using roll-to-roll methods is taken as a premise, and thus the progression from a highly successful laboratory technique (i.e., spin coating) to large-scale roll-to-roll equipment is described in terms of all of the intermediate steps that must be available to make the transfer possible. Spin coating is compatible with materials availability on the small scale and efficient scaling of equipment is a demanding task that must be performed in parallel with increasing materials availability. We outline that 3–5 processing platforms are necessary to efficiently take the laboratory technology to a version that represents the lower end of the industrial scale. The machinery bridges the gap through firstly achieving improved ink efficiency without surface contact, followed by better ink efficiency at higher speeds, and finally large-area processing at high speed with very high ink efficiency.

Ecodesign of organic photovoltaic modules from Danish and Chinese perspectives

The life cycle of a solar park made using organic photovoltaic (OPV) technology is assessed here. The modules have been fabricated in a pilot scale plant and they have been installed together with other components to evaluate the balance of system, in a solar park located in Denmark. Three possible waste management practices have been contemplated for the end of life of the solar park: recycling, incineration or the average local mix. The assessment of the environmental impacts of such a system reveals that silver used in the electrodes is overall the largest source of impacts, such as chemical pollution and metal depletion. The establishment of resource recovery systems for the end-of-life management of the OPV modules is therefore crucial to reduce overall environmental impacts. Liability on the manufacturers or on the operators should be implemented. The electricity produced from OPV solar parks yields similar footprints to other traditional energy technologies; e.g. coal and natural gas. However, when the efficiency of the OPV modules is increased from 1% to 5% they are comparable to other mature PV technologies already on the market. The effects of outsourcing or exporting the production of the OPV modules from Denmark to China have additionally been studied to determine the most advantageous configuration. The stakeholders should aim at anchoring the manufacturing of solar parks in countries with stringent emission standards and/or high technology efficiencies, e.g. Denmark, and at deploying them in countries with high solar radiation to maximise the environmental benefits of the PV technology.
Effects of constant voltage and constant current stress in PCBM:P3HT solar cells

The aim of this work is the investigation of forward and reverse bias stress effects, cell self-heating and annealing in roll coated organic solar cells with PCBM:P3HT active layer. In reverse bias stress cells show a constant degradation over time. In forward current stress cells alternate degradation and annealing phases, which are explained through the high power dissipation during the current stress, and the consequent self-heating. The high temperature is able to recover the cell performances at least until a critical temperature is reached. The degradation can be explained by the following mechanisms: the decrease of the net generation rate (due to formation of exciton quenching centres or the reduction of exciton separation rate); the formation of small leaky paths between anode and cathode, which reduces the total current extracted from the cell. The stress-induced damage can be recovered by thermal annealing at 120 °C. © 2015 Elsevier
Electrical characterization of fluorinated benzothiadiazole based conjugated copolymer – a promising material for high-performance solar cells

Measurements of electrical conductivity, electron work function, carrier mobility of holes and the diffusion length of excitons were performed on samples of conjugated polymers relevant to polymer solar cells. A state of the art fluorinated benzothiadiazole based conjugated copolymer (PBDTTHD − DTBTff) was studied and benchmarked against the reference polymer poly-3-hexylthiophene (P3HT). We employed, respectively, four electrode conductivity measurements, Kelvin probe work function measurements, carrier mobility using charge extraction by linearly increasing voltage (CELIV) measurements and diffusion length determination using surface photovoltage measurements.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Charles University, Academy of Sciences of the Czech Republic
Authors: Toušek, J. (Ekstern), Toušková, J. (Ekstern), Remeš, Z. (Ekstern), Chomutová, R. (Ekstern), Čermák, J. (Ekstern), Helgesen, M. (Intern), Carlé, J. E. (Intern), Krebs, F. C. (Intern)
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Web of Science (2016): Indexed yes
Scopus rating (2015): SJR 0.541 SNIP 0.695 CiteScore 1.17
Web of Science (2015): Indexed yes
Scopus rating (2014): SJR 0.737 SNIP 0.794 CiteScore 1.38
Web of Science (2014): Indexed yes
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ISI indexed (2013): ISI indexed yes
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ISI indexed (2012): ISI indexed no
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Enabling Flexible Polymer Tandem Solar Cells by 3D Ptychographic Imaging
The realization of a complete tandem polymer solar cell under ambient conditions using only printing and coating methods on a flexible substrate results in a fully scalable process but also requires accurate control during layer formation to succeed. The serial process where the layers are added one after the other by wet processing leaves plenty of room for error and the process development calls for an analytical technique that enables 3D reconstruction of the layer stack with the possibility to probe thickness, density, and chemistry of the individual layers in the stack. The use of ptychography on a complete 12-layer solar cell stack is presented and it is shown that this technique provides the necessary insight to enable efficient development of inks and processes for the most critical layers in the tandem stack such as the recombination layer where solvent penetration in fully solution processed 12-layer stacks is critical in eleven of the steps.

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Web of Science (2018): Indexed yes
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Scopus rating (2017): SNIP 2.347 SJR 8.23
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 12.96 SJR 6.515 SNIP 2.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 6.219 SNIP 2.546 CiteScore 14.2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 6.668 SNIP 2.942 CiteScore 15.27
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.006 SNIP 2.949 CiteScore 13.24
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 5.575 SNIP 2.181 CiteScore 9.64
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Relations
Projects:
Enabling Flexible Polymer Tandem Solar Cells by 3D Ptychographic Imaging
Environmental benefits of parking-integrated photovoltaics: A 222kWp experience

The life cycle assessment of a grid-connected, parking integrated, 222kWp cadmium telluride photovoltaic system has been performed. The system was built at the University of Murcia and has been monitored for 2.5 years (sampling data every 5 min). The detailed material inventory, the energy embedded in the system, the energy payback time, and the energy return factor of the facility have been obtained and are 6.31 TJ equivalent primary energy, 2.06 and 12.16 years, respectively. The average performance ratio is 0.8 with a slight monthly variation. Additionally, the environmental benefits of the architectural integration (in this case parking integration) have been quantified using a standard methodology for the calculation of several environmental parameters. Finally, the environmental benefits of renewable energy generation because of the savings of producing the same amount of electricity by the Spanish grid system have been assessed. © 2013 John Wiley & Sons, Ltd.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imperial College London, Universidad Politécnica de Cartagena
Authors: Serrano-Luján, L. (Ekstern), García-Valverde, R. (Ekstern), Espinosa, N. (Intern), García-Cascales, M. S. (Ekstern), Sánchez-Lozano, J. M. (Ekstern), Urbina, A. (Ekstern)
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 2.175 SJR 1.772
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 2.227 SNIP 2.645 CiteScore 6.54
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.724 SNIP 3.258 CiteScore 7.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 3.328 SNIP 3.899 CiteScore 7.7
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 3.987 SNIP 5.613 CiteScore 8.93
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 3.483 SNIP 4.895 CiteScore 6.81
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 3.21 SNIP 5.766 CiteScore 6.81
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 3.689 SNIP 4.247
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.948 SNIP 3.307
Environmental impacts of electricity generation at global, regional and national scales in 1980–2011: What can we learn for future energy planning?

The generation of electricity has been known to cause important damages to ecosystems and human health. The recognition of the global challenges posed by climate change and energy security has guided several countries to change their electricity policies over the past decades. However, have such changes entailed reduced or increased environmental impacts? Are there any identifiable patterns that could serve for steering future energy planning? To address these questions, we applied life cycle assessment to quantify a whole spectrum of environmental impacts caused by electricity generation in 199 countries for the period 1980–2011, with national differentiation of energy sources and, wherever possible, technology efficiencies. The results show that (i) environmental impact burden-shifting has occurred in the past for several countries as a result of national policies, (ii) all environmental impacts have globally increased since 1980 but with faster increase rates over the last decade, and (iii) important variations exist in the impact trends across countries and across impact categories. Our findings therefore demonstrate the need for integrating quantitative assessments of all relevant environmental impacts associated with foreseen energy systems when identifying the most sustainable energy pathways. We provide recommendations on the use of life cycle assessment for such purposes with a strong focus on application at the country level so that it can directly support national energy policy-making.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Energy Conversion and Storage, Functional organic materials
Authors: Laurent, A. (Intern), Espinosa Martinez, N. (Intern)
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
Fullerene alloy formation and the benefits for efficient printing of ternary blend organic solar cells

Composition average dependent properties for blends of the conjugated polymer P3HT and the fullerenes [60]PCBM, [60]ICBA and their mixtures were studied using cross-polarization magic-angle-spinning solid-state NMR techniques. We found that the blended fullerenes form an alloy and that when mixed with a third polymer component, the system exhibits pseudo-binary phase behaviour instead of the expected ternary phase behaviour. Our results experimentally confirm the earlier hypothesis that the unexpected composition average dependent IV-behaviour for these supposed ternary mixtures are indeed due to them behaving as pseudo-binary mixtures due to alloying of the fullerene components. This finding has vast implications for the understanding of polymer–fullerene mixtures and quite certainly also their application in organic solar cells where performance hinges critically on the blend behaviour which is also investigated in this study.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Aarhus University, University of Southern California
Authors: Angmo, D. (Intern), Bjerring, M. (Ekstern), Nielsen, N. C. (Ekstern), Thompson, B. C. (Ekstern), Krebs, F. C. (Intern)
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Main Research Area: Technical/natural sciences

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Volume: 3
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Improving organic tandem solar cells based on water-processed nanoparticles by quantitative 3D nanoimaging

Organic solar cells have great potential for upscaling due to roll-to-roll processing and a low energy payback time, making them an attractive sustainable energy source for the future. Active layers coated with water-dispersible Landfester particles enable greater control of the layer formation and easier access to the printing industry, which has reduced the use of organic solvents since the 1980s. Through ptychographic X-ray computed tomography (PXCT), we image quantitatively a roll-to-roll coated photovoltaic tandem stack consisting of one bulk heterojunction active layer and one Landfester particle active layer. We extract the layered morphology with structural and density information including the porosity present in the various layers and the silver electrode with high resolution in 3D. The Landfester particle layer is found to have an undesired morphology with negatively correlated top- and bottom interfaces, wide thickness distribution and only partial surface coverage causing electric short circuits through the layer. By top coating a polymer material onto the Landfester nanoparticles we eliminate the structural defects of the layer such as porosity and roughness, and achieve the increased performance larger than 1 V expected for a tandem cell. This study highlights that quantitative imaging of weakly scattering stacked layers of organic materials has become feasible by PXCT, and that this information cannot be obtained by other methods. In the present study, this technique specifically reveals the need to improve the coatability and layer formation of Landfester nanoparticles, thus allowing improved solar cells to be produced.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis, Norwegian University of Science and Technology, Paul Scherrer Institut
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BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.442 SJR 2.934
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Influence of Functionality on Direct Arylation of Model Systems as a Route Toward Fluorinated Copolymers via Direct Arylation Polymerization (DArP)

A screening of direct arylation conditions on a model small molecule system is carried out to develop suitable conditions for the direct arylation polymerization (DArP) of fluorinated copolymers, which are incompatible with conditions previously utilized successfully for nonfluorinated systems. The model system features a coupling between a 2-substituted thiophene and a pentafluorobenzene, where one of the partners was brominated. A substantial difference in reactivity is observed, demonstrating that the optimal functionalization for direct arylation between a thiophene-based donor and a highly fluorinated acceptor is a halogenated thiophene and an unfunctionalized fluorinated unit, which is opposite of typical cross coupling reactions, where the acceptor is typically halogenated. The best conditions are applied to the copolymerization of 1,2,4,5-tetrafluorobenzene and 2,2′-(2,5-bis((2-hexyldecyl)oxy)-21,4-phenylene)dithiophene. Polymers are free of β-defects and significant homocoupling. This work further underscores the attractive simplicity, relevance, and ease of DArP while reconfirming its broad compatibility withincreasingly popular fluorinated copolymers.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, University of Southern California
Authors: Livi, F. (Intern), Gobalasingham, N. S. (Ekstern), Bundgaard, E. (Intern), Thompson, B. C. (Ekstern)
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Influence of Side Chain Position on the Electrical Properties of Organic Solar Cells Based on Dithienylbenzothiadiazole-alt-phenylene Conjugated Polymers

Seven conjugated copolymers, based on dithienylbenzothiadiazole and benzene, have been synthesized with side chains placed in different position along the conjugated backbone. An additional polymer with a small modification of the investigated backbone was also included in the study. Alkoxy and alkyl side chains were considered, depending on the aromatic ring they were anchored to. Our goal was to perform an extensive study, by evaluating the possible anchoring positions of the same backbone, in order to demonstrate the huge influence of the position of side chains on a well-performing polymer backbone for polymer solar cells. All the polymers were roll slot die coated under ambient conditions on flexible ITO-free plastic substrates to give inverted polymer solar cell devices with an upscaled active area of 1 cm². The best characteristics were found for the polymer carrying alkoxy side chains on the benzene ring where power conversion efficiencies of up to 3.6% were achieved. All studied materials were prepared with an objective of low-cost starting materials, simple synthesis, and simple processing conditions which was most successful for the polymer P5. The polymer P7 containing fluorine atoms showed excellent performance under constant illumination and high temperature (exhibiting stable photovoltaic properties even after 670 h under conditions similar to ISOS-L-2 lifetime protocol). This makes P7 a good candidate for further upscaling and device optimization. The photovoltaic performance results were corroborated with full optical and morphological characterization of the conjugated polymers. We conclude that the determination of the best anchoring position for the side chains is the most rational starting point for the optimization of a polymer with a potential for large-scale fabrication of polymer solar cells.

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Scopus rating (2017): SNIP 1.513 SJR 2.419
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 5.76 SJR 2.564 SNIP 1.483
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.357 SNIP 1.599 CiteScore 5.82
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.524 SNIP 1.695 CiteScore 5.83
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.578 SNIP 1.736 CiteScore 6.09
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 2.78 SNIP 1.568 CiteScore 5.35
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.556 SNIP 1.571 CiteScore 5.15
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Interfacial engineering of self-assembled monolayer modified semi-roll-to-roll planar heterojunction perovskite solar cells on flexible substrates

The morphologies of the perovskite (e.g., CH3NH3PbI3) layer are demonstrated to be critically important for highly efficient perovskite solar cells. This work applies 3-aminopropanoic acid as a self-assembled monolayer (C3-SAM) on a poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) hole transport layer (HTL) to modify the crystallinity and coverage of the CH3NH3PbI3 Cl-x(x) film, resulting in a much smoother perovskite surface morphology together with a PCE increase from 9.7% to 11.6%. Since all fabrication steps of these inverted structure devices are carried out under low temperature conditions (processing temperature <120 degrees C), it is possible to employ this method on flexible polymer substrates using roll-coating for the layer deposition. The roll-coated perovskite film on C3-SAM modified PEDOT:PSS presents a similar trend of improvement and results in enhanced PCE from 3.7% to 5.1%. The successful application of the facile HTL modification indicates a common strategy for SAM material design and selection for efficiency enhancement in perovskite photovoltaic devices.

General information

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Zhejiang University
Authors: Gu, Z. (Ekstern), Zuo, L. (Ekstern), Larsen-Olsen, T. T. (Intern), Ye, T. (Ekstern), Wu, G. (Ekstern), Krebs, F. C. (Intern), Chen, H. (Ekstern)
Number of pages: 7
Pages: 24254-24260
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Publication information

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Volume: 3
Lifetime of organic photovoltaics: Linking outdoor and indoor tests

A comprehensive outdoor study of polymer solar cells and modules for duration of one year was conducted. Different sample geometries and encapsulations were employed in order to study the spread in the lifetimes. The study is a complimentary report to previous work that focused on indoor ageing tests. Comparison of the indoor and outdoor lifetimes was performed by means of the o-diagram, which constitutes the initial steps towards establishing a method for predicting the lifetime of an organic photovoltaic device under real operational conditions based on a selection of accelerated indoor tests. Acceleration factors were determined using the ISOS-protocols, which enabled reproducible data acquisition between different laboratories and operators within the OPV community. A semi-automatic filtering method was employed for processing data acquired in outdoor tests. It was found that the lifetime of the samples tested under outdoor conditions was somewhere between the lifetimes of samples measured in accelerated indoor test conditions of damp heat and light soaking (ISOS-D-3 and ISOS-L-2) and in moderate indoor test conditions (shelf life and high temperature storage). The presented results reveal that while the accelerated ageing studies reveal days and weeks of lifetime for the studied samples, in outdoor real operational conditions the samples demonstrate stability up to months and seasons.
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.182 SNIP 2.577 CiteScore 5.16
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.494 SNIP 2.105
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.942 SNIP 1.957
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.626 SNIP 1.449
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.363 SNIP 1.49
Web of Science (2007): Indexed yes
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Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.15 SNIP 1.607
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.94 SNIP 1.174
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.997 SNIP 1.322
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.168 SNIP 1.102
Scopus rating (2001): SJR 0.883 SNIP 1.229
Scopus rating (2000): SJR 0.686 SNIP 0.987
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Making Ends Meet: Flow Synthesis as the Answer to Reproducible High-Performance Conjugated Polymers on the Scale that Roll-to-Roll Processing Demands

Continuous flow methods are employed for the controlled polymerization of the roll-to-roll (R2R) compatible polymer PBDTTTz-4 including optimization and upscaling experiments. The polymerization rate and materials’ quality can be increased significantly with the continuous flow method where reaction times down to 10 min afforded PBDTTTz-4 with high molecular weight and a constant quality. The flow method enables full control of the molecular weight via tuning of the flow speed, catalyst loading, and temperature and avoids variation in materials’ quality associated with conventional batch synthesis. Upscaling from 300 mg batch synthesis to 10 g flow synthesis affords PBDTTTz-4 with a production rate of up to 120 g day⁻¹ for a very simple in-house build flow reactor. An average power conversion efficiency (PCE) of 3.5% is achieved on a small scale (1 cm²) and an average PCE of 3.3% is achieved on a large scale (29 cm²). This shows that small device efficiencies can be scaled when using full R2R processing of flexible and encapsulated carbon-based modules without the use of vacuum, indium-tin-oxide, or silver, with the best achieving a PCE of 3.8% PCE.
Matrix Organization and Merit Factor Evaluation as a Method to Address the Challenge of Finding a Polymer Material for Roll Coated Polymer Solar Cells

The results presented demonstrate how the screening of 104 light-absorbing low band gap polymers for suitability in roll coated polymer solar cells can be accomplished through rational synthesis according to a matrix where 8 donor and 13 acceptor units are organized in rows and columns. Synthesis of all the polymers corresponding to all combinations of donor and acceptor units is followed by characterization of all the materials with respect to molecular weight, electrochemical energy levels, band gaps, photochemical stability, carrier mobility, and photovoltaic parameters. The photovoltaic evaluation is carried out with specific reference to scalable manufacture, which includes large area (1 cm²), stable inverted device architecture, an indium-tin-oxide-free fully printed flexible front electrode with ZnO/PEDOT:PSS (poly(3,4-ethylenedioxythiophene):polystyrene sulfonate), and a printed silver comb back electrode structure. The matrix organization enables fast identification of active layer materials according to a weighted merit factor that includes more than simply the power conversion efficiency and is used as a method to identify the lead candidates. Based on several characteristics included in the merit factor, it is found that 13 out of the 104 synthesized polymers outperformed poly(3-hexylthiophene) under the chosen processing conditions and thus can be suitable for further development.

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Over 2 Years of Outdoor Operational and Storage Stability of ITO-free, Fully Roll-to-Roll Fabricated Polymer Solar Cell Modules

We report on the stability of large-area (100 cm²), low-cost, indium-tin-oxide (ITO)-free modules over two years (>17 500 h) under outdoor operational conditions in Denmark and under indoor storage condition by following ISOS-O-3 and ISOS-D-2 protocols. Irrespective of the testing regimes (storage and outdoor), all modules maintain the maximum power point (MPP) above T80 (the duration over which a solar cell retains above 80% of its initial MPP) over two years using a simple low-cost packaging barrier with a water vapor transmission rate (WVTR) of 0.04 g m⁻² day⁻¹, an oxygen transmission rate (OTR) of 0.01 cm³ m⁻² bar⁻¹ day⁻¹, and a UV cut-off at 390 nm. Unlike previous studies, localized degradation through edges and contact points in the modules are not overwhelming even after more than two years; therefore, the differences in degradation under long-term outdoor and storage conditions could be probed. The results suggest that oxygen permeation may be mainly responsible for degradation under outdoor conditions, whereas WVTR has a larger bearing under storage conditions.

Photochemical stability of random poly(3-hexylthiophene-co-3-cyanothiophene) and its use in roll coated ITO-free organic photovoltaics

The photochemical stability of the active layer blend for organic solar cells was explored by introducing electron withdrawing cyano groups into the backbone of poly-3-hexylthiophene (P3HT). Random copolymerization of 2-bromo-3-hexyl-5-trimethylstannylthiophene and 2-bromo-3-cyano-5-trimethylstannylthiophene enabled introduction of the
cyanogroups along the polythiophene backbone. The percentage of the cyano groups was 10%. The photochemical stability of poly(3-hexylthiophene-co-3-cyanothiophene) (CN-P3HT) was shown to be significantly better than pristine P3HT and the addition of CN-P3HT to P3HT also increased the photochemical stability of the blend. The photochemical stability of bulk heterojunction mixtures of the polymers and their blends with the fullerene phenyl-C61-butyric acid methyl ester ([60]PCBM) were then studied and it was found that [60]PCBM had a significantly more stabilizing effect on P3HT than CN-P3HT and that the stabilization of the bulk heterojunction mixture was dominated by the fullerene. The mixture comprising both fullerene and CN-P3HT, however, demonstrated the highest degree of photochemical stability supporting earlier observations that the stabilizing effects are additive. Finally, the blends were explored in fully printed flexible ITO-free roll coated inverted devices (with an active area of 0.8 cm2) using two different back PEDOT: PSS electrode compositions and the operational stability of the devices was studied under ISOS-L-2 conditions. The pure P3HT:PCBM devices were found to be the most stable in operation demonstrating that photochemical stability alone is not necessarily the dominant factor for overall device stability.
Probing individual subcells of fully printed and coated polymer tandem solar cells using multichromatic opto-electronic characterization methods

In this study, a method to opto-electronically probe the individual junctions and carrier transport across interfaces in fully printed and coated tandem polymer solar cells is described, enabling the identification of efficiency limiting printing/coating defects. The methods used are light beam induced current (LBIC) mapping, External quantum efficiency (EQE) measurements, and monochromatic current-voltage (I-V) characterization. Using these methods, inherent limitations to the accuracy of EQE and LBIC measurements on non-ideal tandem solar cells are identified and described through the use of a small-signal electrical model. The model is able to predict the EQE spectrum of the non-ideal polymer tandem solar cell, using extracted values of shunt- and series resistance of the individual junction of the tandem cell. This finally enables LBIC mapping of the individual junctions of the tandem polymer solar cells, using a combination of light and voltage-biasing.
Roll and roll-to-roll process scaling through development of a compact flexo unit for printing of back electrodes

We report manufacture of fully printed and coated polymer solar cells on a small scale roll-to-roll coater representing the intermediate scale between laboratory and pilot scale. We highlight the enormous span in scale between the laboratory scale and the intended industrial scale by a factor of >100,000 and detail how this enormous scale must be covered by equipment that follow the scale. Especially the intermediate scale between equipment that can fit inside a fume cupboard and the typical pilot equipment with a footprint having the size of a large room presents a challenge that comprises some of the most critical steps in the scaling process. We describe the development of such a machine that comprise web guiding, tension control and surface treatment in a compact desk size that is easily moved around and also detail the development of a small cassette based flexographic unit for back electrode printing that is parsimonious in terms of ink usage and more gentle than laboratory scale flexo units where the foil transport is either driven by the flexo unit or the flexo unit is driven by the foil transport. We demonstrate fully operational flexible polymer solar cell manufacture using this new roll and roll-to-roll (R3) approach and compare with the existing methods.

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Roll-Coated Fabrication of Fullerene-Free Organic Solar Cells with Improved Stability

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Roll-coating fabrication of ITO-free flexible solar cells based on a non-fullerene small molecule acceptor

We report organic solar cells (OSCs) with non-fullerene small molecule acceptors (SMAs) prepared in large area via a roll coating process. We employ all solution-processed indium tin oxide (ITO)-free flexible substrates for inverted solar cells with a new SMA of F(DPP)(2)B-2. By utilizing poly(3-hexylthiophene) as donor blended with F(DPP)(2)B-2 as acceptor, ITO-free large-area flexible SMA based OSCs were produced under ambient conditions with the use of slot-die coating and flexographic printing methods on a lab-scale compact roll-coater that is readily transferrable to roll-to-roll processing. The effect of different processing solvents on the device performance was investigated, and the best performance with a power conversion efficiency of 0.65%, an open circuit voltage of 0.85 V, a short-circuit current density of 2.19 mA cm(-2), and a fill factor of 35% was obtained.
Roll-to-Roll Printed Silver Nanowire Semitransparent Electrodes for Fully Ambient Solution-Processed Tandem Polymer Solar Cells

Silver nanowires (AgNWs) and zinc oxide (ZnO) are deposited on flexible substrates using fast roll-to-roll (R2R) processing. The AgNW film on polyethylene terephthalate (PET) shows >80% uniform optical transmission in the range of 550-900 nm. This electrode is compared to the previously reported and currently widely produced indium-tin-oxide (ITO) replacement comprising polyethylene terephthalate (PET) silver grid|poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS)|ZnO known as Flextrode. The AgNW/ZnO electrode shows higher transmission than Flextrode above 490 nm in the electromagnetic spectrum reaching up to 40% increased transmission at 750 nm in comparison to Flextrode. The functionality of AgNW electrodes is demonstrated in single and tandem polymer solar cells and compared with parallel devices on traditional Flextrode. All layers, apart from the semitransparent electrodes which are large-scale R2R produced, are fabricated in ambient conditions on a laboratory roll-coater using printing and coating methods which are directly transferrable to large-scale R2R processing upon availability of materials. In a single cell structure, Flextrode is preferable with active layers based on poly-3-hexylthiophene(P3HT):phenyl-C61-butyric acid methylester (PCBM) and donor polymers of similar absorption characteristics while AgNW/ZnO electrodes are more compatible with low band gap polymer-based single cells. In tandem devices, AgNW/ZnO is more preferable resulting in up to 80% improvement in PCE compared to parallel devices on Flextrode. Rolling in tandem: Roll-to-roll rotary screen printing of silver nanowires (AgNWs) and zinc oxide (ZnO) is realized on flexible substrates enabling large-area semi-transparent electrodes with >80% transmission. This electrode is employed in all-ambient roll-coating of single and tandem polymer solar cells. AgNW/ZnO proves highly suitable especially for tandem structures while the traditional indium-tin-oxide replacement - Flextrode - remains unbeaten in single cells with wide band-gap polymers.

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Scopus rating (2011): CiteScore 9.47
ISI indexed (2011): ISI indexed no
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Round-Robin Studies on Roll-Processed ITO-free Organic Tandem Solar Cells Combined with Inter-Laboratory Stability Studies

Roll-processed, indium tin oxide (ITO)-free, flexible, organic tandem solar cells and modules have been realized and used in round-robin studies as well as in parallel inter-laboratory stability studies. The tandem cells/modules show no significant difference in comparison to their single-junction counterparts and the use of round-robin studies as a consensus tool for evaluation of organic solar cell parameters is judged just as viable for the tandem solar cells as for single-junction devices. The inter-laboratory stability studies were conducted according to testing protocols ISOS-D-2, ISOS-D-3, and ISOS-L-2, and in spite of a much more complicated architecture the organic tandem solar cells show no significant difference in stability in comparison to their single-junction counterparts.

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Scalable single point power extraction for compact mobile and stand-alone solar harvesting power sources based on fully printed organic photovoltaic modules and efficient high voltage DC/DC conversion

Patterns for fully printed polymer solar cells are presented that inherently enable scaling of the power output with single point electrical energy connection is presented. Connection is made to only one end of the printed foil that can be rolled out for light energy harvesting. The power level is simply increased/decreased by increasing/decreasing the length of the foil with a corresponding increase/decrease in operating voltage. The current flow runs in both directions along the printed foil thus alleviating the need for post process addition of complex busbar topologies. The power conversion takes place in a HVDC–DC converter that is tailored specifically for operation with polymer solar cells by regulation on the input side. The system charges a lithium-polymer battery thus enabling storage of 82 Wh for a printed OPV foil measuring 0.305 m×9 m having a nominal power output of at least 15 W (AM1.5G, 1000 W m−2). As a demonstration we present a scalable fully integrated and compact power unit for mobile applications comprising solar energy harvesting OPV modules, power conversion and storage. Applications possible include electrical charging of mobile devices, illumination using LED lamps and low mechanical power applications such as pumping water.
Solution and vapour deposited lead perovskite solar cells: Ecotoxicity from a life cycle assessment perspective

We present a life cycle analysis (LCA) and an environmental impact analysis (EIA) of lead based perovskite solar cells prepared according to the two most successfully reported literature methods that comprise either vapour phase deposition or solution phase deposition. We have developed the inventory for all the components employed for the two different device architectures that resemble respectively a traditional dye sensitised solar cell (DSSC) and an inverted polymer solar cell (OPV). We analyse the impacts from generation of 1 kWh of electricity and assume a lifetime of 1 year in the analysis and further present a sensitivity analysis with the operational lifetime as a basis. We find that the major impact comes from the preparation of the perovskite absorber layer due to the electrical energy required in the manufacture and also make the striking observation that the impact of toxic lead(II)halides is very limited compared to methylammoniumhalides employed. This applies during the raw materials extraction, synthesis of the starting materials and manufacture of the perovskite solar cells and from these points of view the lead based perovskite solar cells do not pose extra concerns when compared to contending solar cell technologies in the cradle-to-gate scenario considered here. The environmental impact of the perovskite solar cells in the operational phase and the decommissioning phase representing a cradle-to-grave analysis is not currently possible and will have to await large scale outdoor demonstration where emission to the environment during the operation and decommissioning phase can be measured. The main conclusion is that in the cradle-to-gate analysis there are no compelling reasons to dismiss lead based perovskites as a solar cell technology.
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Structure and crystallinity of water dispersible photoactive nanoparticles for organic solar cells

Water based inks would be a strong advantage for large scale production of organic photovoltaic devices. Formation of water dispersible nanoparticles produced by the Landfester method is a promising route to achieve such inks. We provide new insights into the key ink properties of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) nanoparticles such as the internal structure and crystallinity of the dispersed nanoparticles and the previously unreported drastic changes that occur when the inks are cast into a film. We observe through transmission electron microscopy (TEM) and small angle X-ray scattering (SAXS) that the nanoparticles in dispersion are spherical with the nanodomains of P3HT being partly crystalline. When wet processed and dried into films, the nanoparticles lose their spherical shape and become flattened into oblate shapes with a large aspect ratio. Most particles are observed to have a diameter 13 times of the particle height. After casting into a film, the crystal domains adopt a preferred orientation with the majority of the nanocrystals (68%) with face-on orientation to the substrate. We propose that low substrate surface energy is responsible for particle deformation and texturing.

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The Critical Choice of PEDOT: PSS Additives for Long Term Stability of Roll-to-Roll Processed OPVs

The impact of additives mixed with poly(3,4-ethylenedioxythiophene):polystyrenesulfonate (PEDOT:PSS) on the stability of organic photovoltaic modules is investigated for fully ambient roll-to-roll (R2R) processed indium tin oxide free modules. Four different PEDOT:PSS inks from two different suppliers are used. The modules are manufactured directly on barrier foil without a UV filter to accelerate degradation and enable completion of the study in a reasonable time span. The modules are subjected to stability testing following well-established protocols developed by the international summit on organic photovoltaic stability (ISOS). For the harsh indoor test (ISOS-L-3) only a slight difference in stability is observed between the different modules. During both ISOS-L-3 and ISOS-D-3 one new failure mode is observed as a result of tiny air inclusions in the barrier foil and a R2R method is developed to detect and quantify these. During outdoor operation (ISOS-O-1) the use of ethylene glycol (EG) as an additive is found to drastically increase the operational stability of the modules as compared to dimethylsulfoxide (DMSO) and a new failure mode specific to modules with DMSO as the additive is identified. The data are extended in an ongoing experiment where DMSO is used as additive for long-term outdoor testing in a solar park.

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The effect of mesomorphology upon the performance of nanoparticulate organic photovoltaic devices

Scanning transmission X-ray microscopy (STXM) compositional mapping has been used to probe the mesomorphology of nanoparticles (NPs) synthesized from two very different polymer:fullerene blends: poly(3-hexylthiophene) (P3HT): phenyl-C61-butyric acid methyl ester (PCBM) and poly[4,8-bis(2-ethylhexyloxy)benzo(1,2-b:4,5-b’)dithiophene-alt-5,6- bis(octyloxy)-4,7-di(thiophen-2-yl)(2,1,3-benzothiadiazole)-5,5'-diyl] (PSBTBT): PCBM. The STXM data shows that both blends form core-shell NP structures with similar shell compositions, but with different polymer:fullerene ratios in the core regions. P3HT:PCBM and PSBTBT:PCBM NP organic photovoltaic (OPV) devices have been fabricated and exhibit similar device efficiencies, despite the PSBTBT being a much higher performing low band gap material. By comparing the measured NP shell and core compositions with the optimized bulk hetero-junction (BHJ) compositions, we show that the relatively higher performance of the P3HT:PCBM NP device arises from the fact that its shell composition is much closer to the optimal BHJ value than that of the PSBTBT:PCBM NP device. [All rights reserved Elsevier].
The effect of molecular geometry on the photovoltaic property of diketopyrrolopyrrole based non-fullerene acceptors

The non-fullerene acceptors with different geometric structures have great impact on light absorption, exciton dissociation, and charge transportation in the active layer of organic solar cells (OSCs). In this paper, we designed and synthesized two diketopyrrolopyrrole based non-fullerene acceptors, Ph(DPP)2 and PhDMe(DPP)2 with similar chemical components but different molecular geometries. Due to its more twisted molecular conformation, PhDMe(DPP)2 shows more blue-shifted absorption bands, higher electron mobility, and better miscibility with the polymer donor poly(3-hexylthiophene) (P3HT) while compared to Ph(DPP)2. Therefore, the resulting P3HT:PhDMe(DPP)2 based OSCs shows a better power conversion efficiency (PCE) of 0.65%, higher than that from P3HT:Ph(DPP)2 based OSCs (0.48%), which can be ascribed to more efficient exciton dissociation and electron transportation in the active layer of P3HT:PhDMe(DPP)2.
The Solar Textile Challenge: How It Will Not Work and Where It Might

Solar textiles are highlighted as a future technology with transformative power within the fields of both textiles and solar cells provided that developments are made in critical areas. Specifically, these are fundamental solutions to materials and material combinations with mechanical stability and flexibility imposed by textile architectures, scientific solutions to achieve high carrier transport efficiency and optical transmission in a textile topology, technical solutions to controlling the...
physical disposition of the anode and cathode along with their specific and error-free contacting and, finally, practical solutions to fast and efficient manufacture and integration. The areas of application and the penetration of solar textiles into our everyday life are expected to be explosive pending efficient developments within these four key areas. A shortcoming in one or more of these will, however, lead to the solar textiles being banned to academic existence.

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Scopus rating (2010): SJR 1.959 SNIP 1.143
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 0.979 SNIP 0.718
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Scopus rating (2008): SJR 0.297 SNIP 0.508
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Scopus rating (2007): SJR 0.281 SNIP 0.49
Scopus rating (2006): SJR 0.242 SNIP 0.37
Scopus rating (2005): SJR 0.195 SNIP 0.287
Scopus rating (2004): SJR 0.214 SNIP 0.272
Scopus rating (2003): SJR 0.276 SNIP 0.417
Scopus rating (2002): SJR 0.3 SNIP 0.584
Scopus rating (2001): SJR 0.29 SNIP 0.496
Scopus rating (2000): SJR 0.425 SNIP 0.571
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Thiophene in Conducting Polymers: Synthesis of Poly(thiophene)s and Other Conjugated Polymers Containing Thiophenes, for Application in Polymer Solar Cells

Conducting polymers based on thiophene are described. The polymers include poly(thiophene) with and without side-chains and other conjugated polymers in general, based on thiophene. The synthesis and characteristics of the polymers are described along with the application of these as light-absorbing materials in polymer solar cells.

Three dimensional corrugated organic photovoltaics for building integration; improving the efficiency, oblique angle and diffuse performance of solar cells

The lamination of OPV modules to corrugated roof cladding has been undertaken. The 3-dimensional form of the cladding provides three advantages for outdoor OPV deployment; firstly the ‘footprint’ of the solar cell is reduced, which leads to B10% improved power conversion (PCE) efficiency per unit area. Secondly, the oblique angle performance is enhanced, leading to increased output in the early morning and evening. Indoor characterisation showed a 9-fold enhancement in efficiency was obtainable, when compared to a flat module. Thirdly, an improvement in performance under diffuse lighting conditions was measured, when compared to a flat module. The average daily yield of the 3D module was 17–29% higher than a flat module, with higher relative enhancements observed on cloudier days. Geographically, the 3D module appears to be well-suited to countries with a high latitude, due to the enhanced diffuse light levels and the fact that tilting the module in both ‘latitude’ and ‘longitude’ directions away from normal, leads to the best achievable enhancement in solar cell performance. The approach set out in this paper could yield a product that has profound advantages over existing BIPV products and is potentially applicable to other flexible inorganic solar cell technologies.
Tin- and Lead-Based Perovskite Solar Cells under Scrutiny: An Environmental Perspective

The effect of substituting lead with tin in perovskite-based solar cells (PSCs) has shows that lead is preferred over tin by a lower cumulative energy demand. The results, which also include end-of-life management, show that a recycling scenario that carefully handles emission of lead enables use of lead in PSCs with little environmental impact. All other scenarios result in catastrophic emission of lead to the environment that would spell an end to widespread use of lead in PSCs.
Trends in energy supply integration: Solar PV

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Lauritzen, H. (Intern)
Pages: 56-58
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Host publication information
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Publisher: Technical University of Denmark (DTU)
Editors: Hvidtfeldt Larsen, H., Sønderberg Petersen, L.
ISBN (Print): 978-87-550-3970-4
Main Research Area: Technical/natural sciences
Electronic versions:
Publication: Research - peer-review › Book chapter – Annual report year: 2015
Upscaling of Perovskite Solar Cells: Fully Ambient Roll Processing of Flexible Perovskite Solar Cells with Printed Back Electrodes

A scaling effort on perovskite solar cells is presented where the device manufacture is progressed onto flexible substrates using scalable techniques such as slot-die roll coating under ambient conditions. The printing of the back electrode using both carbon and silver is essential to the scaling effort. Both normal and inverted device geometries are explored and it is found that the formation of the correct morphology for the perovskite layer depends heavily on the surface upon which it is coated and this has significant implications for manufacture. The time it takes to form the desired layer morphology falls in the range of 5–45 min depending on the perovskite precursor, where the former timescale is compatible with mass production and the latter is best suited for laboratory work. A significant loss in solar cell performance of around 50% is found when progressing to using a fully scalable fabrication process, which is comparable to what is observed for other printable solar cell technologies such as polymer solar cells. The power conversion efficiency (PCE) for devices processed using spin coating on indium tin oxide (ITO)-glass with evaporated back electrode yields a PCE of 9.4%. The same device type and active area realized using slot-die coating on flexible ITO-polyethyleneterphthalate (PET) with a printed back electrode gives a PCE of 4.9%.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
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Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed Yes
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Scopus rating (2016): CiteScore 12.96 SJR 6.515 SNIP 2.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 6.219 SNIP 2.546 CiteScore 14.2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 6.668 SNIP 2.942 CiteScore 15.27
A solar park based on polymer solar cells is described and analyzed with respect to performance, practicality, installation speed, and energy payback time. It is found that a high voltage installation where solar cells are all printed in series enables an installation rate in Watts installed per minute that far exceed any other PV technology in existence. The energy payback time for the practical installation of polymer solar cell foil on a wooden 250 square meter platform in its present form is 277 days when operated in Denmark and 180 days when operated in southern Spain. The installation and de-installation rate is above 100 m min⁻¹, which, with the present performance and web width, implies installation of >200 W min⁻¹. In comparison, this also exceeds the overall manufacturing speed of the polymer solar cell foil with a width of 305 mm which is currently 1 m min⁻¹ for complete encapsulated and tested foil. It is also significant that simultaneous installation and de-installation which enables efficient schemes for decommissioning and recycling is possible. It is highlighted where research efforts should most rationally be invested in order to make grid electricity from OPV a reality (and it is within reach).

General information
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Main Research Area: Technical/natural sciences

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BFI (2018): BFI-level 3
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 17.79
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 18.5
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 16.79
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 15.78
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
2D Characterization of OPV from Single and Tandem Cells to Fully Roll-to-Roll Processed Modules with and without Electrical Contact

A new type of light beam-induced current 2D mapping system is developed that speeds up acquisition time from hours and days to minutes or even seconds. It is particularly relevant as a tool to characterize printed, large-scale, organic photovoltaics. Defects inherent to the multi-layer printing or degradation effects that develop later can be detected with a spatial resolution of

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Krebs, F. C. (Intern), Jørgensen, M. (Intern)
Pages: 465-477
Publication date: 2014
Main Research Area: Technical/natural sciences

Publication information
Journal: Advanced Optical Materials
Volume: 2
Issue number: 5
ISSN (Print): 2195-1071
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
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Scopus rating (2017): SNIP 1.723 SJR 3.121
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 5.96 SJR 2.747 SNIP 1.629
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.248 SNIP 1.792 CiteScore 5.14
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.812 SNIP 1.677 CiteScore 3.45
A comparative study of fluorine substituents for enhanced stability of flexible and ITO-free high-performance polymer solar cells

Two low-band gap polymer series based on benzo[1,2-b:4,5-b′]dithiophene (BDT) and dithienylbenzothiadiazole, with different numbers of fluorine substituents on the 2,3,1-benzothiadiazole unit, have been synthesized and explored in a comparative study of the photochemical stability and operational lifetime in flexible large area roll-coated bulk heterojunction solar cells. The two polymer series have different side chains on the BDT unit, namely 2-hexyldecyloxy (BDTHDO) (P1-P3) or 2-hexyldecylthiophene (BDT THD) (P4-P6). The photochemical stability clearly shows that the stability enhances along with the number of fluorine atoms incorporated on the polymer backbone. Fabrication of the polymer solar cells based on the materials was carried out in ambient atmosphere on a roll coating/printing machine employing flexible and indium-tin-oxide-free plastic substrates. Solar cells based on the P4-P6 series showed the best performance, reaching efficiencies up to 3.8% for an active area of 1 cm², due to an enhanced current compared to P1-P3. Lifetime measurements, carried out according to international summit on OPV stability (ISOS), of encapsulated devices reveals an initial fast decay for P1-P6 in the performance followed by a much slower decay rate, still retaining 40-55% of their initial performance after 250 h of testing under ISOS-L-1 conditions. © 2014 Wiley Periodicals, Inc.
All-Solution-Processed, Ambient Method for ITO-Free, Roll-Coated Tandem Polymer Solar Cells using Solution-Processed Metal Films

A solution-processed silver film is employed in the processing of top-illuminated indium-tin-oxide (ITO)-free polymer solar cells in single- and double-junction (tandem) structures. The nontransparent silver film fully covers the substrate and serves as the bottom electrode whereas a PEDOT:PSS/Ag grid forms the semitransparent top electrode. All layers are roll-coated/printed on a flexible substrate by using only two techniques: slot–die coating for up to 11 consecutive layers and flexo-printing for the last Ag grid layer. The slot–die coated Ag film is compared to an evaporated Ag film in terms of surface morphological and topographical properties and to ITO in terms of flexibility. The slot–die coated Ag film demonstrates extremely low roughness (a root-meansquare roughness of 3 nm was measured over 240_320 mm² area), is highly conductive (<1 W/å), highly flexible, and cost-effective in comparison to other reported metal films applied in polymer solar cells. Such properties result in high fill factors exceeding 50% in both single and tandem structures on large-area devices (1 cm²) and the corresponding efficiencies exceed 2%.
A rational method for developing and testing stable flexible indium- and vacuum-free multilayer tandem polymer solar cells comprising up to twelve roll processed layers

We demonstrate a method for the preparation of multijunction polymer solar cells without the use of vacuum evaporation methods or indium tin oxide (ITO). The entire layer stack is prepared by printing or coating of each layer. The number of layers typically employed in complete devices exceeds ten and to efficiently identify layers and interfaces that are not robust we developed a double sided illumination method and demonstrate how layer thicknesses can be optimized with respect to the roll processing in the aim of achieving functional tandem devices. The devices were prepared directly on barrier foil and were later encapsulated. In this study the same active material comprising poly-3-hexylthiophene (P3HT) and phenyl-C61-butyric acid methyl ester ([60]PCBM) was employed using nanoparticle based zinc oxide for electron selectivity and several different PEDOT:PSS formulations for hole selectivity, electrode- and recombination layer formation. A novel slanted comb silver grid electrode structure was employed to enable efficient double sided illumination and minimize shunts. The operational stability of the tandem devices evaluated under ISOS-D-2 conditions demonstrated less variation in stability between devices than similar single junctions prepared in the same manner for reference. We demonstrate lifetime studies for 480 h without any sign of degradation and estimate that the tandem or multijunction polymer solar cells are as stable as single junctions.
Tandem polymer solar cells, ITO free, Vacuum free, Flexible, Roll printed, Stability

DOIs:
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Relations
Projects:
A rational method for developing and testing stable flexible indium- and vacuum-free multilayer tandem polymer solar cells comprising up to twelve roll processed layers
Source: dtu
Source-ID: u::8825
Publication: Research - peer-review › Journal article – Annual report year: 2013
Carbon: The Ultimate Electrode Choice for Widely Distributed Polymer Solar Cells

As mass-produced, low-cost organic electronics enter our everyday lives, so does the waste from them. The challenges associated with end-of-life management must be addressed by careful design and carbon-based electrodes are central to these developments. Here, the reproducible production of vacuum-, indium tin oxide (ITO)-, and silver-free solar cells in a fully packaged form using only roll-to-roll processing is reported. Replacing silver with carbon as electrode material significantly lowers the manufacturing cost and makes the organic photovoltaic (OPV) modules environmentally safe while retaining their flexibility, active area efficiency, and stability. The substitution of silver with carbon does not affect the roll-to-roll manufacturing of the modules and allows for the same fast printing and coating. The use of carbon as electrode material is one step closer to the wide release of low-cost plastic solar cells and opens the door to new possible applications where silver recycling is not manageable.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
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Web of Science (2018): Indexed yes
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Scopus rating (2017): SNIP 2.347 SJR 8.23
Web of Science (2017): Indexed Yes
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Scopus rating (2016): CiteScore 12.96 SJR 6.515 SNIP 2.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 6.219 SNIP 2.546 CiteScore 14.2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 6.668 SNIP 2.942 CiteScore 15.27
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.006 SNIP 2.949 CiteScore 13.24
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 5.575 SNIP 2.181 CiteScore 9.64
ISI indexed (2012): ISI indexed no
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English

Comparison of additive amount used in spin-coated and roll-coated organic solar cells
All-polymer and polymer/fullerene inverted solar cells were fabricated by spin-coating and roll-coating processes. The spin-coated small-area (0.04 cm²) devices were fabricated on indium tin oxide (ITO) coated glass substrates in nitrogen.
The roll-coated large-area (1.0 cm$^2$) devices were prepared on ITO-free flexible substrates under ambient conditions. The use of a solvent additive, 1,8-diiodooctane (DIO), facilitated phase separation and enhanced power conversion efficiencies (PCEs). The PCE of polymer/fullerene solar cells increased from 4.58% to 8.12% (v/v) DIO when using the spin-coating process, and increased from 1.37% to 2.09% with 5% (v/v) DIO in the roll-coating process. The PCE of all-polymer solar cells increased from 1.44% to 3.51% with 4% (v/v) DIO when employing the spin-coating process. For the roll-coated large area devices the PCE increased from 0.15% to 0.73% with 9% (v/v) DIO. The optimal amounts of DIO, when using the roll-coating process for the two different active layers (5% and 9% respectively) are significantly higher than those for the spin-coating process (2.5% and 4%, respectively), which is ascribed to a fundamentally different drying mechanism.

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Chinese Academy of Sciences, Zhejiang University, Peking University
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**Publication information**

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Volume: 2
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BFI (2018): BFI-level 2
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Scopus rating (2017): SJR 3.488 SNIP 1.55
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 8.46 SJR 3.075 SNIP 1.479
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.62 SNIP 1.643 CiteScore 8.36
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.331 SNIP 1.514 CiteScore 7.27
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
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Web of Science (2013): Indexed yes
Original language: English
CHEMISTRY, ENERGY, MATERIALS, BULK-HETEROJUNCTION, HIGH-PERFORMANCE, EFFICIENCY ENHANCEMENT, PHOTOVOLTAIC POLYMERS, SOLVENT ADDITIVES, SELF-ORGANIZATION, DEVICE EFFICIENCY, SMALL MOLECULES, ACTIVE LAYERS, SIDE-CHAINS

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**Relations**

Projects:
Comparison of additive amount used in spin-coated and roll-coated organic solar cells
Source: FindIt
Source-ID: 272521330
Publication: Research - peer-review → Journal article – Annual report year: 2014

**Cost analysis of roll-to-roll fabricated ITO free single and tandem organic solar modules based on data from manufacture**

We present a cost analysis based on state of the art printing and coating processes to fully encapsulated, flexible ITO- and vacuum-free polymer solar cell modules. Manufacturing data for both single junctions and tandem junctions are presented and analyzed. Within this calculation the most expensive layers and processing steps are identified. Based on large roll-to-
roll coating experiments the exact material consumptions were determined. In addition to the data for the pilot scale experiment presented here, projections to medium and large scale scenarios serve as a guide to achieve cost targets of 5 €ct per Wp in a detailed material and cost analysis. These scenarios include the replacement of cost intensive layers, as well as process optimization steps. Furthermore, the cost structures for single and tandem devices are listed in detail and discussed. In an optimized model the material costs drop below 10 € per m² which proves that OPV is a competitive alternative to established power generation technologies.

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BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 4.819 SJR 14.59
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 7.769 SNIP 4.001 CiteScore 19.28
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.019 SNIP 2.996 CiteScore 14.81
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 5.868 SNIP 2.599 CiteScore 11.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 3.737 SNIP 2.505 CiteScore 9.96
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 3.87 SNIP 2.42
Web of Science (2010): Indexed yes
Scopus rating (2009): SJR 2.11 SNIP 1.15
Original language: English
DOIs:
10.1039/c4ee01222d
Source: PublicationPreSubmission
Source-ID: 96644232
Digital grayscale printing for patterned transparent conducting Ag electrodes and their applications in flexible electronics

Grayscale (halftone) laser printing is developed as a low-cost and solution processable fabrication method for ITO-free, semi-transparent and conducting Ag electrodes extendable over large area on a flexible substrate. The transmittance and sheet resistance is easily tunable by varying the grayscale value of the color fill between 10% to 20%. The operation of electrodes is demonstrated by fabricating a transparent push button, an electrochromic window and a solar cell.

General information

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Jawaharlal Nehru Centre for Advanced Scientific Research
Authors: Gupta, R. (Ekstern), Hösel, M. (Intern), Jensen, J. (Intern), Krebs, F. C. (Intern), Kulkarni, G. U. (Ekstern)
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Scopus rating (2017): SNIP 1.3 SJR 1.917
Web of Science (2017): Indexed Yes
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Scopus rating (2016): CiteScore 5.14 SJR 1.825 SNIP 1.266
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.713 SNIP 1.508 CiteScore 5.32
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.517 SNIP 1.351 CiteScore 4.64
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
ISI indexed (2013): ISI indexed no
Original language: English
DOIs:
10.1039/c3tc32229g

Bibliographical note
10.1039/c3tc32229g
Source: dtu
Source-ID: u::10710

Editorial for the special issue dedicated to tandem solar cells based on organic and polymer materials

Organic photovoltaics (OPV) have been tremendously successful at the academic level as evidenced by an enormous body of scientific reports. The power conversion efficiency for OPV has as a consequence of the intense research effort experienced a corresponding growth and today single junction OPV reportedly present record power conversion efficiencies of around 10% for tiny active areas. The scaled power conversion efficiency however still remains significantly lower. In an effort to improve both record and scaled power conversion efficiencies several schemes have been pursued and one of the most promising is the well-known tandem concept where one or more junctions are stacked on top of each other. In the context of OPV this presents a significant processing challenge which is the subject of this issue where a selection of papers have been collected that cover very broadly from roll processing of multi-junctions through tandem modules, interlayer design and life cycle analysis. All-in-all an excellent collection of papers for the student as well as the researcher working on and developing OPV. I wish you a good few hours of reading.

General information
Efficient decommissioning and recycling of polymer solar cells: justification for use of silver
Large 100 m long polymer solar cell modules were installed in a solar park using fast installation (>100 m min\(^{-1}\)) and operated for 5 months ensuring a meaningful energy return factor (ERF > 1) followed by fast de-installation (>200 m min\(^{-1}\)) and end-of-life management. Focus was on recovery of silver that is an essential component of the two electrodes. We employed life cycle analysis as a tool to evaluate the most efficient silver extraction method as well as the impact on the overall life cycle of the solar cells. Silver from the electrodes could be recovered as silver chloride in 95% yield, which diminishes the overall energy payback time by 13%. The efficient recovery of silver justifies the use of silver electrodes in OPV even in a scenario where it is scaled to production volumes of 1 GWp per day.
Environmental impacts of global and regional electricity generation from 1980 to 2010: What can we learn for sound energy transition planning?

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Energy Conversion and Storage, Functional organic materials
Authors: Laurent, A. (Intern), Espinosa, N. (Intern)
Publication date: 2014
Event: Poster session presented at Sustainability Science Congress 2014, Copenhagen, Denmark.
Main Research Area: Technical/natural sciences

Environmental Printing Efficient Organic Tandem Solar Cells with High Fill Factors: A Guideline Towards 20% Power Conversion Efficiency

The tandem concept involves stacking two or more cells with complementary absorption spectra in series or parallel connection, harvesting photons at the highest possible potential. It is strongly suggested that the roll-to-roll production of organic solar cells will employ the tandem concept to enhance the power conversion efficiency (PCE). However, due to the undeveloped deposition techniques, the challenges in ink formulation as well as the lack of commercially available high performance active materials, roll-to-roll fabrication of highly efficient organic tandem solar cells currently presents a major challenge. The reported high PCE values from lab-scale spin-coated devices are, of course, representative, but not helpful for commercialization. Here, organic tandem solar cells with exceptionally high fill factors and PCE values of 7.66% (on glass) and 5.56% (on flexible substrate), which are the highest values for the solution-processed tandem solar cells fabricated by a mass-production compatible coating technique under ambient conditions, are demonstrated. To predict the highest possible performance of tandem solar cells, optical simulation based on experimentally feasible values is performed. A maximum PCE of 21% is theoretically achievable for an organic tandem solar cell based on the optimized bandgaps and achieved fill factors.

General information
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Authors: Li, N. (Ekstern), Baran, D. (Ekstern), Spyropoulos, G. D. (Ekstern), Zhang, H. (Ekstern), Berny, S. (Ekstern), Turbiez, M. (Ekstern), Ameri, T. (Ekstern), Krebs, F. C. (Intern), Brabec, C. J. (Ekstern)
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Web of Science (2018): Indexed yes
Environmental sustainability of electricity supply in the world between 1980 and 2011: Lessons learnt and perspectives

The generation of electricity is known to cause important damages to environment and human health. The political awareness of the global challenges posed by climate change and resource depletion has guided several countries to gradually move from a dominant use of fossil fuels towards more utilisation of renewables. However, has such moves led to burden-shifting from these environmental impacts to others as relevant? Considering the whole spectrum of environmental problems, are there any identifiable patterns across regions or impact categories that could serve to draw recommendations for energy planning? To address these questions, we collected annual data on electricity generation for 199 countries and territories for the period 1980-2011, differentiated per types of energy sources. These data were combined with region-specific life cycle inventories of pollutant emissions and resource consumptions to assess ten environmental impact categories, e.g. climate change, water use or chemical pollution. The results show that, for several regions, the majority of these impacts have increased between 1980 and 2011. Asia and the Middle East – and to a lesser degree, Africa and Latin America – thus show steep increase, up to more than one order of magnitude, when compared to their 1980- baseline values. To estimate the “environmental cleanness” of the grid mixes over time, the impact scores were normalized by the electricity generated yearly within each country. This revealed burden-shifting occurrences in almost all regions within the period 1980-2011. For example, in Asia, normalized impacts of particulate matters on human health have more than doubled, while increase in climate change scores have been limited to ca. 35%. Based on our findings, we therefore recommend that electricity planning be accompanied with quantification of all relevant environmental impacts of the foreseen energy systems to prevent or minimise problem-shiftings ensuring an environmentally-sound energy transition.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Energy Conversion and Storage, Functional organic materials
Authors: Laurent, A. (Intern), Espinosa Martinez, N. (Intern)
Number of pages: 1
Publication date: 2014

Host publication Information
Title of host publication: Abstract Book - DTU Sustain Conference 2014
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Main Research Area: Technical/natural sciences
Failure Modes and Fast Repair Procedures in High Voltage Organic Solar Cell Installations

Steadily increasing efficiencies of organic solar cells are frequently published but the practical demonstration of actual large-scale installations with high power output has been very limited. Here, the real-world challenges and opportunities of organic solar cells fabricated on thin plastic foil and mounted in solar cell arrays of more than 1 kW are shown. In this configuration defects in form of burns that have never been reported before are observed. The reason can be seen in the combination of high power production, water ingress, and the use of thin plastic foil as the substrate. Environmental impact such as lightning was also observed to cause randomly distributed burn holes that initiate self-sustained damaging under illumination. The large solar cell modules each with more than 220 Wpeak are based only on serially connected cells and need no time-consuming manual wiring of single cells. Although burns that locally destroy the modules are observed the efficiency is not much affected. Simple repair procedures developed throughout the lifetime study enable the cut and replace of small pieces of the module. A complete replacement as it is carried out for malfunctioning conventional Si-based PV modules is not necessary. This enables cost-effective maintenance over the lifetime of the organic solar cells.
Fast Switching ITO Free Electrochromic Devices

Indium-doped tin oxide free electrochromic devices are prepared by coating electrochromic polymers onto polyethylene terephthalate substrates encompassing two different silver grids as electrodes. One design comprises a flexoprinted highly conductive silver grid electrode, yielding electrochromic devices with a response time of 2 s for an optical contrast of 27%. The other design utilizes an embedded silver grid electrode whereupon response times of 0.5 s for a 30% optical contrast are realized when oxidizing the device. A commercially available conductive poly(3,4-ethylenedioxythiophene):poly(4-styrenesulfonate acid) formulation (PEDOT:PSS) is coated onto the silver grids as a charge balancing polymer, and is in this setting found to be superior to a polypyrrole previously employed in electrochromic devices. In addition, the PEDOT:PSS layer increases the conductivity in the hexagonal grid structure.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Korea Institute of Machinery and Materials
Authors: Jensen, J. (Intern), Hösel, M. (Intern), Kim, I. (Ekstern), Yu, J. (Ekstern), Jo, J. (Ekstern), Krebs, F. C. (Intern)
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Scopus rating (2014): CiteScore 11.32
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Scopus rating (2013): CiteScore 10.6
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
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Scopus rating (2011): CiteScore 9.47
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
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Flexible organic tandem solar modules with 6% efficiency: combining roll-to-roll compatible processing with high geometric fill factors

Organic solar cell technology bears the potential for high photovoltaic performance combined with truly low-cost, high-volume processing. Here we demonstrate organic tandem solar modules on flexible substrates fabricated by fully roll-to-roll compatible processing at temperatures...
From the Bottom Up – Flexible Solid State Electrochromic Devices

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Jensen, J. (Intern), Krebs, F. C. (Intern)
Number of pages: 4
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 17.79
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 18.5
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 16.79
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Web of Science (2013): Indexed yes
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Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 12.28
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Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
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Fully printed multi square meter large organic solar cell modules for real energy production

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials
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Generic roll-to-roll compatible method for insolubilizing and stabilizing conjugated active layers based on low energy electron irradiation

Irradiation of organic multilayer films is demonstrated as a powerful method to improve several properties of polymer thin films and devices derived from them. The chemical cross-linking that is the direct result of the irradiation with ~100 keV electrons is fast and has a penetration power compatible with thin plastic foils of one to two hundreds of microns typical of devices explored in organic electronics. We demonstrate here that active layers and complete devices can be subjected to electron irradiation-induced cross-linking thus facilitating multilayer solvent processing and morphological stability. The method is fast, generic, contactless, and fully compatible with high-speed roll-to-roll processing of i.e. polymer solar cells at web speeds in excess of 60 m min−1. We employ fully printed, flexible, and foil-based indium-tin-oxide free polymer solar cells in this study to demonstrate the technique. We also demonstrate that polymer solar cells are exceptionally stable towards ionizing radiation and find that doses as high as 100 kGy can be used before any significant decrease in performance is observed. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 2014, 131, 40795.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Center for Nuclear Technologies, Radiation Physics
Authors: Helgesen, M. (Intern), Carlé, J. E. (Intern), Helt-Hansen, J. (Intern), Miller, A. (Intern), Krebs, F. C. (Intern)
Number of pages: 8
Publication date: 2014
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.73 SJR 0.588 SNIP 0.792
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.587 SNIP 0.846 CiteScore 1.74
High‐Volume Processed, ITO‐Free Superstrates and Substrates for Roll‐to‐Roll Development of Organic Electronics

The fabrication of substrates and superstrates prepared by scalable roll-to-roll methods is reviewed. The substrates and superstrates that act as the flexible carrier for the processing of functional organic electronic devices are an essential component, and proposals are made about how the general availability of various forms of these materials is needed to accelerate the development of the field of organic electronics. The initial development of the replacement of indium-tin-oxide (ITO) for the flexible carrier materials is described and a description of how roll-to-roll processing development led to simplification from an initially complex make-up to higher performing materials through a more simple process is also presented. This process intensification through process simplification is viewed as a central strategy for upscaling,
Increasing throughput, performance, and cost reduction.

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Number of pages: 12
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**Publication information**

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Scopus rating (2017): SNIP 1.554 SJR 4.982
Web of Science (2017): Indexed Yes
Scopus rating (2016): CiteScore 1.66 SJR 2.976 SNIP 0.978
Scopus rating (2015): SNIP 1.143 SJR 2.626
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Source: PublicationPreSubmission
Source-ID: 102672368
Publication: Research - peer-review › Journal article – Annual report year: 2014

**In situ monitoring of structure formation in the active layer of polymer solar cells during roll-to-roll coating**

The active layer crystallization during roll-to-roll coating of organic solar cells is studied in situ. We developed an X-ray setup where the coater unit is an integrated part of the small angle X-ray scattering instrument, making it possible to control the coating process while recording scattering measurements in situ, enabling us to follow the crystal formation during drying. By varying the distance between the coating head and the point where the X-ray beam hits the film, we obtained measurements of 4 different stages of drying. For each of those stages, the scattering from as long a foil as possible is summed together, with the distance from coating head to scattering point kept constant. The results are average crystallographic properties for the active layer coated on a 30 m long foil. With this insight into the dynamics of crystallization in a roll-coated polymer film, we find that the formation of textured and untextured crystallites seems uncorrelated, and happens at widely different rates. Untextured P3HT crystallites form later in the drying process than expected which may explain previous studies speculating that untextured crystallization depends on concentration. Textured crystallites, however, begin forming much earlier and steadily increases as the film dries, showing a development similar to other in situ studies of these materials.

**General information**

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**Publication information**

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Web of Science (2018): Indexed yes
Polymer solar cell (PSC) is the latest of all photovoltaic technologies which currently lies at the brink of commercialization. The impetus for its rapid progress in the last decade has come from low-cost high throughput production possibility which in turn relies on the use of low-cost materials and vacuum-free manufacture. Indium tin oxide (ITO), the commonly used transparent conductor, imposes the majority of the cost of production of PSCs, limits flexibility, and is feared to create bottleneck in the dawning industry due to indium scarcity and the resulting large price fluctuations. As such, finding a low-cost replacement of ITO is widely identified to be very crucial for the commercial feasibility of PSCs. In this regard, a variety of nanomaterials have shown remarkable potential matching up to and sometimes even surpassing the properties of ITO. This chapter elaborates the recent developments in ITO replacement which include, but are not limited to, the use of nanomaterials such as metal nanogrids, metal nanowires, carbon nanotubes, and graphene. The use of polymers and metals as replacement to ITO are described as well. Finally, recent progress in large-scale experiments on ITO-free PSC modules is also presented.
Infinitely Large Organic Solar Cell Modules: At The Edge Of Traditional Territories For Power Supply

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Espinosa Martinez, N. (Intern), Krebs, F. C. (Intern)
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Interlaboratory indoor ageing of roll-to-roll and spin coated organic photovoltaic devices: Testing the ISOS tests
The inter-comparability of ageing of organic photovoltaic (OPV) technologies in dark is addressed. Four primary factors that affect the reproducibility of the ageing rate determination and inter-comparison are discussed: production/encapsulation of the samples, current–voltage (IV) characterization, testing conditions for ageing and lifetime determination from a decay curve. Results of inter-laboratory ageing studies of roll-to-roll and spin coated samples with correspondingly flexible plastic packaging and glass stored in dark conditions among 7 laboratories are presented. ISOS test conditions, proposed recently as guiding protocols for testing OPV stability, are applied in the study. The reproducibility of the performance versus the production and encapsulation techniques is firstly studied. The results reveal a significant improvement in the reproducibility when going from manual spin coating to roll-to-roll production. Furthermore, the reproducibility of current–voltage (IV) measurement and preconditioning (light soaking treatments) are addressed. Additionally, the inter-comparison of the degradation rates of the samples aged under three different dark test conditions (ambient, dry/heat, damp heat) reported by different groups are analyzed revealing a reasonable agreement. Finally, a logarithmic diagram for OPV lifetime associated with common time units is proposed that allows conveniently categorizing and intercomparing the stability performance of different samples aged under different test conditions.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imperial College London, European Commission - Joint Research Center, Centro de Investigaciones Energéticas, MedioAmbientales y Tecnológicas, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Institut National de l'Energie Solaire, National Physical Laboratory
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Web of Science (2016): Indexed yes
Large-Area Processing of Organic Photovoltaics

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials

Authors: Søndergaard, R. R. (Intern), Hösel, M. (Intern), Krebs, F. C. (Intern)

Pages: 639-662

Publication date: 2014
Large scale deployment of polymer solar cells on land, on sea and in the air
With the development of patterns that connect all cells in series, organic photovoltaics have leapt a step forward being ahead of other solar and even other energy technologies in terms of manufacturing speed and energy density. The important questions of how they are meant to be installed for producing power and what the requirements are yet to be explored. We present here the installation of organic solar cell modules in different settings (terrestrial, marine and airborne). For the evaluation of these installations deployed at DTU, we have used the life cycle assessment tools, and calculated key parameters in order to assess their environmental impact. The novel technology when installed in a solar park system can generate more than 1300 kW h kWp$^{-1}$ of electricity a year, which means that the whole system can pay the energy invested back before the first year of operation, in 320 days. If this electricity is fed back to the same electricity supply system that was used for manufacturing the potential saving of more than 13 GJ of primary energy per kWp per year can be reached. With the real data logged, a dynamic energy payback time has been furthermore calculated for the case of the solar tube installation, giving a value of 1.1 years.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Espinosa Martinez, N. (Intern), Hösel, M. (Intern), Jørgensen, M. (Intern), Krebs, F. C. (Intern)
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Publication date: 2014
Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 7.769 SNIP 4.001 CiteScore 19.28
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.019 SNIP 2.996 CiteScore 14.81
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 5.868 SNIP 2.599 CiteScore 11.84
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 3.737 SNIP 2.505 CiteScore 9.96
Life cycle analysis of organic tandem solar cells: When are they warranted?

One approach to use solar radiation more effectively in solar cells is to stack, in series, multiple photoactive layers with complementary absorption spectra. Such devices are often termed tandem or multi-junction solar cells. The larger number of different materials and processing steps involved in their making when compared with the single junction solar cell has to be justified and compensated by a higher efficiency. A central question to ask is how much energy you need to invest in a system in order for it to produce energy and return the investment at least once and preferably a number of times. As an initial investigation into the potential viability of the tandem or multi-junction approach we have engaged in a detailed analysis based on the manufacturing energy for each step within the tandem module supply chain for full ambient processing of thin flexible polymer tandem solar cells prepared entirely by roll processing methods. We present a comprehensive overview of relevant research results on how the energy consumption affects the energy balance when using single and multi-junction solar cells. Based on the above question we calculate the minimum efficiency that the tandem or multi-junction should present to determine the minimum energy payback time; that is whether (or when) the increase in materials use and complexity of the tandem architecture is compensated by better performance. After analysing the performance and the consideration of a series of technical improvement opportunities, we project that the tandem solar cell has to be ~20% higher performing than the corresponding single junction solar cell to be warranted. We also highlight that there is a range in the reciprocal EBPT–efficiency relationship where the tandem solar cell is an advantage. Specific to polymer and organic solar cells are however that they embody very little energy and this implies that the single junction may be an advantage, especially in cases where land mass is not critical.

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Espinosa Martinez, N. (Intern), Krebs, F. C. (Intern)
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
Massive scale production and installation of flexible printed solar cells

Printed solar cells can be prepared on a large scale (kilometers) on relatively small equipment using little material. The performance and lifetime are lower and shorter than many conventional PV technology but manufacturing speed, manufacturing cost, energy pay back time and installation speed can by far exceed known energy technologies with a significant potential for further improvement through architecture development and process intensification.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Hösel, M. (Intern)
Publication date: 2014
Medium area, flexible single and tandem junction solar cells based on roll coated semi-random copolymers

We report on medium area (1 cm²) slot-die coated organic photovoltaic devices (OPVs) of a recently developed semi-random copolymer of poly-3-hexylthiophene and diketopyrrolopyrrole (P3HTT-DPP-10%) mixed with phenyl-C61-butyric acid methyl ester ([60]PCBM). The devices were prepared using a compact laboratory roll-coater using only slot-die coating and flexographic printing under ambient conditions on a flexible ITO-free substrate. In order to overcome a low JSC and FF obtained for single junction devices, devices were also prepared in a tandem geometry making it possible to employ thinner junction films. Power conversion efficiencies of up to 1.36% and 1.31% were achieved for the tandem and single junction geometries, respectively.

Micromechanical String Resonators: Analytical Tool for Thermal Characterization of Polymers

Resonant microstrings show promise as a new analytical tool for thermal characterization of polymers with only few nanograms of sample. The detection of the glass transition temperature (Tg) of an amorphous poly(d,l-lactide) (PDLLA) and a semicrystalline poly(l-lactide) (PLLA) is investigated. The polymers are spray coated on one side of the resonating
microstrings. The resonance frequency and quality factor (Q) are measured simultaneously as a function of temperature. Change in the resonance frequency reflects a change in static tensile stress, which yields information about the Young's modulus of the polymer, and a change in Q reflects the change in damping of the polymer-coated string. The frequency response of the microstring is validated with an analytical model. From the frequency independent tensile stress change, static Tg values of 40.6 and 57.6 °C were measured for PDLLA and PLLA, respectively. The frequency-dependent damping from Q indicates higher Tg values of 62.6 and 88.8 °C for PDLLA and PLLA, respectively, at ~105 Hz. Resonant microstrings facilitate thermal analysis of nanogram polymer samples measuring the static and a dynamic glass transition temperature simultaneously.

Outdoor Operational Stability of Indium-Free Flexible Polymer Solar Modules Over 1 Year Studied in India, Holland, and Denmark

We present an outdoor interlaboratory stability study of fully printed and coated indium-tin-oxide (ITO)-free polymer solar cell modules in JNCASR Bangalore (India), ECN (Holland), and DTU (Denmark) carried over more than 1 year. The modules comprising a fully printed and coated stack (Ag grid/PEDOT:PSS/ZnO/P3HT:PCBM/PEDOT:PSS/Ag grid) were prepared in two successive generations and evaluated for outdoor operational stability according to the test protocols laid out by the International Summit on OPV stability (ISOS-3). The modules (70–100 cm² active area) were encapsulated between two sheets of low-cost plastic barrier material with the use of a UV curing adhesive. The impact of differences in the climatic conditions on the performance of the modules is highlighted and the performance of the modules under storage conditions in parallel with the outdoor study is investigated. While all Gen-I modules failed, the best devices of Gen-II module in which simple improvement in the encapsulation scheme (Gen-II modules) was carried out maintained 95% of the initial performance after 1 year of outdoor testing. We provide detailed insight into the failure mode and offer a discussion on the need for improvement in flexible encapsulation. Finally, recommendations on future encapsulation schemes are also presented.

General information
Outdoor Operational Stability of Indium-Free Flexible Polymer Solar Modules Over 1 Year Studied in India, Holland, and Denmark

Photovoltaic mounting/demounting unit
The present invention relates to a photovoltaic arrangement comprising a photovoltaic assembly comprising a support structure defining a mounting surface onto which a photovoltaic module is detachably mounted; and a mounting/demounting unit comprising at least one mounting/demounting apparatus which when the mounting/demounting unit is moved along the mounting surface, causes the photovoltaic module to be mounted or demounted to the support structure; wherein the photovoltaic module comprises a carrier foil and wherein a total thickness of the photovoltaic module is below 500 micrometers. The present invention further relates to an associated method for mounting/demounting photovoltaic modules.

Predicting, categorizing and intercomparing the lifetime of OPVs for different ageing tests
The presented work addresses the issue of lifetime prediction and intercomparison for organic photovoltaic (OPV) devices tested under different environmental conditions according to ISOS guidelines proposed recently at the International Summit on Organic Photovoltaic Stability. The studies employed P3HT:PCBM based devices produced with different
architectures and methods ranging from spin coating to roll-to-roll manufacturing. The purpose of the chosen diversity was to establish the possible spread in the ageing rates generated by different architectures. A logarithmic lifetime diagram associated with the common time units was used for presenting the ageing data, which regardless of the spread in the lifetimes allowed categorizing the level of the stability of P3HT:PCBM based devices tested under different ageing conditions. Moreover, the approach also allowed for estimating the acceleration factors between the moderate and harsh ISOS test conditions employed in the study, as well as identifying the level of improvement of the device stability after encapsulation. The effects of different device architectures and encapsulation techniques on ageing rates of the samples were also studied. This report presents the early steps towards establishing a prediction tool for identifying the lifetime of OPV devices under operational conditions based on the tests under harsh (accelerated) conditions.

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Corazza, M. (Intern), Krebs, F. C. (Intern), Gevorgyan, S. (Intern)
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- Web of Science (2017): Indexed yes
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- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 2
- Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
- Web of Science (2014): Indexed yes
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- Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 2.182 SNIP 2.577 CiteScore 5.16
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 2.494 SNIP 2.105
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 1.942 SNIP 1.957
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 1.626 SNIP 1.449
Roll-coating fabrication of flexible large area small molecule solar cells with power conversion efficiency exceeding 1%

All solution-processed flexible large area small molecule bulk heterojunction solar cells were fabricated via roll-coating technology. Our devices were produced from slot-die coating on a lab-scale mini roll-coater under ambient conditions without the use of spin-coating or vacuum evaporation methods. Four diketopyrrolopyrrole based small molecules (SMs 1-4) were utilized as electron donors with (6,6)phenyl-C61-butyric acid methyl ester as an acceptor and their photovoltaic performances based on roll-coated devices were investigated. The best power conversion efficiency (PCE) of 1.01%, combined with an open circuit voltage of 0.73 V, a short-circuit current density of 3.13 mA cm\(^2\) and a fill factor of 44% were obtained for the device with SM1, which was the first example reported for efficient roll-coating fabrication of flexible large area small molecule solar cells with PCE exceeding 1%. In addition, rollcoated devices based on SMs 2-4 also showed good performances with PCEs of 0.41%, 0.54%, and 0.31%, respectively. Our results prove that small molecules have the potential for use in industries for large scale production of efficient organic solar cells.
Round robin performance testing of organic photovoltaic devices

This study addresses the issue of poor intercomparability of measurements of organic photovoltaic (OPV) devices among different laboratories. We present a round robin performance testing of novel OPV devices among 16 laboratories, organized within the framework of European Research Infrastructure Project (SOPHIA) and European Energy Research Alliance (EERA). Three types of OPVs with different structures, dimensions and encapsulations are studied and compared with reference Si solar cells certified by accredited laboratories. The agreement of the measurements of these among different laboratories is analyzed by focusing on testing procedures, testing equipment and sample designs. A number of deviations and pitfalls are revealed and based on the analyses, a set of recommendations are suggested for improving the agreement among the measurements of such OPV technologies. © 2013 Elsevier Ltd. All rights reserved.

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Scalable, ambient atmosphere roll-to-roll manufacture of encapsulated large area, flexible organic tandem solar cell modules

Inline printing and coating methods have been demonstrated to enable a high technical yield of fully roll-to-roll processed polymer tandem solar cell modules. We demonstrate generality by employing different material sets and also describe how the ink systems must be carefully co-developed in order to reach the ambitious objective of a fully printed and coated 14-layer flexible tandem solar cell stack. The roll-to-roll methodologies involved are flexographic printing, rotary screen printing, slot-die coating, X-ray scattering, electrical testing and UV-lamination. Their combination enables the manufacture of completely functional devices in exceptionally high yields. Critical to the ink and process development is a carefully chosen technology transfer to industry method where first a roll coater is employed enabling contactless stack build up, followed by a small roll-to-roll coater fitted to an X-ray machine enabling in situ studies of wet ink deposition and drying mechanisms, ultimately elucidating how a robust inline processed recombination layer is key to a high technical yield. Finally, the transfer to full roll-to-roll processing is demonstrated.

General information

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Organisations:

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- Web of Science (2018): Indexed yes
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- Scopus rating (2017): SNIP 4.819 SJR 14.59
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 2
- Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 2
Scaling Up ITO-free solar cells

Indium-tin-oxide-free (ITO-free) polymer solar cells with composite electrodes containing current-collecting grids and a semitransparent poly(3,4-ethylenedioxythiophene):polystyrenesulfonate (PEDOT:PSS) conductor are demonstrated. The up-scaling of the length of the solar cell from 1 to 6 cm and the effect of the grid line resistance are explored for a series of devices. Laser-beam-induced current (LBIC) mapping is used for quality control of the devices. A theoretical modeling study is presented that enables the identification of the most rational cell dimension for the grids with different resistances. The performance of ITO-free organic solar cells with different dimensions and different electrode resistances are evaluated for different light intensities. The current generation and electric potential distribution are found to be not uniformly distributed in large-area devices at simulated 1 Sun illumination. The generated current uniformity increases with decreasing light intensities.

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Solution processed large area fabrication of Ag patterns as electrodes for flexible heaters, electrochromics and organic solar cells

A simple method for producing patterned Ag electrodes on transparent and flexible substrates is reported. The process makes use of laser printed toner as a sacrificial template for an organic precursor, which upon thermolysis and toner lift off produced highly conducting Ag electrodes. Thus, the process takes only a few minutes without any expensive instrumentation. The electrodes exhibited excellent adhesion and mechanical properties, important for flexible device application. Using Ag patterned electrodes, heaters operating at low voltages, pixelated electrochromic displays as well as organic solar cells have been demonstrated. The method is extendable to produce defect-free patterns over large areas as demonstrated by roll coating.

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Solvent-resistant small molecule solar cells by roll-to-roll fabrication via introduction of azide cross-linkable group
A novel cross-linkable azide-functionalized diketopyrrolopyrrole based compound DPP(BT-N-3)(2) was designed and synthesized via Stille coupling. Cross-linking of such molecule could help us fabricate insoluble film which could be used to fabricate heterostructures through solution processing, without dissolving the pre-patterned layers. In order to investigate the photovoltaic performances of the newly synthesized compound, large area solar cells were produced by roll coating technique. Two set of devices were fabricated by employing DPP(BT-N-3)(2) as either an electron donor or acceptor. A best power conversion efficiency of 0.067%, combined with an open circuit voltage of 0.53 V, and a fill factor of 37.6% were obtained for the device with DPP(BT-N-3)(2) as an electron acceptor. In addition, we could prove that the large area small molecule based organic solar cells could be fabricated using roll coating, which could be used in the industries for large-scale of production. (C) 2014 Elsevier B.V. All rights reserved.

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Spatial degradation mapping and componentwise degradation tracking in polymer-fullerene blends

Using X-ray absorption the effects of photodegradation in active layer materials for polymer solar cells are investigated. Through the observation of changes in the X-ray absorption energy spectra the degradation of the individual components is tracked in blends of poly-3-hexyl-thiophene (P3HT) and C60 butyric acid methyl ester (PCBM). The degradation rates in the blend are decreased by a factor of 3 for P3HT and by a factor between 1.1 and 2.3 for PCBM compared to the pure materials. For P3HT, degradation is resolved spatially using scanning transmission X-ray microscopy and the photodegradation process is found to be intrinsically homogeneous at the nanometer scale.

General information
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The influence of additives on the morphology and stability of roll-to-roll processed polymer solar cells studied through ex situ and in situ X-ray scattering

The effect of twelve different additives on organic solar cells with an active layer based on poly-3-hexylthiophene (P3HT) and phenyl-C61-butyric acid methyl ester (PCBM) has been studied in this work and tested for suitability in roll-to-roll slot-die coating. Three of the twelve additives increased the solar cell efficiency while the rest showed no effect or a negative influence on the efficiency and coatability. In cases where the additive caused an increase in performance the relation to surface topography and the structure was investigated using Atomic Force Microscopy (AFM), UV-Vis Spectroscopy and Small Angle X-ray Scattering (SAXS) for cells prepared with 1-chloronaphthalene (CN), N-methyl-2-pyrrolidone (NMP) and 1,3-dimethyl-barbituric acid (BARB) as processing additives. The studies suggested that the use of these additives resulted in films with improved morphology and electrical properties of the active layer. The effect of the CN on structural evolution during different solvent evaporation and annealing times was further investigated with an in situ roll-to-roll X-ray study. Lifetime studies under continuous illumination were used to assess the impact of the additives on the stability of the prepared devices that had an active area of 1 cm².
Towards large-scale production of solution-processed organic tandem modules based on ternary composites: Design of the intermediate layer, device optimization and laser based module processing

We report on a novel approach including: 1. the design of an efficient intermediate layer, which facilitates the use of most high performance active materials in tandem structure and the compatibility of the tandem concept with large-scale production; 2. the concept of ternary composites based on commercially available materials, which enhances the absorption of poly(3-hexylthiophene) (P3HT) and as a result increase the PCE of the P3HT-based large-scale OPV devices; 3. laser-based module processing, which provides an excellent processing resolution and as a result can bring the power conversion efficiency (PCE) of mass-produced organic photovoltaic (OPV) devices close to the highest PCE values achieved for lab-scale solar cells through a significant increase in the geometrical fill factor. We believe that the combination of the above mentioned concepts provides a clear roadmap to push OPV towards large-scale production and commercial applications. (C) 2013 Elsevier B.V. All rights reserved.
Up-scaling from single cells to modules – fabrication of vacuum- and ITO-free polymer solar cells on flexible substrates with long lifetime

Fabrication of polymer solar cell (PSC) modules was done on a previously reported compact coating/printing machine and tested in a readily scalable roll process on flexible substrates without applying vacuum, ITO or spin coating. Our aim was to establish loss upon scaling from cells to small modules. We studied from single cells (1 cm2) to modules comprising four serially connected devices with a total active area of 8 cm2. Four different polymers (P3HT, PV-D4610, PDTSTTz-4 and PBDTTTz-4) were applied in the preparation of the modules and efficiencies of more than 3% were achieved which is comparable to single cell devices prepared using the same process. This proves that it is possible to scale up new materials in an ITO free device context to modules without having an efficiency drop, due to reliable and consistent processing. The main loss observed was due to the packaging using barrier materials. The photochemical stability of the materials was therefore studied using intense light along with the operational stability of the corresponding devices according to the ISOS-D-1 and ISOS-L-1 standards. For devices under constant illumination we found that barrier materials from Mitsubishi and 3M provide better operational stability over time, compared to the barrier foil obtained from Amcor, for all the polymers, which is ascribed to the cut-off at higher wavelengths thereby lowering the degree of UV light that reaches the device. When comparing the operational stability of the four polymers under constant illumination, P3HT generally retains its performance better with higher T80 values, while the polymer PV-D4610 shows the highest PCE (1.6%) after 300 hours of operation.
Upscaling of Indium Tin Oxide (ITO)-Free Polymer Solar Cells: Performance, Scalability, Stability, and Flexibility

Polymer solar cells (PSCs) aim to produce clean energy that is cost-competitive to energy produced by fossil fuel-based conventional energy sources. From an environmental perspective, PSCs already compare favorably to other solar cell technologies in terms of fewer emissions of greenhouse gases during production. The costcompetitiveness of PSCs is envisioned achievable by the use of inexpensive materials and high throughput roll-to-roll (R2R) printing and coating techniques. The state-of-the-art of the laboratory PSCs is, however, far removed from the vision of the widely disseminated low-cost solar cells as the laboratory solar cells are mostly focused on increasing the power conversion efficiency through materials design with little emphasis on the choice of materials, operational stability and large-scale processing. Indium-tin-oxide (ITO), the commonly used transparent conductor, represents majority of the share of cost and energy footprint in terms of materials and processing in a conventional PSC module. Furthermore, the scarcity of indium is feared to create bottleneck in the dawning PSC industry and its brittle nature is an obstacle for fast processing of PSCs on flexible substrates as well as for applications in flexible end products. Thus, the replacement of ITO with low-cost alternatives is crucial for the commercial feasibility of PSCs.

Encompassing these concerns, my PhD study has contributed to the development and evaluation of alternatives to ITO in laboratory cells, upscaling of ITO-free concepts from laboratory cells to R2R produced large-area modules, and integration of these module in demonstrator consumer applications. Accordingly, this dissertation is organized into nine chapters. Chapter 1 is aimed at contextualizing PSCs on the world energy map. It aims to address the question: why should PSCs be pursued? Chapter 2 attempts to provide a concise yet encompassing introduction to PSCs; and the problem with ITO and possible solutions. It also lays out specific targets that were set before the beginning of PhD study which provides a frame-of-reference for the later chapters. A holistic evaluation of several ITO-free concepts was carried out to determine low-cost upscaling compatibility of these concepts (Chapter 3). The results highlighted three architectures that represented different competencies with regards to photovoltaic performance, stability, and low-cost processing. These three architectures were upscaled (Chapter 5-7) using R2R techniques described in detail in Chapter 4. One of the three upscaled architecture (Chapter 7) represented an efficient alternative to ITO in terms of photovoltaic performance and were further investigated for stability and flexibility. These modules were then integrated in a credit-card size laser pointer for demonstration purposes. A colleague, Nieves Espinosa, has conducted life-cycle analyses (LCA) on all the three upscaled ITO-free architectures. Drawing upon the data from her published work, Chapter 8 provides concise and comparative LCA of the three upscaled ITO-free architectures in order to determine which technology can be pursued further among the three architectures. LCA results of the ITO-free architectures are also compared against ITO-based upscaled PSCs as well as against other photovoltaic technologies. Finally, the last chapter (Chapter 9) puts everything in the nutshell and identifies future challenges.
Worldwide outdoor round robin study of organic photovoltaic devices and modules

Accurate characterization and reporting of organic photovoltaic (OPV) device performance remains one of the important challenges in the field. The large spread among the efficiencies of devices with the same structure reported by different groups is significantly caused by different procedures and equipment used during testing. The presented article addresses this issue by offering a new method of device testing using “suitcase sample” approach combined with outdoor testing that limits the diversity of the equipment, and a strict measurement protocol. A round robin outdoor characterization of roll-to-roll coated OPV cells and modules conducted among 46 laboratories worldwide is presented, where the samples and the testing equipment were integrated in a compact suitcase that served as both a sample transportation tool and as a holder and test equipment during testing. In addition, an internet based coordination was used via plasticphotovoltaics.org that allowed fast and efficient communication among participants and provided a controlled reporting format for the results that eased the analysis of the data. The reported deviations among the laboratories were limited to 5% when compared to the Si reference device integrated in the suitcase and were up to 8% when calculated using the local irradiance data. Therefore, this method offers a fast, cheap and efficient tool for sample sharing and testing that allows conducting outdoor measurements of OPV devices in a reproducible manner.

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Accurate characterization of OPVs: Device masking and different solar simulators
One of the prime objects of organic solar cell research has been to improve the power conversion efficiency. Unfortunately, the accurate determination of this property is not straightforward and has led to the recommendation that record devices be tested and certified at a few accredited laboratories following rigorous ASTM and IEC standards. This work tries to address some of the issues confronting the standard laboratory in this regard. Solar simulator lamps are investigated for their light field homogeneity and direct versus diffuse components, as well as the correct device area determination using various types of masks, are discussed. The main findings are that the light field inhomogeneity and a large diffuse component in combination with masking give rise to a substantial variation in the measured efficiency. As a result the device efficiency can easily be over or underestimated. We offer a set of recommendations for the device masking and efficiency characterization that enable accurate determination of the efficiency in a standard OPV characterization laboratory.

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Advanced Functional Polymers for Increasing the Stability of Organic Photovoltaics

The development of new advanced polymers for improving the stability of OPV is reviewed. Two main degradation pathways for the OPV active layer are identified: photochemically initiated reactions primarily starting in the side chains and morphological changes that degrade the important nanostructure. Chemical units can be introduced that impart an increased stability. Similarly, the morphological degradation of the optimal nanostructure can be reduced. Active polymers and blends with acceptor material are used to create nanoparticle links with controlled size. Most of these advanced polymers and processing methods have only been utilized in small-scale devices prepared by standard techniques such
as spin coating, but a few cases of roll-to-roll processed solar cells with heat-cleaved side chains are discussed.
A laboratory scale approach to polymer solar cells using one coating/printing machine, flexible substrates, no ITO, no vacuum and no spincoating

Printing of the silver back electrode under ambient conditions using simple laboratory equipment has been the missing link to fully replace evaporated metal electrodes. Here we demonstrate how a recently developed roll coater is further developed into a single machine that enables processing of all layers of the polymer solar cell without moving the substrate from one machine to another. The novel approach to polymer solar cells is readily scalable using one compact laboratory scale coating/printing machine that is directly compatible with industrial and pilot scale roll-to-roll processing. The use of the techniques was successfully demonstrated in one continuous roll process on flexible polyethyleneterphthalate (PET) substrates and polymer solar cells were prepared by solution processing of five layers using only slot-die coating and flexographic printing. The devices obtained did not employ indium–tin-oxide (ITO) or vacuum evaporation steps making it a significant step beyond the traditional laboratory polymer solar cell processing methods involving spin coating and metal evaporation.

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All polymer photovoltaics: From small inverted devices to large roll-to-roll coated and printed solar cells

Inverted all polymer solar cells based on a blend of a perylene diimide based polymer acceptor and a dithienosilole based polymer donor were fabricated from small area devices to roll-to-roll (R2R) coated and printed large area modules. The device performance was successfully optimized by using solvent additive to tune the phase separation. By adding 2% chloronaphthalene as solvent additive for small area (0.25 cm²) devices, a power conversion efficiency (PCE) up to 0.63% was achieved for inverted geometry, higher than that (0.39%) of conventional geometry. This polymer blend showed excellent solution processibility and R2R coated and printed large area (4.2 cm²) solar cells exhibited a PCE of 0.20%. © 2013 Elsevier B.V.

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Ambient roll-to-roll fabrication of flexible solar cells based on small molecules

All solution-processed roll-to-roll flexible solar cells based on a star-shaped small molecule donor and PCBM acceptor were fabricated by slot-die coating, as the first successful example reported for small molecule roll-to-roll flexible solar cells.

An Efficient Solution-Processed Intermediate Layer for Facilitating Fabrication of Organic Multi-Junction Solar Cells

Photovoltaic tandem technology has the potential to boost the power conversion efficiency of organic photovoltaic devices. Here, a reliable and efficient fully solution-processed intermediate layer (IML) consisting of ZnO and neutralized poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) is demonstrated for series-connected multi-junction organic solar cells (OSCs). Drying at 80 °C in air is sufficient for this solution-processed IML to obtain excellent functionality and reliability, which allow the use of most of high performance donor materials in the tandem structure. An open circuit voltage (Voc) of 0.56 V is obtained for single-junction OSCs based on a low band-gap polymer, while multi-junction OSCs based on the same absorber material deliver promising fill factor values along with fully additive Voc as the number of junctions increases. Optical and electrical simulations, which are reliable and promising guidelines for the design and investigation of multi-junction OSCs, are discussed. The outcome of optical and electrical simulations is in excellent
agreement with the experimental data, indicating the outstanding efficiency and functionality of this solution-processed IML. The demonstration of this efficient, solution-processed IML represents a convenient way for facilitating fabrication of multi-junction OSCs to achieve high power conversion efficiency.

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Authors: Ning Li (Ekstern), Baran, D. (Ekstern), Forberich, K. (Ekstern), Turbiez, M. (Ekstern), Ameri, T. (Ekstern), Krebs, F. C. (Intern), Brabec, C. J. (Ekstern)
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**A novel benzodipyrrolidone-based low band gap polymer for organic solar cells**
A low band gap polymer PBDPD-DTP, with alternating benzodipyrrolidone (BDP) unit and dithienopyrrole, was synthesized and characterized. A PCE of 2.60% and a Voc of up to 0.74 V were realized in PSCs, which demonstrated the strong potential of BDP as the electron deficient unit in the design of donor–acceptor conjugated polymers for PSCs.

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A photovoltaic module

The present invention relates to a photovoltaic module comprising a carrier substrate, said carrier substrate carrying a purely printed structure comprising printed positive and negative module terminals, a plurality of printed photovoltaic cell units each comprising one or more printed photovoltaic cells, wherein the plurality of printed photovoltaic cell units are electrically connected in series between the positive and the negative module terminals such that any two neighbouring photovoltaic cell units are electrically connected by a printed interconnecting electrical conductor. The carrier substrate comprises a foil and the total thickness of the photovoltaic module is below 500 \([\mu\text{m}]\). Moreover, the nominal voltage level between the positive and the negative terminals is at least 5 kV DC.
A round robin study of polymer solar cells and small modules across China

A round robin study across 15 laboratories in China was carried out using single junction devices with an active area of 1 cm² and differently sized small module with an active area of 20 and 24 cm² respectively. The devices represented the state of the art in terms of processing as they did not employ indium or vacuum and were prepared using only printing and coating techniques on flexible substrates. The devices were studied in their flexible form and thus approach the vision of what the polymer solar cell is. The main purpose of the work was to establish and chart geographic and cultural differences in what constitutes a competent IV-characterization procedure and also to establish the spread in measured data across the globe. The main finding is that efficiency data deviated up to 30% from the mean while an overall relative standard deviation of 12% was observed. Collating this spread with previous findings points toward a seemingly region-independent i.e. global observation of the uncertainty in the IV-characterization of a polymer solar cell. Finally, we highlight what might be done to improve the accuracy of the reported data. © 2013 Elsevier B.V. All rights reserved.
Coating, Degrading and Testing of Organic Polymer Devices - Reducing the route from Laboratory to Production scale devices

Organic electronics is a vast and fast improving research area, with widespread uses proposed since the 1991 discovery of semiconducting polymers. The premise of this thesis is based on finding more effective ways towards making cheap organic electronics and enabling a shorter path from the lab scale manufacturing of organic electronics to the large scale manufacturing, by downsizing some of the methods used in full size roll to roll (R2R) coating techniques into a lab scale setting. The enabling of similar techniques in both lab and production settings allows an optimization in the lab to be more directly transferred to the production environment, in contrast to the presently often used spin coating technique, for which optimizations of parameters are close to impossible to transfer to the larger scale operations. Therefore a mini lab scale roll coating system was developed to enable lab scale fabrication of organic electronic devices, using the techniques of the larger R2R systems. The lab scale slot-die roll coating technique reported, not only allow a faster route from lab scale to production scale, but also has the added advantage of a smaller material consumption. The solution volume, which for spin coating allowed making a single 1 cm2 device, using the mini roll coater (MRC) enable the coating of a 100 cm2 area, resulting in 60 1cm² devices with the present mask designs. With the relative expensive polymers, this translates into a large saving for performing the same amount of tests, not to mention the saved time in the preparation of the devices. The lab scale roll coater system was used to manufacture a range of solar cells from different polymers, testing the influence of thicknesses, and post treatment processes. It was used to fabricate tandem solar cells with several thousand cells manufactured in the process for creating a recipe that would allow a wet processed layer on layer coating to function without having penetration and dissolution through the up to 12 separately printed layers. Testing and analysis of a nanoparticle based method with water used as the transport agent for the active layer inks in solar cells was conducted, with a primary focus on testing the morphology of the nanoparticles. This type of ink could allow a more environmentally friendly production of solar cells, due to a lower use of organic solvents, while further allowing a new level of control for the active layer morphology. Besides solar cells, the lab scale coating method was applied to both electrochromic devices and light emitting electrochemical cells. In these cases relatively large devices could be manufactured, without the use of protective atmospheres and without using evaporated electrode materials. The performance of the devices was lower than the state of the art, however this was to be expected due to the proof of concept manufacturing. Finally a section has been included on the use of an open source electronic platform with a dedicated sourcemeter board developed to test solar cell devices without the need of expensive multipurpose source meters. This also shows the potential for stand-alone test, especially relevant for the various outdoor test conducted around the world and for the logging of various high-impact parameters, such as temperature, humidity and solar insolation.
Comparison of Fast Roll-to-Roll Flexographic, Inkjet, Flatbed, and Rotary Screen Printing of Metal Back Electrodes for Polymer Solar Cells

The majority of polymer solar cells reported today employs processing under high vacuum for one or more of the layers in the solar cell stack. Most notably the highly conducting metal back electrode is almost exclusively applied by evaporation of the pure metal. While it is not impossible to envisage mass production of polymer solar cells using vacuum processing it does present some drawbacks in terms of both processing speed, capital investment in processing equipment technical yield and direct process energy. From this point of view it is clear that vacuum processed electrodes should be avoided and electrodes should be printable using methods that provide a high degree of accuracy and high technical yield. When considering large area polymer solar cells (i.e., not laboratory devices) a few reports have employed printable back electrodes mostly by use of silver formulations[1–4] but also carbon[5] and copper has been discussed whereas copper is unlikely to yield the necessary cost reduction and resistance to oxidation. Most reports have employed flatbed or rotary screen printing whereas other methods are available and described later on. The important question to answer is which technique is most suited for manufacture of polymer solar cell modules in terms of technical yield, materials use and processing speed? Evidently the back electrode has to be of high conductivity, which implies the use of a thick electrode. Therefore thick film printing techniques such as the screen printing techniques have proven excellent while they do present disadvantages in speed due to significant drying requirements but also they do require significant amounts of material.[2,6]

In this paper we employ four different roll-to-roll (R2R) printing methods for printing silver back electrodes for polymer solar cell modules based on the IOne process which is a fully printable, indium-tin-oxide (ITO), and vacuum free technology that provide similar performance to ITO-based polymer solar cell modules when using poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester ([60]PCBM) as the active layer. We analyze advantages and disadvantages for each method and also outline boundaries of their use and highlight a few areas where development could lead to disruptive progress for the polymer solar cell as a technology.
Comparison of Two Types of Vertically Aligned ZnO NRs for Highly Efficient Polymer Solar Cells

Vertically aligned ZnO nanorods (NR) are prepared by two different synthesis methods and applied on polymer solar cells (PSCs). The ZnO electrodes work as the electron transport layer with the P3HT:PCBM blend acting as the active material. Several organic blend solution conditions are optimized: concentration, solvent, and deposition speed. The effect of different NR electrode morphologies is analyzed on the solar cell performance and characterized by current-voltage relations.

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Comparison of Two Types of Vertically Aligned ZnO NRs for Highly Efficient Polymer Solar Cells
Vertically aligned ZnO nanorods (NR) are prepared by two different synthesis methods and applied on polymer solar cells (PSCs). The ZnO electrodes work as the electron transport layer with the P3HT:PCBM blend acting as the active material. Several organic blend solution conditions are optimized: concentration, solvent, and deposition speed. The effect of different NR electrode morphologies is analyzed on the solar cell performance and characterized by current-voltage relations.
curves and IPCE analyses. The photovoltaic performance of the solar cells was observed to be influenced by many factors, among them infiltration of the organic P3HT:PCBM blend within the ZnO NR layer. The infiltration of the active layer was monitored by cross section SEM and energy dispersive X-ray spectroscopy analyses. Our results show that higher power conversion efficiencies are achieved when shorter NRs lengths are applied. The best power conversion efficiency obtained was 2.0% for a 400 nm ZnO NR electrode. © 2012 Wiley Periodicals, Inc.

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Comparison of UV-Curing, Hotmelt, and Pressure Sensitive Adhesive as Roll-to-Roll Encapsulation Methods for Polymer Solar Cells

The most distinct advantage of the polymer solar cell is the possibility for roll-to-roll (R2R) fabrication compatibility based on printing and coating processes. The R2R encapsulation is the last crucial process step in the manufacturing workflow and is evaluated in this study. Polymer solar cell modules are directly printed on barrier foil and encapsulated with the same barrier foil either on the backside or on both sides of the device. The three lamination methods comprise of UV-curable epoxy resin, hotmelt, and pressure sensitive adhesive (PSA). It is shown that a single sided encapsulation with UV-curable adhesive is enough to achieve the same or better lifetime than double-sided encapsulation with all the adhesives utilized here. This is mainly due to the good edge sealing effect of the thin adhesive with no edge bleaching after 900 h of constant illumination. Although the fabrication of the PSA method is the fastest method (in this study) it generates a considerable amount of waste (paper liner) and two lamination steps are required to achieve a sufficient lifetime. We conclude that UV-curing presents the largest advantages of all methods with a good upscaling potential and low embodied energy due to the possibility for single sided encapsulation.
Concentrated Light for Accelerated Photo Degradation of Polymer Materials

Concentrated light is used to perform photochemical degradation of polymer solar cell materials with acceleration factors up to 1200. At constant temperature the photon efficiency in regards to photo degradation is constant for 1–150 suns and oxygen diffusion rates are not a limiting factor. Accelerated degradation by concentrated light thus allows for rapid and precise evaluations of one sun polymer stabilities.
Conductance Enhancement of InAs/InP Heterostructure Nanowires by Surface Functionalization with Oligo(phenylene vinylene)

We have investigated the electronic transport through 3 μm long, 45 nm diameter InAs nanowires comprising a 5 nm long InP segment as electronic barrier. After assembly of 12 nm long oligo(phenylene vinylene) derivative molecules onto these InAs/InP nanowires, we observed a pronounced, nonlinear I–V characteristic with significantly increased currents of up to 1 μA at 1 V bias, for a back-gate voltage of 3 V. As supported by our model calculations based on a nonequilibrium Green Function approach, we attribute this effect to charge transport through those surface-bound molecules, which electrically bridge both InAs regions across the embedded InP barrier.
Cyclopolymerization-derived block-copolymers of 4,4-bis(octyloxymethyl)-1,6-heptadiyne with 4,4- dipropargyl malonodinitrile for use in photovoltaics

The synthesis of AB-type block copolymers of 4,4-bis(octyloxymethyl)-1,6-heptadiyne (M1) and dipropargyl malonodinitrile (M2) via metathesis-based cyclopolymerization using well-defined molybdenum- and ruthenium-based initiators is described. While backbiting reactions were observed in the case where polymerizations were triggered by [Ru(NCO)2(IrMesH2)(CH-2-(2-PrO)–C6H4)] (I2) and [Ru(NCO)2(3-Br-Py)2(IrMesH2)(CHPh)] (I3), ([IrMesH2 ¼ 1,3-dimesitylimidazolin-2-ylidene, 3-Br-Py ¼ 3-bromopyridine), the use of RuCl2(Py)2(IrMesH2)(CHPh) (I1) in THF allowed for the synthesis of poly(M1) without any backbiting, though with a broad PDI. Block copolymers, i.e. poly(M1)-b-poly(M2), could be prepared in a living manner without any backbiting by the use of the Mo-based Schrock-type initiator Mo(N-2,6-i-Pr2C6H3)(CHCMe2Ph)(OCH(CH3)2)2 (I4) and THF as solvent. Poly(M1)-b-poly(M2) was characterized by UV and fluorescence spectroscopy and used for the construction of a photovoltaic device.
Determining the coating speed limitations for organic photovoltaic inks

To determine the output capability of present organic photovoltaic (OPV) materials, it is important to know the theoretical maximum coating speeds of the used semiconductor formulations. Here, we present a comprehensive investigation of the coating stability window of several prototype organic semiconductor inks relevant for organic solar cells. The coating stability window was first determined experimentally by a sheet to sheet coater at velocities of up to 10 m/min. A numerical simulation model based on the Coating Window Suite 2010 software was established to give insight into the coating stability limitations at higher coating velocities. An analysis of PEDOT:PSS [poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)] in a water/isopropyl alcohol mixture as well as P3HT:PCBM [poly(3-hexylthiophene-2,5-diyl):Phenyl-C61-butyric acid methyl ester] in chlorobenzene, o-xylene and tetrahydronaphthalene showed the possibility of coating speeds up to 60 m/min. The simulation further revealed the maximum coating head distances for a given wet film thickness. Finally, we show a solar-cell with slot-die coated PEDOT:PSS and P3HT:PCBM-layer based on the parameters obtained by the simulated data, which exhibits reasonable performance. © 2012 Elsevier B.V. All rights reserved.
Nuremberg, FMP Technology GmbH, Heraeus Precious Metals GmbH & Co. KG

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Development of polymers for large scale roll-to-roll processing of polymer solar cells

Development of polymers for large scale roll-to-roll processing of polymer solar cells. Conjugated polymers potential to both absorb light and transport current as well as the perspective of low cost and large scale production has made these kinds of material attractive in solar cell research. The research field of polymer solar cells (PSCs) is rapidly progressing along three lines: Improvement of efficiency and stability together with the introduction of large scale production methods. All three lines are explored in this work. The thesis describes low band gap polymers and why these are needed. Polymer of this type display broader absorption resulting in better overlap with the solar spectrum and potentially higher current density. Synthesis, characterization and device performance of three series of polymers illustrating how the absorption spectrum of polymers can be manipulated synthetically and how this affects the PSC parameters are presented. It is generally found that it is possible to synthetically control the absorption spectrum of conjugated polymer systems. One way to alter the spectrum is by incorporating alternating donor-acceptor motifs, resulting in an additional optical absorption band, the charge transfer (CT) band. A second approach is to introduce fused donor systems. A third method is to use several different monomer units in the polymerization hereby creating semirandom polymers with multiple chromophores. By changing the fed ratio of the monomers the absorption spectrum can effectively be tuned and a significant broadening of the absorption spectrum is obtained. A focus in this thesis is stabilization of the active layer morphology and the photochemical stability of its components. In terms of stability PSC degrades under illumination and the operational lifetime are generally limited. A fundamental understanding of the degradation of PSCs allows one to develop improved materials that can increase their lifetime. Synthesis and characterization of polymer materials for improved stability in PSCs is presented. Stabilization of the active layer was accomplished by incorporating different types of crosslinking functionalities into the polymer TQ1. Cross-linking was achieved by UV-light illumination to give solvent resistant films and reduced phase separation and growth of PCBM crystallites in polymer:PCBM films. This study showed that cross-linking can improve morphological stability but that it has little influence on the operational stability of the device. The photochemical stability of a wide range of materials relevant to PSC is presented and compared. General rules relative to the polymer structure–stability relationship are proposed and can be used as a guideline for further development of PSCs. One of the main advantages of PSCs is that they can be produced using printing techniques which allows for large scale roll-to-roll (R2R) production. A laboratory roll coater that enables solution processing of five layers on ITO-free flexible substrates using slot-die coating and flexographic printing is presented. As little as one ml of active material solution is needed to produce more than a hundred devices. This laboratory scale approach to PSCs was found to be directly scalable to the large scale R2R equipment making it suitable as a test platform for polymer development. PSC devices based on PDTSTTz-4 and PCBM were produced using the laboratory roll coater and through optimization of the processing parameters a PCE of 2.95 % at ambient condition. This efficiency is among the highest obtained on flexible ITO-free substrates using slot-die coating.
**Direct Photopatterning of Electrochromic Polymers**

Propylenedioxythiophene (ProDOT) polymers are synthesized using an oxidative polymerization route that results in methacrylate substituted poly(ProDOTs) having a $M_n$ of 10–20 kDa wherein the methacrylate functionality constitutes from 6 to 60% of the total monomer units. Solutions of these polymers show excellent film forming abilities, with thin films prepared using both spray-casting and spin-coating. These polymers are demonstrated to crosslink upon UV irradiation at 350 nm, in the presence of an appropriate photoinitiator, to render the films insoluble to common organic solvents. Electrochemical, spectroelectrochemical, and colorimetric analyses of the crosslinked polymer films are performed to establish that they retain the same electrochromic qualities as the parent polymers with no detriment to the observed properties. To demonstrate applicability for multi-film processing and patterning, photolithographic patterning is shown, as is desired for fully solution processed and patterned devices.

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Fast Inline Roll-to-Roll Printing for Indium-Tin-Oxide-Free Polymer Solar Cells Using Automatic Registration

Fast inline roll-to-roll printing and coating on polyethylene terephthalate (PET) and barrier foil was demonstrated under ambient conditions at web speeds of 10 m/min for the manufacture of indium-tin-oxide-free (ITO-free) polymer solar cells comprising a 6-layer stack: silver-grid/PEDOT:PSS/ZnO/P3HT:PCBM/PEDOT:PS/silver-grid. The first and second layers were printed at the same time using inline processing at a web speed of 10 m/min where flexographic printing of a hexagonal silver grid comprises the first layer followed by rotary-screen printing of a PEDOT:PSS electrode as the second layer. The third and fourth layers were slot-die coated at the same time again using inline processing at a web speed of 10 m/min of firstly zinc oxide as the electron transport layer followed by P3HT:PCBM as the active layer. The first three layers (silver-grid/PEDOT:PSS/ZnO) comprise a generally applicable ITO-free, semitransparent, electron-selective front electrode for inverted polymer solar cells. This electrode shows a low sheet resistance (~10 W/&) and good optical transmission in the visible range (~60%). The solar cell stack was completed by rotary-screen printing of a hole-collecting PEDOT:PSS layer at 2 m/min and a comb-patterned silver-grid back electrode at the same speed. The solar cells were post processed by using fast roll-to-roll switching to a functional state.

Fast printing of thin, large area, ITO free electrochromics on flexible barrier foil

Processing of large area, indium tin oxide (ITO) free electrochromic (EC) devices has been carried out using roll-to-roll (R2R) processing. By use of very fine high-conductive silver grids with a hexagonal structure, it is possible to achieve good transparency of the electrode covered substrates and when used in EC devices switching times are similar to corresponding ITO devices. This is obtained without the uneven switching of larger areas, which is generally observed when using ITO because of its high-sheet resistance. The silver electrode structures for 18 ×18 cm2 devices can be processed at high speed (10 m/min) on PET by flexographic printing and the EC polymer ECP-Magenta as well as a minimal color changing polymer MCCP by slot-die coating, showing the potential for fast fabrication of large volumes of low-priced flexible EC devices by use of R2R processing techniques. © 2012 Wiley Periodicals, Inc. J Polym Sci Part B: Polym Phys 000: 000–000, 2012
Flexible ITO-Free Polymer Solar Cells

Indium tin oxide (ITO) is the material-of-choice for transparent conductors in any optoelectronic application. However, scarce resources of indium and high market demand of ITO have created large price fluctuations and future supply concerns. In polymer solar cells (PSCs), ITO is the single-most cost driving factor due to expensive raw materials and processing. Given the limited lifetime and stability of PSCs as compared with other mature technologies such as silicon-based solar cells, the technological future of PSCs beyond that of academic interests rests in reducing cost of production. In this regard, replacing ITO has the potential to dramatically reduce material and processing cost and the energy payback time of PSCs. Several alternatives to ITO are present but not all of them bring competitive advantage over ITO for application in PSCs. This review explores some potentially low-cost alternatives to ITO suitable for use in PSCs. These alternatives belong to four material groups: polymers; metal and polymer composites; metal nanowires and ultra-thin metal films; and carbon nanotubes and graphene. We further present the progress of employing these alternatives in PSCs and identify future challenges. © 2012 Wiley Periodicals, Inc.
High-temperature Thermoelectric Properties of Ca$_{0.9}$Y$_{0.1}$Mn$_{1-x}$Fe$_x$O$_3$ (0 ≤ x ≤ 0.25)

Polycrystalline compounds of Ca$_{0.9}$Y$_{0.1}$Mn$_{1-x}$Fe$_x$O$_3$ for 0 ≤ x ≤ 0.25 were prepared by solid-state reaction, followed by spark plasma sintering process, and their thermoelectric properties from 300 to 1200 K were systematically investigated in terms of Y and Fe co-doping at the Ca- and Mn-sites, respectively. Crystal structure refinement revealed that all the investigated samples have the O-type orthorhombic structure, and the lattice parameters slightly increased with increasing Fe concentration, causing a crystal distortion. It was found that with increasing the content of Fe doping, the Seebeck coefficient of Ca$_{0.9}$Y$_{0.1}$Mn$_{12}$Fe$_x$O$_3$ tended to increase, while the tendency toward the electrical conductivity was more complicated. The highest power factor was found to be 2.19 × 10$^{-4}$ W/mK$^2$ at 1150 K for the sample with x = 0.05 after annealing at 1523 K for 24 h in air. Thermal conductivity of the Fe-doped samples showed a lower value than that of the x = 0 sample, and the highest dimensionless figure of merit, ZT was found to be improved about 20% for the sample with x = 0.05 as compared to that of the x = 0 sample at 1150 K.

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Industrialisation of polymer solar cells. Phase 2: Consolidation

The present report refers to the project “Industrialization of polymer solar cells – phase 2”. Both the project and this report build directly upon the prior phase 1 where the basic OPV technology, ProcessOne, was transferred to Mekoprint. This second phase focuses on an anchoring of the transferred technology in Mekoprint’s industrial environment and an anchoring of the technology as an attractive solution for low-demanding PV applications. This second phase is also concerned with DTU’s further development of the OPV technology towards DTU’s ultimate goal of qualifying OPV for large-scale power production. The project represents thus a crossroad, where Mekoprint and DTU gradually differentiate themselves with respect to applications and therefore also their R&D priorities. The key targets of phase 2 relate to production cost, stabilization of the production and operational lifetime of the OPV
devices – targets that are import both for niche applications and bulk power production. Besides the work dedicated to solving these three key targets, two more activities have been included in the project; a pre-study on OPV solar parks and an evaluation of the business opportunities arising not only from this project but from the entire Danish OPV effort.

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**Inkjet Printing of Back Electrodes for Inverted Polymer Solar cells**
Evaporation is the most commonly used deposition method in the processing of back electrodes in polymer solar cells used in scientific studies. However, vacuum-based methods such as evaporation are uneconomical in the upscaling of polymer solar cells as they are throughput limiting steps in an otherwise fast roll-to-roll production line. In this paper, the applicability of inkjet printing in the ambient processing of back electrodes in inverted polymer solar cells with the structure ITO/ZnO/P3HT:PCBM/PEDOT:PSS/Ag is investigated. Furthermore, the limitation of screen printing, the commonly employed method in the ambient processing of back electrode, is demonstrated and discussed. Both inkjet printing and screen printing of back electrodes are studied for their impact on the photovoltaic properties of the polymer solar cells measured under 1000 Wm⁻² AM1.5. Each ambient processing technique is compared with evaporation in the processing of back electrode. Laser beam induced current (LBIC) imaging is used to investigate the impact of the processing techniques on the current collection in the devices. We report that inkjet printing of back electrode delivers devices having photovoltaic performance comparable to devices with evaporated back electrodes. We further confirm that inkjet printing represent an efficient alternative to screen printing.

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Interlaboratory outdoor stability studies of flexible roll-to-roll coated organic photovoltaic modules: Stability over 10,000 h

This work attempts to reveal the comparability issues related to outdoor testing procedures of organic photovoltaic (OPV) modules via studies of inter-laboratory long-term outdoor measurements of roll-to-roll coated flexible OPV modules (P3HT:PCBM, inverted architecture) in different geographic locations from both Southern and Northern hemispheres. The interpretation of the module degradation via sub-cell analyses is presented and the poor reproducibility of the module performance linked to the barrier properties of the encapsulation around the device terminals is addressed. We demonstrate that the modules' t80 lifetime may vary between a few hundred to over 10,000 h depending on how well the device terminals are sealed. We additionally demonstrate up to 17 months of stable performance for sub-cells within the modules. Furthermore, the effects of different geographical locations, weather conditions and measurement setups on the comparability of test results are analyzed. A strong link between the device temperature and performance is revealed, which is ascribed to the reaction of PEDOT:PSS layer with water. The estimation of the true performance of the modules by accommodation of variations in testing conditions is performed. Based on the results a set of recommendations from the ISOS-O guiding protocols are highlighted, which can help remove the factors that affect the comparability of the test results. CrownCopyright © 2013 Published by Elsevier B.V. All rights reserved.
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Large-scale Roll-to-Roll Fabrication of Organic Solar Cells for Energy Production

The global energy consumption is increasing steadily while natural energy sources are running out sooner or later. Solar electricity is one of many renewable energy sources that contributes to the world’s demand. Organic solar cells (OPV) are an attractive 3rd generation solar technology that can be produced cheaply and very fast from solution with printing processes. The current research all around the world is still focused on lab-scale sized devices « cm², ITO-glass substrates, and spin coating as the main fabrication method. These OPV devices are far from any practical application although record efficiencies beyond 10% could be achieved.

This dissertation describes process workflows and roll-to-roll (R2R) fabrication methods for upscaling the OPV technology
to solar module sizes that enable real power production even at efficiencies < 2%. The fundamental cell technology was based on flexible plastic substrates and ITO-free transparent conductive electrodes made from special designed flexo printed silver grids, rotary screen printed PEDOT:PSS, and slot-die coated ZnO (= Flextrode). The organic solar cell was fabricated by slot-die coating a light absorbing photoactive layer (e.g. P3HT:PCBM) on top of the Flextrode substrate and completed by rotary screen printed PEDOT:PSS and silver electrodes. All layers were R2R printed and coated from solution under full ambient vacuum-free conditions with fabrication speeds reaching 25mm/min for some of the layers.

Fabrication of modules with high power output requires intelligent connection of single cells that should involve as less as possible manual processes such as wiring or soldering. The problem was solved by serially connecting thousands of single cells entirely during the R2R processing by printing thin-film silver conductors. High voltage networks require only thin conductors to efficiently transport the relatively low current of the organic solar cells. The serial connection was possible through a special designed pattern layout that combined 1-dimensional coating and 2-dimensional printing processes. The so-called Infinity concept allowed the fabrication of virtually infinitely large module sizes without manual wiring. High voltage modules with 21000 cells, open circuit voltage > 10 kV and power output > 220Wpeak could be successfully manufactured while having only two terminal contacts.

Real energy production from these modules was studied by setting up a whole solar park based on OPV modules. Infinity modules with a length of 100m (width 0.3m) were rolled out and taped onto a wooden structure. The maximum power output of six parallel-connected modules with a total active area of 88.2m2 was beyond 1.3 kW while having energy payback times P1 year. Alternative installation concepts such as a balloon or special designed solar tubes on land or water were proved to be functional as well. Solar tubes with Infinity modules of around 200 W generated 18 kWh in 5 weeks. The energy was fed back into the Danish power grid.

The dissertation contains a brief introduction of organic solar cell technology and reviews important R2R compatible manufacturing methods including photonic sintering. The fabrication, design, and challenges of Flextrode and Infinity modules are described in detail. The potential future energy production is presented through large-scale OPV installation scenarios and performance analyses. Fatal failures such as fully burned cells are described while easy repair mechanisms are shown that avoid costly replacements of full modules. A conclusion and outlook finalizes the dissertation.

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**Lengthening the lifetime of roll-to-roll produced polymer solar cells**

The field of polymer solar cells is a field with an exponential growth in the number of published papers. It is a field defined by a set of challenges including; efficiency, stability and processability. Before all of these challenges have been addressed; polymer solar cells will not be a commercial success.

This dissertation is devoted primarily to the study of the stability of polymer solar cells, and more specifically to designing and verifying experimental techniques, procedures, and automated solutions to stability tests and characterization. The goal of the project was to expand the knowledge of the degradation mechanisms involved in roll-to-roll coated polymer solar cells. While only a part of the experiments have directly involved roll-to-roll coated devices, most of the work is applicable to coated devices.

The first part of the dissertation is devoted to the study of in-depth morphology of polymer solar cells using ellipsometry. It was demonstrated that ellipsometry can be used as a non destructive depth profiling technique to obtain compositional morphology of the active layer of roll-to-roll coated samples. The second and third part is devoted to the study of photo-chemical degradation of the active layer materials. The second part details the building of an automated setup for stability tests and presents results on thickness and absorbance dependence of the photo-chemical stability, acceptor stability, and the influence of intrinsic polymer parameters on stability. In the third part two light concentrating setups, built during the PhD, are detailed and results based on high intensity photodegradation studies presented. In the last part of the dissertation the use of TOF-SIMS for polymer solar cell characterization is detailed and the results on intrinsic barrier effects and degradation patterns are summarized.
Low-Cost Upscaling Compatibility of Five Different ITO-Free Architectures for Polymer Solar Cells

Five different indium-tin-oxide free (ITO-free) polymer solar cell architectures provided by four participating research institutions that all presented a laboratory cell performance sufficient for use in mobile and information and communication technology (ICT) were evaluated based on photovoltaic performance and lifetime tests according to the ISOS protocols. The comparison of the different device architectures was performed using the same active material (P3HT: PCBM) and tested against an ITO-based reference device. The active area was 1 cm² and rigid glass or flexible polyester substrates were employed. The performance results were corroborated by use of a round robin methodology between the four participating laboratories (DTU/DK, ECN/NL, Fraunhofer ISE/DE, and the Holst Centre/NL), while the lifetime testing experiments were carried out in only one location (DTU). Five different lifetime testing experiments were carried out for a minimum of 1000 h: (1) shelf life (according to ISOS-D-1); (2–3) stability under continuous 1 sun illumination (1000 Wm⁻², AM1.5G) at low (37 ± 3 °C) and high (80 ± 5 °C) temperatures (according to ISOS-L-1 and ISOS-L-2); (4) stability under continuous low-light conditions at 0.1 sun (100 Wm⁻², AM1.5G, 32 °C) (according to ISOS-LL); (5) continuous illumination (670 Wm⁻², AM1.5G) at high temperature (65 °C) and high humidity (50% RH) (according to ISOS-L-3). Finally, the upscaling compatibility of these device architectures based on the device photovoltaic behavior, stability and scalability were identified and we confirm that an architecture that presents a high score in only one aspect of the solar cell performance is not sufficient to justify an investment in upscaling. Many will require further technical development. © 2013 Wiley Periodicals, Inc.
Efficient and stable polymer bulk-heterojunction solar cells based on regioregular poly(3-hexylthiophene):[6,6]-phenyl-C61-butyric acid methyl ester (P3HT:PC61BM) blend active layer have been fabricated with a MoO3–Au co-evaporation composite film as the anode interfacial layer (AIL). The optical and electrical properties of the composite MoO3–Au film can be tuned by altering the concentration of Au. A composite film with 30% (weight ratio) Au was used as the AIL and...
showed a better performance than both pure MoO3 and PEDOT:PSS as AIL. The surface morphology of the MoO3–Au composite film was investigated by atomic force microscopy (AFM) and showed that the originally rough ITO substrate became smooth after depositing the composite film, with the root mean square roughness (RMS) decreased from 4.08nm to 1.81nm. The smooth surface reduced the bias-dependent carrier recombination, resulting in a large shunt resistance and thus improving the fill factor and efficiency of the devices. Additionally, the air stability of devices with different AILs (MoO3–Au composite, MoO3 and PEDOT:PSS) were studied and it was found that the MoO3–Au composite layer remarkably improved the stability of the solar cells with shelf life-time enhanced by more than 3 and 40 times compared with pure MoO3 layer and PEDOT:PSS layer, respectively. We argue that the stability improvement might be related with the defect states in MoO3 component. © 2012 Elsevier B.V. All rights reserved.
Morphology of polymer solar cells

Organic electronic devices are an intense area of research. While some devices, such as organic light emitting diodes (OLED) have matured and are found in a vast amount of consumer electronic devices, their energy producing counterpart, organic photovoltaics (OPV), are still in the process of making the transition from the laboratory into the commercial market. One of the biggest challenges in this process is upscaling the production. The object of this thesis is to investigate the morphology of OPV devices produced from pilot scale roll to roll (R2R) coaters. OPV devices still struggle with low performance, and the morphology is known to have a critical impact on the performance of a device. Several studies have tried to identify the optimal morphology of OPV devices and how to achieve it. Most work has been focused on OPVs produced by spin coating in a small laboratory scale. Devices produced by R2R coating, which works fundamentally different, have not been studied. Traditional production of OPV has required the use of toxic solvents. A new environmentally friendly approach using water based inks, made of nanoparticles, is now being tested. However, nothing is known about the morphology of the active layer of the solar cells when produced with water based inks using R2R coating. Using a broad range of scattering and imaging techniques, cells coated with water based inks were investigated, and compared to their spin coated counterpart. Two challenges to be addressed were small domain size to be studied, in the nanometer regime, and the poor contrast due to the similarity of the organic materials. The physical impact of the ink and the process of coating it, was investigated by electron microscopy, X-ray scattering, hard X-ray ptychography and soft X-ray transmission imaging. Utilizing the robustness and high resolution of transmission electron microscopy, different preparations of inks were studied. Electron microscopy offers good visualization, but lacks contrast to distinguish similar organic materials, such as P3HT and PCBM, two components of the active layer. Electron diffraction yields information about the crystal structure of the samples but have a coarse spot size. X-ray scattering is a well known technique for measuring shapes, sizes, crystal structures and orientation. Both small- and wide-angle scattering were used to measure the crystallinity of the layers as a function of polymer, type of ink, annealing etc. Ptychography is a new state of the art X-ray imaging technique based on coherent scattering. Together with Scanning X-ray Transmission Microscopy (STXM) it has been used in this study to inspect the morphology of the active layer taken from working solar cells. Ptychography offers desirable properties such as potentially high resolution, quantitative contrast and possibility for tomography. Both these X-ray imaging techniques were used to measure the samples with high spatial and chemical resolution. In addition, these experiments explored and reviewed the viability of ptychography as a characterization technique for OPVs evaluated. The ink studies showed that the nanoparticles in the active layer were disrupted. Dense parts of the nanoparticles could be observed surrounded by a bulk of less dense material. The same pattern was seen in preparations made by both coating methods. A difference, observed between the two methods was that the layer produced by R2R consisted of aggregates of particles. The particles in the spin coated samples were uniformly distributed. Furthermore, this thesis focused on developing, and testing, a new method for high throughput characterization of OPV devices. An advantage with R2R coating is the continuous production of layers and the possibility to change production parameters continuously during the process. It would therefore be an advantage if the characterization could also be done continuously. For this purpose a small film winder-underwinder was tested. The crystalline structure was measured using small angle X-ray scattering on three samples. The high spatial resolution obtained, made it possible to see the changes in crystalline structure as a function of coating parameters. These changes would not have been possible to see using a series of spin coated samples.

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Multi-THz spectroscopy of mobile charge carriers in P3HT:PCBM on a sub-100 fs time scale

The dynamics of mobile charge carrier generation in polymer bulk heterojunction films is of vital importance to the development of more efficient organic photovoltaics. As with conventional semiconductors, the optical signatures of mobile carriers lie in the far-infrared (1-30 THz) although the electrodynamics deviate strongly from the Drude model. The key time scales for the process are sub-100 fs to picoseconds, and is a challenge to perform low energy spectroscopy on these time scales as it is less than the period of oscillation for the probing light. In this work, we demonstrate sub-100 fs spectroscopy of a polymer bulk heterojunction film P3HT:PCBM using a single-cycle, phase-locked and coherently detected multi-THz transient as a probe pulse following femtosecond excitation at 400 nm. By observing changes to the reflected THz transients from the film surface following photoexcitation, we can extract the complex optical conductivity spectrum for the film in snapshots of 40 fs following photoexcitation. We find that for our excitation conditions mobile charges are created in less than 120 fs and are characterized by a spectrum which is characteristic of a two dimensional delocalized polaron. A large fraction of mobile carriers relax to a localized state on a 1 ps time scale. Pump energy dependent photon-to-mobile carrier conversion efficiency supports hot exciton dissociation as a mechanism for such fast mobile carrier generation.

The photo-oxidation mechanism of thin-film blends based on poly(3-hexylthiophene):phenyl-C-61-butyric acid methyl ester (P3HT:PCBM) upon irradiation with ultraviolet-visible light (UV-Vis) was studied. The use of deuterated P3HT, i.e., poly(3-hexyl-d(13)-thiophene) (P3HdT), permitted discrimination of carbon originating from the hexyl-d(13) chain and carbon originating from PCBM and the nondeuterated thiophene unit. The photo-oxidation of both components of the blend was monitored using the combination of various analytical techniques to probe the bulk and the surface of the deposits. The results show that the stabilization of P3HT by PCBM is due to a morphological reorganization between P3HT and PCBM. This change occurs at a low temperature (ca. 42 degrees C) and increases the lifetime of the primary property, i.e., the ability of the active layer to absorb light. However, this is counterbalanced by the enhanced formation of oxidized PCBM molecules, which may act as electrons traps. It is shown that UV light is harmful for P3HT, PCBM, and P3HT:PCBM blend stabilities, even if PCBM provides a filter effect that is strongest at short wavelengths. It is proposed that the photochemical behavior of the chromophoric species involved in the chain radical oxidation of P3HT is a key characteristic in the underlying mechanism. The results obtained in this work advance the understanding of active layer stability and will help improve the design of long lifetime organic solar cells thanks to the use of cutoff filter in the substrate or encapsulation of the devices.
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Optical coherence tomography (OCT) as a 3-dimensional imaging technique for non-destructive testing of roll-to-roll coated polymer solar cells

We have recently demonstrated the first application of optical coherence tomography (OCT) as a 3-dimensional (3D) imaging technique to visualize the internal structure of complete multilayered polymer solar cell modules (Thrane et al., Solar Energy Materials & Solar Cells 97, 181-185 (2012)). The 3D imaging of complete polymer solar cells prepared by roll-to-roll coating was carried out using a high-resolution 1322nm OCT system having a 4.5 microns axial resolution and a 12 microns lateral resolution. It was possible to image the 3-dimensional structure of the entire solar cell that comprise UV-barrier, barrier material, adhesive, substrate and active solar cell multilayer structure. In addition, it was found that the OCT technique could be readily employed to identify coating defects in the functional layers, making it a potential technique to enable process control by real-time adjustment to the production process.

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OPV for mobile applications: an evaluation of roll-to-roll processed indium and silver free polymer solar cells through analysis of life cycle, cost and layer quality using inline optical and functional inspection tools

Organic photovoltaic modules have been evaluated for their integration in mobile electronic applications such as a laser pointer. An evaluation of roll-to-roll processed indium and silver free polymer solar cells has been carried out from different perspectives: life cycle assessment, cost analysis and layer quality evaluation using inline optical and functional inspection tools. The polymer solar cells were fabricated in credit card sized modules by three routes, and several encapsulation alternatives have been explored, with the aim to provide the simplest but functional protection against moisture and oxygen, which could deteriorate the performance of the cells. The analysis shows that ITO- and silver-free options are clearly advantageous in terms of energy embedded over the traditional modules, and that encapsulation must balance satisfying the protection requirements while having at the same time a low carbon footprint. From the economic perspective there is a huge reduction in the cost of the ITO- and silver-free options, reaching as low as 0.25 V for the OPV module. We used inspection tools such as a roll-to-roll inspection system to evaluate all processing steps during the fabrication and analyse the layers’ quality and forecast whether a module will work or not and establish any misalignment of the printed pattern or defects in the layers that can affect the performance of the devices. This has been found to be a good tool to control the process and to increase the yield.

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Organic Based Solar Cells with Morphology Control

The field of organic solar cells has in the last years gone through an impressive development with efficiencies reported up to 12 %. For organic solar cells to take the leap to being a laboratory scale technology to being utilized as renewable energy source, several issues need to be addressed. Among these are a more direct transfer of new materials tested on a laboratory scale to large scale production than offered by spincoating, a method offering direct control of the morphology in the active layer, and a more environmental friendly processing, where the vast use of organic solvents offers a great challenge. In this thesis the development of inks with a pre-arranged morphology was attempted by two methods. First by grafting of silicon nanoparticles with an organic phenylene vinylene oligomer, the resulting particles were analyzed by 1H-NMR, absorption spectroscopy, Atomic Force Microscopy and as solar cells in a blend with PCBM. It was concluded that these particles did not show a potential large enough for continuous work due to a high material loss and low efficiency when applied in solar cells. The second method to achieve was preparation of pre-arranged morphology organic nanoparticles consisting of a blend of donor and acceptor in an aqueous dispersion, thereby addressing two of the issues remaining in the field of organic solar cells. This approach was used on six different polymers, which all had the ability to prepare aqueous nanoparticle inks. The morphology of the nanoparticles was investigated both internally and externally, both were attempted to be controlled by variation in preparation solvent and particle sizes. The inks were slot-die coated on both the R2R coater and mini roll coater but only after a number of inks modifications and adjustments of the coating parameters. Solar cell prepared by large scale R2R-coating with an active layer consisting of these nanoparticles had an efficiency of up to 0.55 %. In order to shorten the distance from laboratory scale testing of solar cells to R2R production a mini roll coater was invented. This roll coater uses film deposition techniques which have been downscaled from the R2R coater i.e. slot-die coating and flexographic printing. Thereby allowing the device optimizations to be transferred almost directly from small to large scale. This is in contrast to devices prepared by spincoating. Another advantage with the laboratory roll coater is that, it enables the preparation of 250-300 solar cells in an hour from as little as 15-20 mg of polymer. This means that a number of parameters can be optimized with very little material compared to the amount necessary for optimization directly on the R2R equipment. The laboratory roll coater was used in the search of the high efficient organic solar cells by optimizing new electrodes and preparing a number of solar cells from different polymers with various optimization parameters such as thickness of the active layer, ratio between donor and acceptor,
and coating temperature. Further small molecule inks were slot-die coated on this coater with a variation in ink formulations enabling the coating of films of a higher quality and coating of ink employing molecules with cross-linkable side chains to avoid dissolution of the active layer when coating subsequent layers. The mini roll coater was also used to develop a procedure for preparation of tandem devices where all layers were deposited by wet-processing on an ITO-free flexible substrate. The challenging part was the preparation of an intermediate layer, which was both easy to coat and had a good solvent resistance. Thus by pure intermediate optimizations the efficiency increased from 0.067 % to 1.7 %. Main aspects of this thesis worth of further investigation include pre-arranged morphology by aqueous ink, the use of the mini roll coater to investigate and optimize new polymer, and the preparation of tandem devices with high efficiency.

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**Organic photovoltaics: Editorial**
Energy inflation, the constant encouragement to economize on energy consumption and the huge investments in developing alternative energy resources might seem to suggest that there is a global shortage of energy. Far from it, the energy the Sun beams on the Earth each hour is equivalent to a year's supply, even at our increasingly ravenous rate of global energy consumption [1]. But it's not what you have got it's what you do with it. Hence the intense focus on photovoltaic research to find more efficient ways to harness energy from the Sun. Recently much of this research has centred on organic solar cells since they offer simple, low-cost, light-weight and large-area flexible photovoltaic structures. This issue with guest editors Frederik C Krebs and Hongzheng Chen focuses on some of the developments at the frontier of organic photovoltaic technology. Improving the power conversion efficiency of organic photovoltaic systems, while maintaining the inherent material, economic and fabrication benefits, has absorbed a great deal of research attention in recent years. Here significant progress has been made with reports now of organic photovoltaic devices with efficiencies of around 10%. Yet operating effectively across the electromagnetic spectrum remains a challenge. 'The trend is towards engineering low bandgap polymers with a wide optical absorption range and efficient hole/electron transport materials, so that light harvesting in the red and infrared spectrum is enhanced and as much light of the solar spectrum as possible can be converted into an electrical current', explains Mukundan Thelakkat and colleagues in Germany, the US and UK. In this special issue they report on how charge carrier mobility and morphology of the active blend layer in thin film organic solar cells correlate with device parameters [2]. The work contributes to a better understanding of the solar-cell characteristics of polymer-fullerene blends, which form the material basis for some of the most successful solution processable organic photovoltaic devices at present. Andrey E Rudenko, Sangtaik Noh, and Barry C Thompson at the University of Southern California, Los Angeles, combine two approaches to broaden the absorption of conjugated polymers [3]. In atomistic bandgap control, a heavier chalcogen heteroatom is introduced into the aromatic repeat unit to decrease the HOMO–LUMO gap. In the semi-random donor–acceptor polymer architecture, small amounts of electron deficient monomers are incorporated at random. 'We have successfully established the concept of extending photon absorption through the combination of atomistic bandgap control and the donor–acceptor-based semi-random platform using a family of three new semi-random selenophene-based polymers', explain Thompson and colleagues. They add that the polymers exhibit extended and enhanced photon absorption compared with their polythiophene analogues while maintaining semicrystallinity. The benefits of various fabrication treatments are also reported, such as methanol rinsing for modifying the active layer interface [4] and annealing to achieve bicontinuous nanoscale phase separation for efficient exciton dissociation and charge collection [5]. The issue highlights how successfully structure and morphology can be manipulated to optimize solar-cell efficiencies while retaining advantageous material properties, with reports of innovative studies of bulk heterojunction [6–9] and inverse [10–13] structures, as well as innovative replacements for the traditional ITO transparent conducting electrode [14, 15]. Thomas Edison is famously quoted as saying 'I'd put my money on the Sun and solar energy, what a source of power! I hope we don't have to wait until oil and coal run out, before we tackle that'. Born in the wake of the industrial revolution when coal was king, the words seem strangely anachronistic and ahead of his time. As an undisputed genius of inventions it should not surprise us that he had such remarkable foresight, nor that the present generation of innovators are ‘tackling’ the opportunity with such promise and success, as the work in this special issue clearly demonstrates. References [1] http://environment.nationalgeographic.co.uk/environment/global-warming/solar-power-profile [2] Muth M-A, Mitchel W, Tierney S, Lada T A, Xue X, Richter H, Carrasco-Orozco M and Thelakkat M 2013 Influence of charge carrier mobility and morphology on solar cell parameters in devices of mono- and bis-fullerene adducts Nanotechnology 24 484001 [3] Rudenko A E, Noh S and Thompson B C 2013 Influence of selenophene on the properties of semi-random polymers and their blends with PC61BM Nanotechnology 24 484002 [4] Zhang K, Hu Z, Duan C, Ying L,

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Authors: Demming, A. (Ekstern), Krebs, F. C. (Intern), Chen, H. (Ekstern)
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BFI (2017): BFI-level 2
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.87 SJR 1.339 SNIP 0.945
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.257 SNIP 1.035 CiteScore 3.07
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.497 SNIP 1.269 CiteScore 3.09
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.602 SNIP 1.231 CiteScore 2.74
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.861 SNIP 1.307 CiteScore 3.34
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Photochemical stability of electrochromic polymers and devices

The stability of fully printed flexible organic electrochromics based on 11 different conjugated polymers is explored from the fundamental chemical degradation level to the operational device level. The photochemical stability of the electrochromic polymers (ECPs) is studied enabling an analysis of the influence that the chemical constitution of the conjugated polymer backbone has on the photochemical stability. Based on changes in the UV-visible absorption and IR spectra, the polymers were categorized into two distinct groups, each with a separate degradation mechanism. During irradiation (1000 W m⁻², AM 1.5G) under ambient conditions the majority of the polymers degraded within 4-5 hours. Three polymers showed increased stability with degradation rates from 0.44 to 1.58% per hour measured as loss of absorption. Application of oxygen and UV barrier foils was found to drastically slow the photochemical decomposition of the polymer films, such that after 2200 hours of continuous irradiation the less stable polymer films were degraded 27% on average, while the degradation of the most stable polymer films was immeasurable thus indicating that such materials can be sufficiently stable for device operations for many years under indoor conditions and for a few years under outside conditions. Finally, functioning electrochromic devices (ECDs) were made and the effect of illumination on the response time and optical contrast was established. This report shows that encapsulated electrochromic devices based on flexible barrier substrates exhibit increased stability and are indeed viable in devices such as shading elements, light management systems, displays with low switching speed requirements and signage. © 2013 The Royal Society of Chemistry.

General information

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Jensen, J. (Intern), Madsen, M. V. (Intern), Krebs, F. C. (Intern)
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Polymer and organic solar cells viewed as thin film technologies: What it will take for them to become a success outside academia

The polymer and organic solar cell technology is critically presented in the context of other thin film technologies with a specific focus on what it will take to make them a commercial success. The academic success of polymer and organic solar cells far outweigh any other solar cell technology when judging by the number of scientific publications whereas the application of polymer and organic solar cells in real products is completely lacking. This aspect is viewed as a sign of the polymer and organic solar cell field as being more complex and less mature and it raises the question of whether an organic analog to a successful inorganic technology is forcibly needed and indeed whether it is at all worth exploring beyond academia.
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.532 SJR 1.459
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.182 SNIP 2.577 CiteScore 5.16
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.494 SNIP 2.105
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.942 SNIP 1.957
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.626 SNIP 1.449
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.363 SNIP 1.49
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.438 SNIP 1.788
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.15 SNIP 1.607
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.94 SNIP 1.174
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.997 SNIP 1.322
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.168 SNIP 1.102
Scopus rating (2001): SJR 0.883 SNIP 1.229
Scopus rating (2000): SJR 0.686 SNIP 0.987
Scopus rating (1999): SJR 0.646 SNIP 0.779

Original language: English
Thin film solar cells, Polymer solar cells, CdTe, CIGS, a-Si, Q-function
DOIs:
10.1016/j.solmat.2013.05.032

Relations
Projects:
Practical evaluation of organic polymer thermoelectrics by large-area R2R processing on flexible substrates

Here, we present a process based on roll-to-roll (R2R) technology which allows for very fast processing of polymer thermoelectric (TE) devices and we furthermore demonstrate a simplified but more efficient way of serially connecting these devices by means of R2R thin-film processing. The new device architecture makes it possible to use only one TE material (opposed to two materials which are employed in well-known Peltier elements), and a total of 18,000 serially connected junctions were prepared by flexo-printing of silver electrodes and by rotary screen printing of poly(3,4-ethylenedioxythiophene) (PEDOT):polystyrene sulfonate (PSS) as the TE material. Testing of devices revealed that the new architecture clearly showed to be functioning as expected, but also pointed toward challenges for thin-film TE development which is the influence of the substrate thickness on the thermal gradient over a device and the currently low performance available. A life-cycle assessment (LCA) was carried out in order to evaluate the sustainability of the new architecture and to estimate the requirements for development of a successful technology.

Roll-to-Roll Fabricated Polymer Solar Cells: Towards Low Environmental Impact and Reporting Consensus

The sun is by far the largest source of renewable energy available; consequently solar cells, which are able to convert light into electricity, have the technical potential to cover the global energy needs. Polymer solar cells (PSCs) on flexible plastic...
Roll-to-Roll fabrication of large area functional organic materials

With the prospect of extremely fast manufacture of very low cost devices, organic electronics prepared by thin film processing techniques that are compatible with roll-to-roll (R2R) methods are presently receiving an increasing interest. Several technologies using organic thin films are at the point where transfer from the laboratory to a more production-oriented environment is within reach. In this review, we aim at giving an overview of some of the R2R-compatible techniques that can be used in such a transfer, as well as the current status of R2R application within some of the existing research fields such as organic photovoltaics, organic thin film transistors, light-emitting diodes, polymer electrolyte membrane fuel cells, and electrochromic devices.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Søndergaard, R. R. (Intern), Hösel, M. (Intern), Krebs, F. C. (Intern)
Number of pages: 174
Publication date: 2013
Roll-to-Roll Inkjet Printing and Photonic Sintering of Electrodes for ITO Free Polymer Solar Cell Modules and Facile Product Integration

Small polymer solar cell modules that are manufactured without indium-tin-oxide using only roll-to-roll printing and coating techniques under ambient conditions enable facile integration into a simple demonstrator (for example a laser pointer). Semitransparent front electrode grid structures prepared by roll-to-roll inkjet printing in conjunction with photonic sintering enabled preparation of complete modules on flexible substrates and subsequent integration of the modules into a laser pointer demonstrator.

General information
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Main Research Area: Technical/natural sciences

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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 2.347 SJR 8.23
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 12.96 SJR 6.515 SNIP 2.14
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 6.219 SNIP 2.546 CiteScore 14.2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 6.668 SNIP 2.942 CiteScore 15.27
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 6.006 SNIP 2.949 CiteScore 13.24
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 5.575 SNIP 2.181 CiteScore 9.64
ISI indexed (2012): ISI indexed no
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Web of Science (2011): Indexed yes
Original language: English
Roll-to-roll inkjet printing, Roll-to-roll photonic sintering, Transparent conductors, Flexible substrates, ITO-freedom, Roll-to-roll processing, Polymer solar cells
DOIs:
10.1002/aenm.201200520
Rotationsbaseret enkeltrulle trykkemaskine til laboratoriebrug

Denne frembringelse angår en kompakt enkeltrulle baseret slot-die trykkemaskine til forskning og udviklings formål, som udgangspunkt relateret til udvikling af funktionelle organiske materialer. Det nye ved frembringelsen er anvendelse af i enkelt massiv cylinder, anvendelsen af elektriske varmelegemer til opvarmning af aluminium cylinderen frem for anvendelse af varm luft til afdampning af den påtrykte væske - i forbindelse med dannelse af aktive film, de kompakte mål der gör installation i stinkskab muligt, at hele enheder fremstilles udelukkende ved brug af de indbyggede trykkemodtiler, samt reel rulle-till-rulle kompatibilitet.

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Krebs, F. C. (Intern)
Publication date: 2013

Scalability and stability of very thin roll-to-roll processed large area indium-tin-oxide free polymer solar cell modules

Polymer solar cell modules were prepared directly on thin flexible barrier polyethylene terephthalate foil. The performance of the modules was found to be scalable from a single cell with an area of 6 cm² to modules with a total area of up to 186 cm². The substrate thickness was also explored and the performance was found to be independent of thickness in the range of 20–130 lm. The thinner substrates were found to present some challenge regarding handling but were not limited in performance. Large area modules on a substrate thickness of 45 lm were finally prepared by full roll-to-roll processing employing P3HT:PCBM as the active material and were found to exhibit a total area efficiency of >1% (1000 W/m²; AM1.5G) with a typical active-area efficiency in the 1.5–1.6% for total module area of >110 cm² due to high fill factors in excess of 50%. The modules were also found to have an active-area efficiency of >1% under low light levels (100 W/m²). The modules were then subjected to extensive stability testing for a minimum of 1000 h employing several ISOS protocols. The modules presented higher than 80% of the initial performance (T80) in the dark (ISOS-D-1), in dark under elevated temperature of 65 °C (ISOS-D-2), under low light (ISOS-LL), under full sunlight (ISOS-L-2), and under outdoor testing (ISOS-O), which was conducted in two locations in India and Denmark. We estimate maximum T80 for those tests to be 2800, 5000, 1300, 1000, and 3500 h respectively. The modules showed significant sensitivity to high humidity and had low values for T80 for dark storage tests at 50 °C/85%RH (ISOS-D-3) and accelerated operation conditions with 0.7 sun/65 °C/50%RH (ISOS-L-3). We found the modules to be particularly suited for information and communications technology (ICT) and mobile applications where low humidity (<50%) and lower temperatures (<65 °C) can be anticipated and we estimate operational lifetimes in excess of 1 year. © 2013 Elsevier B.V. All rights reserved.

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Main Research Area: Technical/natural sciences

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Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 0.884 SJR 1.085
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.4 SJR 1.081 SNIP 0.944
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.135 SNIP 1.082 CiteScore 3.6
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.346 SNIP 1.188 CiteScore 3.85
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.456 SNIP 1.268 CiteScore 3.94
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.955 SNIP 1.458 CiteScore 4.25
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.941 SNIP 1.466 CiteScore 4.09
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.028 SNIP 1.395
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.046 SNIP 1.268
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.217 SNIP 1.452
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.251 SNIP 1.275
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.704 SNIP 1.868
Scopus rating (2005): SJR 1.81 SNIP 1.2
Scopus rating (2004): SJR 2.968 SNIP 2.078
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.382 SNIP 1.634
Scopus rating (2002): SJR 10.929 SNIP 2.377
Scopus rating (2001): SJR 2.83 SNIP 1.525
Original language: English
ITO free, Roll-to-roll printing and coating, Flexible, Barrier, ICT, Thin foil
DOIs: 10.1016/j.orgel.2012.12.033

Relations
Projects:
Scalability and stability of very thin roll-to-roll processed large area indium-tin-oxide free polymer solar cell modules
Source: dtu
Source-ID: u::7222
Publication: Research - peer-review › Journal article – Annual report year: 2013

Screen-Display-Induced Photoreponse Mapping for Large-Area Photovoltaics
As solar cell modules are becoming larger, it is important to pay attention to defects originating from the fabrication process and degradation during operation in the ambient. In this article, a simple method of using computer screen display as a light source to map the photoreponse of the solar cells, is reported. The method requires only a conventional computer loaded with a software code that enables a light spot of defined size to raster scan across the cell area as the photogenerated voltage is read out by a voltmeter using a USB connection. Screen-display-induced photoresponse (SDIP) mapping is an enabling technique to reveal the defective regions in the active layer as well as at the electrode interface, which, in many instances, cannot be deciphered simply by visual examination. Spectral response mapping by using light
spots of different colors is also possible.

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials, Jawaharlal Nehru Centre for Advanced Scientific Research
Authors: Gupta, R. (Ekstern), Kiruthika, S. (Ekstern), Rao, K. D. M. (Ekstern), Jørgensen, M. (Intern), Krebs, F. C. (Intern), Kulkarni, G. (Forskerdatabase)
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- Scopus rating (2017): SNIP 0.742 SJR 0.952
- Web of Science (2017): Indexed yes
- Scopus rating (2016): CiteScore 0.66 SJR 0.917 SNIP 0.681
- Scopus rating (2015): SNIP 0.729 SJR 0.715 CiteScore 0.21
- Web of Science (2015): Indexed yes
- Scopus rating (2014): SNIP 0.702 SJR 0.872
- Web of Science (2014): Indexed yes
- ISI indexed (2013): ISI indexed no

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Source: dtu
Source-ID: n:oai:DTIC-ART:inspec/427667149::36337
Publication: Research - peer-review › Journal article – Annual report year: 2013

**Slot-die Coating of a High Performance Copolymer in a Readily Scalable Roll Process for Polymer Solar Cells**

Copolymers based on dithieno[3,2-b:2',3'-d]silole (DTS) and dithienylthiazolo[5,4-d]thiazole (TTz) are synthesized and tested in an all-solution roll process for polymer solar cells (PSCs). Fabrication of polymer:[6,6]-phenyl-C61-butyric acid methyl ester (PCBM) solar cells is done on a previously reported compact coating/printing machine, which enables the preparation of PSCs that are directly scalable with full roll-to-roll processing. The positioning of the side-chains on the thiophene units proves to be very significant in terms of solubility of the polymers and consequently has a major impact on the device yield and process control. The most successful processing is accomplished with the polymer, PDTSTTz-4, that has the side-chains situated in the 4-position on the thiophene units. Inverted PSCs based on PDTSTTz-4 demonstrate high fill factors, up to 59%, even with active layer thicknesses well above 200 nm. Power conversion efficiencies of up to 3.5% can be reached with the roll-coated PDTSTTz-4:PCBM solar cells that, together with good process control and high device yield, designate PDTSTTz-4 as a convincing candidate for high-throughput roll-to-roll production of PSCs.

**General information**

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Helgesen, M. (Intern), Carlé, J. E. (Intern), Krebs, F. C. (Intern)
Pages: 1664-1669
Publication date: 2013
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- Web of Science (2018): Indexed yes
Synthesis and characterization of new electron-withdrawing moiety thieno[2,3-c]pyrrole-4,6-dione-based molecules for small molecule solar cells

New conjugated small molecules 5,5’-bis{5-Octyl-2-(2,2’-bithiophen-5-yl)-4H-thieno[2,3-c]pyrrole-4,6-dione}-3,3’-di-octylsilylene-2,2’-bithiophene DTS(BTTPD)2 and 5,5’-bis{5-Octyl-2-(2,5-thiophenyl)-4H-thieno[2,3-c]pyrrole-4,6-dione}-3,3’-di-octylsilylene-2,2’-bithiophene DTS(TTPD)2 of the acceptor–π–donor–π–acceptor type end-capped with thieno[2,3-c]pyrrole-4,6-dione (TPD) units for small molecule solar cells have been prepared through coupling of dithienosilole and TPD units bridged with thienylene and bithienylene. They are soluble in common organic solvents and show an interesting absorption. These small molecules have very similar optical band gaps (1.87 eV and 1.92 eV) and fairly close highest occupied molecular orbital energy levels (−5.52 to −5.55 eV). The best solar cells using DTS(TTPD)2 as an electron donor and [6,6]-phenyl-C61-butyric acid methyl ester (PC61BM) as an electron acceptor demonstrated efficient performance with an obviously high open-circuit voltage (VOC) of 0.97 V and a power conversion efficiency of 1.20% after annealing and using MoO3 as electron-blocking layer. The solar cells based on DTS(BTTPD)2 and PC61BM blend also exhibited a high VOC of 0.97 V under optimized conditions.
Synthesis and photovoltaic properties from inverted geometry cells and roll-to-roll coated large area cells from dithienopyrrole-based donor-acceptor polymers

A series of donor-acceptor low band gap polymers composed of alternating dithienopyrrole or its derivative as donors and phthalimide or thieno[3,4-c]pyrrole-4,6-dione as acceptors (P1-P4) are synthesized by Stille coupling polymerization. All polymers show strong absorption in the visible region, for P2 and P4 possessing thieno[3,4-c]pyrrole-4,6-dione as an acceptor, their film absorption covers the region of 500-800 nm and 500-750 nm respectively, which makes them attractive as low band gap polymer solar cell (PSC) materials. With the incorporation of thiophene bridges, P3 and P4 have 0.24 and 0.21 eV higher HOMO energy levels than P1 and P2, respectively. A bandgap as low as 1.66 eV is obtained for P2. An up-scaling experiment is performed on bulk-heterojunction PSCs with an inverted device geometry fabricated on a small scale by spin coating and on a large scale using roll-to-roll (R2R) slot-die coating and screen printing. In both cases the best performing polymer is P2 with a Voc of 0.56 V, a Jsc of -12.6 mA cm-2, a FF of 40.3%, and a PCE of 2.84% for small
spin coated devices, and a Voc of 0.56 V, a Jsc of -8.18 mA cm-2, a FF of 30.7%, and a PCE of 1.40% are obtained for R2R-fabricated devices with a significantly better performance than a standard P3HT/PCBM driven device. © 2013 The Royal Society of Chemistry.

General information
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Main Research Area: Technical/natural sciences

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Volume: 1
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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SJR 3.488 SNIP 1.55
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 8.46 SJR 3.075 SNIP 1.479
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.62 SNIP 1.643 CiteScore 8.36
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.331 SNIP 1.514 CiteScore 7.27
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
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Web of Science (2013): Indexed yes
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Energy gap, Heterojunctions, Polymers, Solar cells, Thiophene, Plastic coatings
DOIs:
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Source: dtu
Source-ID: n:oai:DTIC-ART:compendex/386148792::34412
Publication: Research - peer-review › Journal article – Annual report year: 2014

Technological status of organic photovoltaics (OPV)
This paper gives a technological status of organic and polymer photovoltaics (OPV) for both single and tandem junctions. We list the current state-of-the-art at the laboratory level for very small rigid and mostly vacuum processed devices to larger area flexible and printed devices. In comparison to other thin film PV the view held is that OPV is at a very early stage of industrial development with future success depending on an application where OPV is uniquely performing.

General information
The state of organic solar cells - A meta analysis

Solar cells that convert sunlight into electrical power have demonstrated a large and consistent growth through several decades. The growth has spawned research on new technologies that potentially enable much faster, less costly and environmentally friendly manufacture from earth abundant materials. Here we review carbon based solar cells through a complete analysis of all the data that has been reported so far and we highlight what can be expected from carbon based technologies and draw scenarios of how it can be made of immediate use.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Zhejiang University, Chinese Academy of Sciences
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Main Research Area: Technical/natural sciences

Publication information
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Ratings:
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.532 SJR 1.459
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.97 SJR 1.599 SNIP 1.71
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.8 SNIP 1.851 CiteScore 5.16
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.19 SNIP 2.348 CiteScore 5.87
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.179 SNIP 2.529 CiteScore 5.58
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.441 SNIP 2.654 CiteScore 5.25
Towards 15% energy conversion efficiency: a systematic study of the solution-processed organic tandem solar cells based on commercially available materials

Owing to the lack of scalable high performance donor materials, studies on mass-produced organic photovoltaic (OPV) devices lag far behind that on lab-scale devices. In this work, we choose 6 already commercially available conjugated polymers and systematically investigate their potential in organic tandem solar cells. All the devices are processed under environmental conditions using doctor-blading, which is highly compatible with mass-production coating technologies. Power conversion efficiencies (PCE) of 6–7% are obtained for OPV devices based on different active layers. Optical simulations based on experimental data are performed for all realized tandem solar cells. An efficiency potential of ~10% is estimated for these compounds in combination with phenyl-C61-butyric acid methyl ester (PCBM) as an acceptor. In addition, we assume a hypothetical, optimized acceptor to understand the limitation of donors. It is suggested that a PCE of >14% is realistic for tandem solar cells based on these commercially available donor materials. Along with the demonstration of novel intermediate layers we believe that this systematic study provides valuable insight for those attempting to realize the high efficiency potential of tandem architectures.

General information
State: Published
Authors: Li, N. (Forskerdatabase), Baran, D. (Ekstern), Forberich, K. (Ekstern), Machui, F. (Ekstern), Ameri, T. (Ekstern), Turbiez, M. (Ekstern), Carrasco-Orozco, M. (Ekstern), Drees, M. (Ekstern), Facchetti, A. (Ekstern), Krebs, F. C. (Intern), Brabec, C. J. (Ekstern)
Ultra high open circuit voltage (>1 V) of poly-3-hexylthiophene based organic solar cells with concentrated light

One approach to increasing polymer solar cell efficiency is to blend poly-(3-hexyl-thiophene) with poorly electron accepting fullerene derivatives to obtain higher open circuit voltage (Voc). In this letter concentrated light is used to study the electrical properties of cell operation at up to 2000 solar intensities of these photoactive blends. Comparison of solar cells based on five different fullerene derivatives shows that at both short circuit and open circuit conditions, recombination remains unchanged up to 50 suns. Determination of Voc at 2000 suns demonstrated that the same logarithmic Voc evolution is observed from 0.4 to 2000 suns, where a maximum Voc of 1019 mV was obtained. © 2013 American Institute of Physics.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Electric properties, Open circuit voltage, Thiophene, Solar cells

Bibliographical note
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Relations
Projects:

Accelerated stability testing of organic photovoltaics using concentrated sunlight
We suggest to use concentrated sunlight for accelerated studies of light-induced mechanisms in the degradation of organic photovoltaics (OPV) based on the polymer (P3HT)/fullerene (PCBM) bulk heterojunctions. Two particular cases of the degradation are reported.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Ben-Gurion University of the Negev
Authors: Katz, E. A. (Ekstern), Manor, A. (Ekstern), Mescheloff, A. (Ekstern), Tromholt, T. (Intern), Krebs, F. C. (Intern)
Pages: 003249-003252
Publication date: 2012

Host publication information
Title of host publication: Conference record of the IEEE Photovoltaic Specialists Conference
Publisher: IEEE
ISBN (Print): 978-1-4673-0066-7
Main Research Area: Technical/natural sciences
Conference: 38th IEEE Photovoltaic Specialists Conference 2012 (PVSC), Austin, TX, United States, 03/06/2012 - 03/06/2012
Accelerated aging, Degradation, Organic semiconductors, Photovoltaic cells, Polymers, Solar energy, Stability, Zinc compounds
DOIs:
10.1109/PVSC.2012.6318270
10.1109/PVSC.2012.6318270

Aesthetically Pleasing Conjugated Polymer: Fullerene Blends for Blue-Green Solar Cells Via Roll-to-Roll Processing
The practical application of organic photovoltaic (OPV) cells requires high throughput printing techniques in order to attain cells with an area large enough to provide useful amounts of power. However, in the laboratory screening of new materials for OPVs, spin-coating is used almost exclusively as a thin-film deposition technique due its convenience. We report on the significant differences between the spin-coating of laboratory solar cells and slot-die coating of a blue-green colored, low bandgap polymer (PGREEN). This is one of the first demonstrations of slot-die-coated polymer solar cells OPVs not utilizing poly(3-hexylthiophene):(6,6)-phenyl-C61-butyric acid methyl ester (PCBM) blends as a light absorbing layer. Through synthetic optimization, we show that strict protocols are necessary to yield polymers which achieve consistent photovoltaic behavior. We fabricated spin-coated laboratory scale OPV devices with PGREEN: PCBM blends as active light absorbing layers, and compare performance to slot die-coated individual solar cells, and slot-die-coated solar
modules consisting of many cells connected in series. We find that the optimum ratio of polymer to PCBM varies significantly when changing from spin-coating of thinner active layer films to slot-die coating, which requires somewhat thicker films. We also demonstrate the detrimental impacts on power conversion efficiency of high series resistance imparted by large electrodes, illustrating the need for higher conductivity contacts, transparent electrodes, and high mobility active layer materials for large-area solar cell modules.

**General information**

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Pages: 1847-1853
Publication date: 2012
Main Research Area: Technical/natural sciences

**Publication information**

Journal: A C S Applied Materials and Interfaces
Volume: 4
ISSN (Print): 1944-8244
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SJR 2.784 SNIP 1.543
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.6 SJR 2.561 SNIP 1.536
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.262 SNIP 1.555 CiteScore 7.38
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.125 SNIP 1.636 CiteScore 6.88
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.992 SNIP 1.548 CiteScore 6.05
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.199 SNIP 1.327 CiteScore 4.94
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.046 SNIP 1.404 CiteScore 4.41
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Scopus rating (2010): SJR 1.597 SNIP 0.944
Web of Science (2010): Indexed yes
Web of Science (2009): Indexed yes
Original language: English
polymer solar cells, roll-to-roll printing/coating, slot-die coating, low band gap polymers

**DOIs:**
10.1021/am300156p

**Bibliographical note**

This work was supported by SESTAR LLC, the Office of Naval Research (N-00014-11-1-0245), the Danish Strategic Research Council (DSF 2104-05-0052 and 2104-07-0022), and EUDP (j. nr. 64009-0050).
All printed transparent electrodes through an electrical switching mechanism: A convincing alternative to indium-tin-oxide, silver and vacuum

Here we show polymer solar cells manufactured using only printing and coating of abundant materials directly on flexible plastic substrates or barrier foil using only roll-to-roll methods. Central to the development is a particular roll-to-roll compatible post-processing step that converts the pristine and non-functional multilayer-coated stack into a functional solar cell through formation of a charge selective interface, in situ, following a short electrical pulse with a high current density. After the fast post-processing step the device stack becomes active and all devices are functional with a technical yield and consistency that is compelling.
In this study, we demonstrate fully solution processed semi-transparent silver electrodes on flexible substrates having a sheet resistance as low as 5Ω/□ and transmittance of ∼30% at 550nm. We demonstrate the use of this electrode as a substitute for ITO in an inverted organic solar cell (OSC) with the layer sequence, PET/Ag/ZnO/P3HT:PCBM/PEDOT:PSS/Ag where illumination is achieved through the first Ag layer. Power conversion efficiency of up to 1.6% under 1 sun illumination (100mWcm−2 and AM1.5G) is achieved for small area (1cm2) test devices. We further demonstrate scalability of the semi-transparent Ag electrode fabrication in a roll-to-roll (R2R) process using slot-die coating. This electrode is further utilized in R2R processing of large area modules (active area 35.5cm2) where all layers in the modules are R2R processed with solution-based materials in ambient conditions without any use of vacuum steps. We further demonstrate the possibility of using barrier foil as the substrate in the R2R processing of modules. Module performance is evaluated by current–voltage characterization and Light Beam Induced Current (LBIC) imaging. Such a semi-transparent Ag electrode incurs very little material and processing cost and is a cost-effective alternative to ITO for low-cost organic solar cells.
Ambient fabrication of flexible and large-area organic light-emitting devices using slot-die coating
The grand vision of manufacturing large-area emissive devices with low-cost roll-to-roll coating methods, akin to how newspapers are produced, appeared with the emergence of the organic light-emitting diode about 20 years ago. Today, small organic light-emitting diode displays are commercially available in smartphones, but the promise of a continuous ambient fabrication has unfortunately not materialized yet, as organic light-emitting diodes invariably depend on the use of one or more time-and energy-consuming process steps under vacuum. Here we report an all-solution-based fabrication of an alternative emissive device, a light-emitting electrochemical cell, using a slot-die roll-coating apparatus. The fabricated flexible sheets exhibit bidirectional and uniform light emission, and feature a fault-tolerant >1-μm-thick active material that is doped in situ during operation. It is notable that the initial preparation of inks, the subsequent coating of the constituent layers and the final device operation all could be executed under ambient air.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Umeå University
Authors: Sandstrom, A. (Ekstern), Dam, H. F. (Intern), Krebs, F. C. (Intern), Edman, L. (Ekstern)
Number of pages: 5
Publication date: 2012

DOIs:
10.1016/j.solmat.2012.07.004

Relations
Projects:
All solution processing of ITO-free organic solar cell modules directly on barrier foil
Source: dtu
Source-ID: u::4657
Publication: Research - peer-review › Journal article – Annual report year: 2012
A Nanoparticle Approach towards Morphology Controlled Organic Photovoltaics (OPV)

Silicon nano-particles grafted with two different organic oligomers were prepared; the oligomers used were a phenylene-vinylene (PV) oligomer and a 3,3'''-didodecylquaterthiophene. The graftings were performed by the use of two different functional groups, the PV oligomer was grafted by a hydroxyl-group in the form of a phenol and a lithium derivative was used to graft the 3,3'''-didodecylquaterthiophene. The morphology and size of the grafted particles were analyzed by atomic force microscopy (AFM) and the extent of the grafting was analyzed by NMR. Organic photovoltaics with normal
geometry (ITO/PEDOT:PSS/active layer/Al) were prepared using these materials as a donor and phenyl-C61-butyric acid methyl ester ([60]PCBM) as the acceptor and yielded a power conversion efficiency (PCE) of 0.27%, an open circuit voltage (VOC) of 0.93 V, a short circuit current density (JSC) of 0.89 mA/cm², and a fill factor (FF) of 32.5% for a lead device with an active area of 0.25 cm².

**General information**

State: Published

Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis, Zhejiang University, Aalborg University


Pages: 1242-1258

Publication date: 2012

Main Research Area: Technical/natural sciences

**Publication information**

Journal: Polymers
Volume: 4
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**Ratings:**
- Web of Science (2018): Indexed yes
- Scopus rating (2017): SNIP 1.213 SJR 0.852
- Web of Science (2017): Indexed Yes
- Scopus rating (2016): SJR 0.977 SNIP 1.384 CiteScore 3.74
- Web of Science (2016): Indexed yes
- Scopus rating (2015): SJR 0.888 SNIP 1.313 CiteScore 3.37
- Web of Science (2015): Indexed yes
- Scopus rating (2014): SJR 1.125 SNIP 1.663 CiteScore 4.1
- Scopus rating (2013): SJR 0.913 SNIP 1.08 CiteScore 3.1
- ISI indexed (2013): ISI indexed yes
- Scopus rating (2012): SJR 0.567 SNIP 0.683 CiteScore 1.68
- ISI indexed (2012): ISI indexed no
- Scopus rating (2011): SJR 0.381 SNIP 0.572 CiteScore 1.02
- ISI indexed (2011): ISI indexed no
- Scopus rating (2010): SJR 0.111 SNIP 0
- Scopus rating (2002): SJR 0.121 SNIP 0
- Scopus rating (2001): SJR 0.121 SNIP 0
- Scopus rating (2000): SJR 0.121 SNIP 0

Original language: English

Organic photovoltaics, Silicon nano-particles, Morphology control

Electronic versions:

Nanoparticle_approach.pdf

**DOIs:**

10.3390/polym4021242

Publication: Research - peer-review › Journal article – Annual report year: 2012

**Barrier Technology and Applications**

**General information**

State: Published

Organisations: Department of Energy Conversion and Storage, Functional organic materials

Authors: Muller-Meskamp, L. (Ekstern), Fahlteich, J. (Ekstern), Krebs, F. C. (Intern)

Pages: 269-330

Publication date: 2012

**Host publication information**

Title of host publication: Stability and Degradation of Organic and Polymer Solar Cells

Publisher: John Wiley & Sons Ltd

Editor: Krebs, F. C.
Carbon dioxide - a themed issue

Guest Editor Frederik Krebs introduces this themed issue on Carbon Dioxide in this editorial.

General information

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Krebs, F. C. (Intern)
Pages: 7238-7239
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information

Journal: Energy & Environmental Science
Volume: 5
Issue number: 6
ISSN (Print): 1754-5692
Ratings:
  BFI (2018): BFI-level 2
  Web of Science (2018): Indexed yes
  BFI (2017): BFI-level 2
  Scopus rating (2017): SNIP 4.819 SJR 14.59
  Web of Science (2017): Indexed yes
  BFI (2016): BFI-level 2
  Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
  Web of Science (2016): Indexed yes
  BFI (2015): BFI-level 2
  Web of Science (2015): Indexed yes
  BFI (2014): BFI-level 2
  Scopus rating (2014): SJR 7.769 SNIP 4.001 CiteScore 19.28
  Web of Science (2014): Indexed yes
  BFI (2013): BFI-level 1
  Scopus rating (2013): SJR 6.019 SNIP 2.996 CiteScore 14.81
  ISI indexed (2013): ISI indexed yes
  Web of Science (2013): Indexed yes
  BFI (2012): BFI-level 1
  Scopus rating (2012): SJR 5.868 SNIP 2.599 CiteScore 11.84
  ISI indexed (2012): ISI indexed yes
  Web of Science (2012): Indexed yes
  BFI (2011): BFI-level 1
  Scopus rating (2011): SJR 3.737 SNIP 2.505 CiteScore 9.96
  ISI indexed (2011): ISI indexed no
  Web of Science (2011): Indexed yes
  Scopus rating (2010): SJR 3.87 SNIP 2.42
  Web of Science (2010): Indexed yes
  Scopus rating (2009): SJR 2.111 SNIP 1.15
Original language: English
DOIs:
  10.1039/c2ee90018a
Source: dtu
Source-ID: n:oai:DTIC-ART:rsc/365224140::16633
Publication: Research - peer-review › Editorial – Annual report year: 2012
Characterization of Thin Films for Polymer Solar Cells: Stability and Response to Concentrated Light

The field of polymer solar cells has undergone an extensive development in recent years after the invention of semiconducting polymers in 1991. Efficiencies have gradually increased to above 10 %, and high throughput processing methods such as roll-to-roll coating allow for production of thousands of solar cells with low embedded time, material, and energy consumption as compared to silicon solar cells. Consequently, different demonstration products of small mobile gadgets based on polymer solar cells have been produced, which are fully competitive with conventional energy technologies, illustrating the maturity of the technology.

However, a limiting factor in terms of full commercialization is the stability of polymer solar cells. While it has been estimated that 10 years lifetime is needed, existing technologies only provide stabilities up to 1 year. Degradation of polymer solar cell is a multi faceted process where oxygen and water diffusion from the atmosphere, morphology evolution, and photo-bleaching of the polymer are some of the dominant processes. Encapsulation by films consisting of multi-layer polymer stacks is a conventional way to reduce the diffusion into the solar cell, by which the lifetime of the cell is highly increased. An alternative approach is to increase the photo stability of the cell components, and especially the light absorbing conjugated polymer has been subject to extensive attention. The photo stability of conjugated polymers varies by orders of magnitude from type to type depending on the chemical structure of the material and consequently, the lifetime is highly influenced by the polymer stability.

Photochemical degradation of polymers, i.e. degradation of thin films of polymer in the ambient under light exposure, is a technique normally applied to evaluate polymer stabilities. Hereby, an extensive list of stabilities of different materials has been established providing an understanding of the stability of the individual building blocks of polymer. While being a highly practical tool, no rigorous reports on the photochemical degradation as a technique exist where the technique is validated and different pitfalls identified. Consequently, a rigorous study on the validation and maturing of this technique was performed during this PhD work (Chapter 2).

Furthermore, as research gradually increases the lifetime of polymers to months or years, stability evaluations at standard degradation conditions become impractical. Accelerated degradation has been performed with heat and different gases by which the timeframe of stability evaluations have been reduced by up to a factor of 20. However, light, which appears at the most intuitive acceleration condition to conjugated polymers, has until this PhD work not been applied as an acceleration condition to polymer degradation. Light can be concentrated up to thousand of solar intensities by optical components, which has the potential to significantly accelerate polymer degradation. Concentration of light was one of the main topics during this PhD, where the construction and development of light concentrators, both by sun light as well as artificial light, was given extensive attention. This resulted in three different light concentrators, a lens based solar concentrator, a mirror based solar concentrator, and an artificial light concentrator for indoor use (Chapter 3).

With these concentration setups, acceleration factors of up to 1200 were obtained for degradation of typical conjugated polymers thus significantly reducing the timeframe of stability evaluations. The potential of this approach is that stability evaluation can become a routine characterization technique for novel conjugated polymers, when these are applied to polymer solar cells and their efficiencies are reported. By making the polymer stability practically accessible, development of polymer stability can become significantly more transparent and focused (Chapter 4).

A direct alternative application of concentrated light is the application to polymer solar cells. Stabilities of polymer solar cells is within the same order of magnitude of photo chemical stabilities of polymers as the oxidation rate of the polymer in the solar cell is lower, but a large number of additional degradation mechanisms are introduced. Consequently, research in the stability of polymer solar cells is impractical since the extensive timeframe of stability testing reduces the pace of the research. This thesis reports the first results on the response of polymer solar cells to concentrated light, both in terms of performance as well as stability. Additionally, concentrated light was used to study some of the mechanisms governing solar cells operation, which are dominant when currents are very high as a consequence of high photon flux. The response in terms of stability of the cells was found to be highly complex and effects not dominant at 1 sun were observed. Thus, specific knowledge of the response of the different layers to concentrated light is needed to use concentrated light as a valid acceleration parameter (Chapter 5).
Combined Characterization Techniques to Understand the Stability of a Variety of Organic Photovoltaic Devices - the ISOS-3 inter-laboratory collaboration

This work is part of the inter-laboratory collaboration to study the stability of seven distinct sets of state-of-the-art organic photovoltaic (OPVs) devices prepared by leading research laboratories. All devices have been shipped to and degraded at the Danish Technical University (DTU, formerly RISO-DTU) up to 1830 hours in accordance with established ISOS-3 protocols under defined illumination conditions. In this work we present a summary of the degradation response observed for the NREL sample, an inverted OPV of the type ITO/ZnO/P3HT:PCBM/PEDOT:PSS/Ag/Al, under full sun stability test. The results reported from the combination of the different characterization techniques results in a proposed degradation mechanism. The final conclusion is that the failure of the photovoltaic response of the device with time under full sun solar simulation, is mainly due to the degradation of the electrodes and not to the active materials of the solar cell.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis
Authors: Andreasen, B. (Intern), Norrman, K. (Intern)
Pages: 17-38
Publication date: 2012

Main Research Area: Technical/natural sciences
Publication information
Journal: Proceedings of SPIE, the International Society for Optical Engineering
Comparative studies of photochemical cross-linking methods for stabilizing the bulk hetero-junction morphology in polymer solar cells
We are here presenting a comparative study between four different types of functionalities for cross-linking. With relatively simple means bromine, azide, vinyl and oxetane could be incorporated into the side chains of the low band-gap polymer TQ1. Cross-linking of the polymers was achieved by UV-light illumination to give solvent resistant films and reduced phase separation and growth of PCBM crystallites in polymer:PCBM films. The stability of solar cells based on the cross-linked polymers was tested under various conditions. This study showed that cross-linking can improve morphological stability but that it has little influence on the photochemical stability which is also decisive for stable device operation under constant illumination conditions.

**General information**
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis
Pages: 24417-24423
Publication date: 2012
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Journal of Materials Chemistry
Volume: 22
Issue number: 46
ISSN (Print): 0959-9428
Ratings:
- BFI (2015): BFI-level 2
- BFI (2014): BFI-level 2
- BFI (2013): BFI-level 2
- ISI indexed (2013): ISI indexed yes
- BFI (2012): BFI-level 2
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 2
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 2
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 2
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 1
- Web of Science (2008): Indexed yes
- Web of Science (2007): Indexed yes
- Web of Science (2006): Indexed yes
- Web of Science (2005): Indexed yes
- Web of Science (2004): Indexed yes
- Web of Science (2003): Indexed yes
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- Web of Science (2000): Indexed yes
Original language: English
Electronic versions:
- Comparative_studies.pdf
DOIs:
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**Bibliographical note**
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Comprehensive Investigation of Silver Nanoparticle/Aluminum Electrodes for Copper Indium Sulfide/Polymer Hybrid Solar Cells

Electrode materials are primarily chosen based on their work function to suit the energy levels of the absorber materials. In this paper, we focus on the modification of aluminum cathodes with a thin silver interlayer (2 nm) in copper indium sulfide/poly[(2,7-silafluorene)-alt-(4,7-di-2-thienyl-2,1,3-benzothiadiazole)] (PSiF-DBT) nanocomposite solar cells, which improves the fill factor compared to pure aluminum electrodes. A comprehensive structural investigation was performed by means of transmission electron microscopy and time-of-flight secondary ion mass spectrometry revealing the presence of silver nanoparticles in an aluminum oxide matrix between the absorber layer and the aluminum cathode. In combination with complementary optical investigations, the origin of the improvement is ascribed to a facilitated charge extraction.
Concentrated Light for Organic Photovoltaics

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Tromholt, T. (Intern)
Pages: 243-268
Publication date: 2012

Host publication information
Title of host publication: Stability and Degradation of Organic and Polymer Solar Cells
Publisher: John Wiley & Sons Ltd
Editor: Krebs, F. C.
ISBN (Print): 978-1-1199-5251-0
Main Research Area: Technical/natural sciences

Relations
Projects:
Concentrated Light for Organic Photovoltaics

Current Collecting Grids for ITO-Free Solar Cells
Indium-tin-oxide (ITO) free polymer solar cells prepared by ink jet printing a composite front electrode comprising silver grid lines and a semitransparent PEDOT:PSS conductor are demonstrated. The effect of grid line density is explored for a large series of devices and a careful modeling study enabling the identification of the most rational grid structure is presented. Both optical and light beam induced current (LBIC) mapping of the devices are used to support the power loss model and to follow the evolution of the performance over time. Current generation is found to be evenly distributed over the active area initially progressing to a larger graduation in areas with different performance. Over time coating defects also become much more apparent in the LBIC images.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Holst Center, Fraunhofer Gesellschaft, TNO Tech Sci (NL), Pomona College, Energy Research Centre of the Netherlands
Direct Observation of Sub-100 fs Mobile Charge Generation in a Polymer-Fullerene Film

The formation of mobile charges in a roll-to-roll processed poly-3-hexylthiophene-fullerene bulk heterojunction film is observed directly by using transient terahertz spectroscopy with sub-100 fs temporal resolution. The transient terahertz ac conductivity reveals that 20% of the incident pump photons are converted into highly delocalized charges within the 40 fs, 3.1 eV pump pulse duration, which then rapidly becomes localized within 120 fs. Approximately 2/3 of these carriers subsequently decay, possibly into an exciton, on a 1 ps time scale.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Terahertz Technologies and Biophotonics, Department of Photonics Engineering, McGill University
Authors: Cooke, D. G. (Ekstern), Krebs, F. C. (Intern), Jepsen, P. U. (Intern)
Pages: 056603
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Physical Review Letters
Volume: 108
Issue number: 5
ISSN (Print): 0031-9007
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 2.464 SJR 3.622
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.33 SJR 4.196 SNIP 2.61
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.656 SNIP 2.538 CiteScore 5.76
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 5.232 SNIP 2.71 CiteScore 6.62
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 5.675 SNIP 2.781 CiteScore 7.46
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 6.292 SNIP 2.867 CiteScore 7.19
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 6.45 SNIP 2.757
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 6.325 SNIP 2.947
Effect of Solvent-Assisted Nanoscaled Organo-Gels on Morphology and Performance of Organic Solar Cells

This paper reports how the morphology of a polymer–fullerene derivative blend is tuned via the different aggregate states of the polymer in solutions. Based on a copolymer with benzodiothiophene and thiophene-3-carboxylate as alternating units (PBDTCT), we explored the polymer aggregation (i.e., organo-gels) behavior as a function of steric hindrance of aromatic solvents imposed by substituents. We showed that the size of organo-gels decreased as the substituents of solvents got larger. Also, the phase separation and domain size of the subsequent spin-coated films increased monotonically with that of the organo-gels in solution. Through this knowledge, we eventually achieve controlled morphology and optimized organic solar cells (OSCs) performance. Our results present a significant step forward for understanding the self-assembly behavior of conjugated polymers, control of their morphology and optimization of OSC performance.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Zhejiang University
Pages: 16893-16900
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Volume: 116
Issue number: 32
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To lower the HOMO (highest occupied molecular orbital) energy level of polythieno[3,4-b]thiophene (~−4.5eV), a series of ester-functionalized polythieno[3,4-b]thiophene derivatives (P1–P3) were designed and synthesized by Stille cross coupling reaction. The resulting copolymers exhibited broad and strong absorption bands from visible to near infrared region with low optical band gaps of 1.23–1.42eV. Through cyclic voltammetry measurements, it was found that the
HOMO energy levels of the copolymers gradually decreased with increasing the content of the thiophene-3,4-dicarboxylate moiety, i.e. approximately −4.91eV for P1, −5.00eV for P2, and −5.11eV for P3. Preliminary photovoltaic properties of the copolymers blended with 6,6-phenyl-C61-butyric acid methyl ester (PCBM) as electron acceptor were investigated. Among the three copolymers, P1 exhibited the best photovoltaic performance with an open circuit voltage (Voc) of 0.54V, a short circuit current density (Isc) of 3.3mA/cm², a fill factor (FF) of 0.57, and a power conversion efficiency (PCE) of 1.02%. A high Voc up to 0.71V was achieved in the solar cell based on a P3:PCBM blend.
High-throughput roll-to-roll X-ray characterization of polymer solar cell active layers

Synchrotron-based X-rays were used to probe active materials for polymer solar cells on flexible polyester foil. The active material was coated onto a flexible 130 micron thick polyester foil using roll-to-roll differentially pumped slot-die coating and presented variation in composition, thickness, and additives. The coated foil was passed through a synchrotron X-ray beam on a small unit comprising unwinder and winder for the foil, an X-ray probe station, and a barcode reader for sample registration. Foil lengths of 10 meters were probed and yielded X-ray scattering data for approximately every 1 cm, probing linear variations in processing and coating parameters along the foil. The demonstration shows that real-time structural characterization of roll-to-roll coating at realistic web-speeds is feasible using synchrotron radiation. Off-line characterization with lower spatial resolution would be possible with dedicated laboratory instruments. We found that poly(3-hexyl)thiophene (P3HT) only crystallizes at a ratio above 1 : 2 with phenyl-C61-butyric acid methyl ester (PCBM) and that an optimum addition of 2 vol% chloronaphthalene (CN) as a processing additive significantly improves polymer crystallinity and crystallite size. In coated films thinner than 275 nm, textured poly(3-hexyl)thiophene crystallites with the lamellar stack aligned with the substrate dominate, similar to what is observed for spin-coated films.
The present invention relates to: a method of preparing a coating ink for forming a zinc oxide layer, which method comprises the steps of: a) mixing zinc acetate and AlOH(OAc)2 in water or methanol and b) filtering out solids; a coating ink comprising zinc acetate and AlOH(OAc)2 in aqueous or methanolic solution; a method of preparing a layer comprising zinc oxide, which method comprises: i) coating a substrate with the coating ink of the invention to form a film, ii) drying the film, and iii) heating the dry film to convert the zinc acetate substantially to ZnO; and a method of preparing an organic photovoltaic device or an organic LED having a polymer/fullerene active layer, the method comprising, in this order: a) providing a substrate bearing a first electrode layer, b) forming an electron transport layer according to the method of preparing a layer comprising zinc oxide according to the invention, c) forming an active layer, d) forming a hole transport layer, and e) forming a second electrode layer.
Improved electron transport layer

The present invention provides: a method of preparing a coating ink for forming a zinc oxide electron transport layer, comprising mixing zinc acetate and a wetting agent in water or methanol; a coating ink comprising zinc acetate and a wetting agent in aqueous solution or methanol; a method of preparing a zinc oxide electron transport layer, which method comprises: i) coating a substrate with the coating ink of the present invention to form a film; ii) drying the film; and iii) heating the film to convert the zinc acetate substantially to ZnO; a method of preparing an organic photovoltaic device or an organic LED having a zinc oxide electron transport layer, the method comprising, in this order: a) providing a substrate bearing a first electrode layer; b) forming an electron transport layer according to the following method: i) coating a coating ink comprising an ink according to the present invention to form a film; ii) drying the film; iii) heating the dry film such that the zinc acetate is substantially converted to ZnO; c) forming an active layer; d) forming a hole transport layer; and e) forming a second electrode layer; and an optoelectronic device comprising an electron transporting layer comprising zinc oxide and a wetting agent.

Incorporation of ester groups into low band-gap diketopyrrolopyrrole containing polymers for solar cell applications

To increase the open circuit voltage (VOC) of polymer solar cells based on diketopyrrolopyrrole (DPP) containing polymers, the weakly electron-withdrawing thiophene-3,4-dicarboxylate unit was introduced into the polymer backbone. Two ester group functionalized DPP containing polymers, PCTDPP with a random structure and PDCTDPP with a regular structure, were designed and synthesized by the Stille coupling reaction. The resulting copolymers exhibit broad and strong absorption bands from 350 to 1000 nm with low optical band gaps below 1.40 eV. Through cyclic voltammetry measurements, it is found that regular PDCTDPP’s HOMO energy level is 0.18 V lower than that of the corresponding random PCTDPP (−5.14 eV for PCTDPP and −5.32 eV for PDCTDPP). Preliminary photovoltaic properties of the copolymers blended with [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) as an electron acceptor were investigated. The PSC based on a PCTDPP:PCBM blend shows a power conversion efficiency (PCE) up to 3.52%, with a VOC of 0.66 V, a short circuit current (ISC) of 8.53 mA cm−2, and a fill factor (FF) of 0.63. For the PDCTDPP:PCBM blend, the highest VOC reaches a value of 0.84 V, and a final PCE (0.92%) is limited by the poor hole mobility of the active layer.
Increasing the Fill Factor of Inverted P3HT:PCBM Solar Cells Through Surface Modification of Al-Doped ZnO via Phosphonic Acid-Anchored C60 SAMs

The influence of aluminum-doped zinc oxide (AZO) electron extraction layers modified with self-assembled monolayers (SAMs) on inverted polymer solar cells is investigated. It is found that AZO modification with phosphonic acid-anchored Fullerene–SAMs leads to a reduction of the series resistance, while increasing the parallel resistance. This results in an
increased efficiency from 2.9 to 3.3%.

**Industrialization of Polymer Solar Cells – phase 1**

Polymer solar cells have unique features such as low weight, slim outline, robustness against breakage and excellent adaptability of size, shape and curvature to the actual application. These features open, not only for cost- and energy effective application of the cell, but also for aesthetic solutions. The potential for reaching low production cost at high production volumes is significant, as the polymer solar cell is produced in a roll-to-roll process. The potential for low-cost processing relates not only to the solar cell itself but also to the further processing of the solar cells into more refined products. Such refined products might be self-powered electronic devices designed for easy integration in the customer's production or solar-powered products for the end-user.

A three-phased project with the objective to industrialize DTU’s basic polymer solar cell technology was started in the summer of 2009. The technology comprises a specific design of the polymer solar cell and a corresponding roll-to-roll manufacturing process. This basic technology is referred to as ProcessOne in the open literature. The present report relates to the project’s phase 1. The key tasks in phase 1 are to stream-line DTU’s technology for the industrial production of solar cells.
industrial utilization, to demonstrate production according to this stream-lined technology at Mekoprint A/S and finally to fertilize the market for polymer solar cells by demonstrating their use in appli-cations that harmonize with their present maturity level.

The main focus in the stream-lining of DTU’s technology has been to demonstrate a convincing rate of re-duction for the production cost, and thereby make a competitive price plausible. This has been materialized as a learning curve showing that the polymer technology presently develops considerably faster than the silicon technology. The polymer solar cells will, under the assumption that both technologies follow a projec-tion of the learning curve, gain a cost-leading position within a reasonable time. A production cost of 5 €/Wp has already been demonstrated in DTU’s pilot plant, and a road map for the further decrease to 1 €/Wp is drawn. This target is expected to be reached in 2013 in the ongoing phase 2 of the project.

Another activity essential for the industrialization has been the launch of specialized materials, equipment and services required for the processing of DTU’s polymer solar cells. Relevant products and services are made available for sale on DTU’s homepage, www.energyconversion.dtu.dk.

A production line for polymer solar cells has been established at Mekoprint. For this a retrofit solution was chosen where the core of an existing screen-printing line was dismantled and fitted to a slot-die printing head manufactured in DTU’s workshop. The line was at the same time adjusted and updated to handle the new production. The very first solar cells produced on this line appeared in July 2010. The line has subse-quentley been upgraded on a running basis, and Mekoprint’s operators have been trained. The technology transfer is continued in the project’s phase 2, where the goal is that Mekoprint fully masters both the pro-duction process and the production line.

During the course of the project several applications for polymer solar cells have been investigated from a technical –, a design –, and a market point of view. Faktor 3 has sketched and visualized a range of ideas. The ideas are communicated to a broader audience by means of a brochure. An on-line version of the bro-chure and a computer tool developed for guiding the designer through the process of dimensioning the electronic system comprising a polymer solar cell, a battery and the electronic function to be powered, are available on Faktor 3’s homepage, www.faktor-3.dk.

Small LED torches have served as a case for gaining experiences with development and production of so-lar powered products. A range of conceptual lamps have been evaluated, and two lamps have been pro-duced in large series and demonstrated in public. Some hundred lamps targeted at school children in non-electrified areas in 3rd world countries were produced and distributed to target users in Asia, Africa and South America in collaboration with the Strømme Foundation (NO). The feedback received was highly posi-tive and proves the necessity for low-cost, off-grid lightening to replace the presently used kerosene lamps. A small credit-card sized lamp was produced in a series of 10.000 units in order to test the production se-tup’s ability to handle large series. Several thousands of the lamps were handed out at an international conference for printed electronics, (LOPE-C, 2011). The response from this audience, who is well qualified to judge the news value of lamp’s, has also been highly positive.

Based upon the positive demonstration events, two products are launched for sale on Mekoprint’s home-page; a laser-pointer and a LED flashlight, see www.mekoprint.com. Both Mekoprint and Faktor 3 have more products in their pipelines.

**General information**

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Lauritzen, H. (Intern), Bork, J. (Ekstern), Andersen, R. B. (Ekstern), Bentzen, B. (Ekstern), Krebs, F. C. (Intern)
Number of pages: 81
Publication date: 2012

**Publication information**

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Original language: English
Main Research Area: Technical/natural sciences

**Bibliographical note**

EUDP project 64009-0050
Publication: Research › Report – Annual report year: 2013

**Influence of processing and intrinsic polymer parameters on photochemical stability of polythiophene thin films**

Intrinsic polymer parameters such as regio-regularity, molecular weight, and crystallinity play an important role when studying polymer stability. 18 different batches of poly-3-hexyl-thiophene (P3HT) were degraded in a solar simulator (AM1.5G, 1000 W/m2) and the degradation kinetics were monitored. The results suggest that the radical reaction responsible for the photodegradation takes place at terminal thiophene rings exposed at points where the conjugation is broken. This proposed mechanism is supported by the fact that stability scales with regio-regularity following the ratio of head-to-tail connected thiophene units. Annealing was found to relax the P3HT films and increase conjugation length and, in turn, increase stability observed as a delayed spectral blueshift caused by photochemical degradation. Crystallinity was found to play a minor role in terms of stability. Oxygen diffusion and light shielding effects were shown to have a negligible effect on the photochemical degradation rate. The results obtained in this work advance the understanding of polymer stability and will help improve the design of materials used for polymer solar cells resulting in longer lifetimes, which will push the technology closer to large-scale applications. © 2012 Elsevier Ltd. All rights reserved.
Influence of processing and intrinsic polymer parameters on photochemical stability of polythiophene thin films

Project: In the ISOS-3 Inter-laboratory collaboration*

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Publication: Research - peer-review › Journal article – Annual report year: 2012

Investigation of the degradation mechanisms of a variety of organic photovoltaic devices by combination of imaging techniques—the ISOS-3 inter-laboratory collaboration

The investigation of degradation of seven distinct sets (with a number of individual cells of n ≤ 12) of state of the art organic photovoltaic devices prepared by leading research laboratories with a combination of imaging methods is reported. All devices have been shipped to and degraded at Risø DTU up to 1830 hours in accordance with established ISOS-3 protocols under defined illumination conditions. Imaging of device function at different stages of degradation was performed by laser-beam induced current (LBIC) scanning; luminescence imaging, specifically photoluminescence (PLI) and electroluminescence (ELI); as well as by lock-in thermography (LIT). Each of the imaging techniques exhibits its specific advantages with respect to sensing certain degradation features, which will be compared and discussed here in detail. As a consequence, a combination of several imaging techniques yields very conclusive information about the degradation processes controlling device function. The large variety of device architectures in turn enables valuable progress in the proper interpretation of imaging results—hence revealing the benefits of this large scale cooperation in making a step forward in the understanding of organic solar cell aging and its interpretation by state-of-the-art imaging methods.

General information

State: Published

Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis, Ilmenau University of Technology, Dresden University of Technology, Katholieke Universiteit, National Renewable Energy Laboratory, Holst Center, Fraunhofer Gesellschaft, Hasselt University, Centre d’Investigació en Nanociència i Nanotecnologia, Université Blaise Pascal, Clermont-Ferrand, TÜBITAK National Metrology Institute, Brookhaven National Laboratory


Pages: 6521-6540

Publication date: 2012

Main Research Area: Technical/natural sciences

Publication information

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Volume: 5
Issue number: 4
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Bibliographical note
This work has been supported by the Danish Strategic Research Council (2104-07-0022), EUDP (j.no. 64009-0050) and the Danish National Research Foundation. Partial financial support was also received from the European Commission as part of the Framework 7 ICT 2009 collaborative project HIFLEX (grant no. 248678), partial financial support from the EU Indian framework of the "Largecells" project that received funding from the European Commission’s Seventh Framework Programme (FP7/2007–2013. grant no. 261936), partial financial support was also received from the European Commission as part of the Framework 7 ICT 2009 collaborative project ROTROT (grant no. 288565) and from PVERA-NET (project acronym POLYSTAR).

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Relations
Projects:
Investigation of the degradation mechanisms of a variety of organic photovoltaic devices by combination of imaging techniques—the ISOS-3 inter-laboratory collaboration
Investigation of the degradation mechanisms of a variety of organic photovoltaic devices by combination of imaging techniques—the ISOS-3 inter-laboratory collaboration

Source: du
Source-ID: u::3517
Publication: Research - peer-review › Journal article – Annual report year: 2012
Large-scale roll-to-roll photonic sintering of flexo printed silver nanoparticle electrodes

In this report we employ static and roll-to-roll (R2R) photonic sintering processes on flexo printed silver nanoparticle-based electrode structures with a heat-sensitive 60 mm thin barrier foil as a substrate. We use large area electrode structures to visualize the increased optical footprint of single and quadruple flashes, and the R2R challenges in the form of overlapping exposures. It is shown that single flash exposure is enough to significantly increase the conductivity and adhesion without damaging the foil or build-up of cracks in the silver layer. Additional flash exposures or increased energies above the threshold level have only minor impact on the conductivity but lead to cracks and substrate deformation. A second silver nanoparticle ink was printed, which was already optimized for lowtemperature drying. Here we show that photonic sintering has only a minor impact on the conductivity as the nanoparticles are already sintered. The advantage of single exposure is the ability to produce higher R2R processing speeds without overlapping, which is shown in the form of theoretical calculations.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Hösel, M. (Intern), Krebs, F. C. (Intern)
Pages: 15683–15688
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Materials Chemistry
Volume: 22
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BFI (2013): BFI-level 2
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ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 2
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
Web of Science (2006): Indexed yes
Web of Science (2005): Indexed yes
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Web of Science (2001): Indexed yes
Web of Science (2000): Indexed yes
Original language: English
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10.1039/c2jm32977h

Bibliographical note
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Relations
Projects:
Large-scale roll-to-roll photonic sintering of flexo printed silver nanoparticle electrodes
Large-scale roll-to-roll photonic sintering of flexo printed silver nanoparticle electrodes
Source: dtu
Source-ID: u::4385
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Low-temperature side-chain cleavage and decarboxylation of polythiophene esters by acid catalysis
Solubility switching of polymers is very useful in thin layer processing of conjugated polymers, as it allows for multilayer processing and increases the stability of the polymer. Acid catalyzed thermocleavage of ester groups from thiophene polymers carrying primary, secondary, and tertiary substituents have been examined by TGA-MS using different sulphonic acids. A substantial lowering of the cleavage temperature is observed, and the ester cleavage can even be performed in situ on roll-to-roll-coated films on polyethylene terephthalate (PET). © 2011 Wiley Periodicals, Inc. J Polym Sci Part A: Polym Chem, 2012

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis
Authors: Søndergaard, R. (Intern), Norrman, K. (Intern), Krebs, F. C. (Intern)
Pages: 1127-1132
Publication date: 2012
Main Research Area: Technical/natural sciences

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Journal: Journal of Polymer Science. Part A, Polymer Chemistry
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Issue number: 6
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BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): SNIP 0.673 SJR 0.735
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 1.069 SNIP 0.782
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.002 SNIP 0.854 CiteScore 2.93
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.101 SNIP 0.95 CiteScore 3.05
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.165 SNIP 0.996 CiteScore 3.41
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.5 SNIP 0.99 CiteScore 3.33
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.653 SNIP 0.998 CiteScore 3.64
ISI indexed (2011): ISI indexed yes
Tertiary ester, Thermogravimetric analysis (TGA), Primary ester, Conducting polymers, Thermocleavage, Polythiophene ester, Low temperature, Secondary ester, Solubility switching, Ester cleavage, Decarboxylation, Acid catalysis, Catalysis

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Relations
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Source-ID: 318765
Publication: Research - peer-review › Journal article – Annual report year: 2012

Manufacture and demonstration of organic photovoltaic-powered electrochromic displays using roll coating methods and printable electrolytes
Electrochromic devices (ECDs) were prepared on flexible substrates using spray coating and slot-die coating methods. The electrochromic materials were the conjugated electroactive polymers, poly([2,2-bis(2-ethylhexyloxy)methyl]-propylene-1,3-dioxy)-3,4-thiophene-2,5-diyl) as a vibrantly colored active material (ECP-Magenta) and poly(N-octadecyl-(propylene-1,3-dioxy)-3,4-pyrrole-2,5-diyl) as a minimally colored, charge balancing material (MCCP). Two electrolyte systems were compared to allow development of fully printable and laminated devices on flexible substrates. Devices of various sizes, up to 7 × 8 cm², are demonstrated with pixelated devices containing pixel sizes of 4 × 4 mm² or 13 × 13 mm². The transmission contrast exhibited by the devices, when switched between the fully bleached and fully colored state, was 58% at a visible wavelength of 550 nm, and the devices exhibited switching times of <10 s. Additionally, we demonstrate the utilization of printed organic photovoltaic devices (with or without the use of a lithium-polymer battery) to power the devices between the colored and bleached state, illustrating a self-powered ECD. © 2012 Wiley Periodicals, Inc. J Polym Sci Part B: Polym Phys, 2012

General information
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Organisations: Department of Energy Conversion and Storage, Functional organic materials, University of Florida
Authors: Jensen, J. (Intern), Dam, H. F. (Intern), Reynolds, J. R. (Ekstern), Dyer, A. L. (Ekstern), Krebs, F. C. (Intern)
Pages: 535-545
Publication date: 2012
Main Research Area: Technical/natural sciences
Method of making optoelectric devices
A method of preparing an optoelectric device, comprising: (a) providing a substrate on which is formed a first electrode layer; (b) forming an electron transport layer according to the following method: i) forming a film of a coating ink comprising zinc acetate in aqueous solution; ii) drying the film; iii) heating the dry film such that the zinc acetate is substantially converted to ZnO; (c) forming an active layer according to either of the following methods: i) applying a coating ink comprising a light-harvesting polymer and a fullerene to the electron transport layer and drying the coating ink layer; or (ii) applying a coating ink comprising a soluble precursor of a light harvesting polymer, a fullerene and a solvent to the electron transport layer, drying the coating ink layer and treating the dried coating ink layer to convert the soluble precursor of a light-harvesting polymer into a light harvesting polymer that is substantially insoluble in the solvent comprised in the coating ink; (d) forming a hole transport layer on the active layer according to the following method: i) coating the active layer with a solution comprising a hole transporting compound, water and an alcohol to form a film; ii) drying the film to form a hole transport layer; (e) forming a second electrode layer on the hole transport layer.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis
Authors: Krebs, F. C. (Intern), Jørgensen, M. (Intern), Normran, K. (Intern), Søndergaard, R. (Intern)
Publication date: 2012

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Country: Denmark
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Publication: Research › Patent – Annual report year: 2012

Mobile charge generation dynamics in P3HT:PCBM observed by time-resolved terahertz spectroscopy
Ultra-broadband time-resolved terahertz spectroscopy is used to examine the sub-ps conductivity dynamics of a conjugated polymer bulk heterojunction film P3HT:PCBM. We directly observe mobile charge generation dynamics on a sub-100 fs time scale.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Department of Photonics Engineering, Terahertz Technologies and Biophotonics, McGill University
Authors: Cooke, D. G. (Ekstern), Krebs, F. C. (Intern), Jepsen, P. U. (Intern)
Number of pages: 2
Publication date: 2012

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Publisher: Optical Society of America
Article number: CM1L.1
Main Research Area: Technical/natural sciences
Conference: Conference on Lasers and Electro-Optics (CLEO 2012), San Jose, CA, United States, 06/05/2012 - 06/05/2012
Heterojunctions, Terahertz spectroscopy, Dynamics
DOIs: 10.1364/CLEO_SI.2012.CM1L.1
Source: dtu
Source-ID: n:oai:DTIC-ART:compendex/428103021::36582
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

Mobile Charge Generation Dynamics in P3HT:PCBM Observed by Time-Resolved Terahertz Spectroscopy
Ultra-broadband time-resolved terahertz spectroscopy is used to examine the sub-ps conductivity dynamics of a conjugated polymer bulk heterojunction film P3HT:PCBM. We directly observe mobile charge generation dynamics on a sub-100 fs time scale.
New Low-Bandgap Materials with Good Stabilities and Efficiencies Comparable to P3HT in R2R-Coated Solar Cells

Roll-to-roll coated organic solar cells of two new polymers processed in ambient conditions show good photochemical stabilities, and their efficiencies are comparable to similar roll-to-roll coated P3HT cells. Optimal blend compositions are achieved by the use of differentially pumped slot die coatings. The final devices show good stabilities in an outdoor experiment carried out over 4 months.
On the origin of metallic conductivity at the interface of LaAlO3/SrTiO3

To determine the origin of the quasi-two-dimensional electron gas formed at the interface between the two complex oxides of LaAlO3 (LAO) and SrTiO3 (STO), various amorphous films of LAO, La2O3, Al2O3, and La7/8Sr1/8MnO3 (LSMO), were deposited on TiO2-terminated (0 0 1) STO substrates by pulsed laser deposition at room temperature. Metallic interfaces are observed when the over-layers are amorphous LAO, La2O3, or Al2O3, while insulating interfaces are observed when the over-layer is LSMO. The interfacial conductivity of these SrTiO3-based hetero-structures shows strong dependence on both film thickness and oxygen pressure during film growth. The possible origin for the occurrence of metallic interfaces in these complex oxide hetero-structures due to redox reactions at the STO substrate surface is discussed. A thermodynamic criterion for designing either metallic or insulating interfaces between complex oxides is proposed.
On the stability of a variety of organic photovoltaic devices by IPCE and in situ IPCE analyses – the ISOS-3 inter-laboratory collaboration

This work is part of the inter-laboratory collaboration to study the stability of seven distinct sets of state-of-the-art organic photovoltaic (OPV) devices prepared by leading research laboratories. All devices have been shipped to and degraded at RISØ-DTU up to 1830 hours in accordance with established ISOS-3 protocols under defined illumination conditions. In this work, we apply the Incident Photon-to-Electron Conversion Efficiency (IPCE) and the in situ IPCE techniques to determine the relation between solar cell performance and solar cell stability. Different ageing conditions were considered: accelerated full sun simulation, low level indoor fluorescent lighting and dark storage. The devices were also monitored under conditions of ambient and inert (N2) atmospheres, which allows for the identification of the solar cell materials more susceptible to degradation by ambient air (oxygen and moisture). The different OPVs configurations permitted the study of the intrinsic stability of the devices depending on: two different ITO-replacement alternatives, two different hole extraction layers (PEDOT:PSS and MoO3), and two different P3HT-based polymers. The response of un-encapsulated devices to ambient atmosphere offered insight into the importance of moisture in solar cell performance. Our results demonstrate that the IPCE and the in situ IPCE techniques are valuable analytical methods to understand device degradation and solar cell lifetime.

Original language: English. DOIs: 10.1039/C2CP40821J

**Bibliographical note**

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Photochemical stability of conjugated polymers, electron acceptors and blends for polymer solar cells resolved in terms of film thickness and absorbance

Photochemical degradation at 1 sun under AM1.5G illumination was performed on six conjugated polymers and five different electron acceptors. Additionally, the respective polymer:PC60BM and P3HT:electron acceptor blends were studied, and all degradations were resolved in terms of film thickness and absorbance. A fully automated degradation setup allowed for inclusion of in excess of 1000 degradations in this study to enable a discussion of reliability of the technique. Degradation rates were found to increase exponentially with decreasing film absorbance for all materials. The relative stabilities within each material group were found to vary for both the pure polymers and the blends. The stability ranking between the materials of the pure polymers was found to be similar to the ranking for their respective blends, implying that the photochemical stability of a pure polymer is a good measure of its associated blend stability. Different electron acceptors were found to stabilize P3HT decreasingly with decreasing donor–acceptor LUMO–LUMO gap. Destabilization of P3HT was observed in the case of the electron acceptor ICBA. Additionally, the decreased stabilization of P3HT by high LUMO electron acceptors poses a challenge to solar cell encapsulation if these materials are to be of commercial interest. The presented method is generally applicable to all types of organic materials to assess photochemical stabilities. The presented results of conjugated polymers demonstrate that this is a powerful tool for conjugated polymer stability assessment if the results are interpreted correctly.
Bibliographical note
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Relations
Projects:
- Photochemical stability of conjugated polymers, electron acceptors and blends for polymer solar cells resolved in terms of film thickness and absorbance
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Photovoltaics efficiency improvements

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile
Authors: Sommer-Larsen, P. (Intern), Roca, F. (Ekstern), Krebs, F. C. (Intern)
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Plastsoiceller

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State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Lauritzen, H. (Intern)
Number of pages: 26
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Publication information
Original language: Danish
Main Research Area: Technical/natural sciences
Source: dtu
Source-ID: u::6432
Publication: Communication › Sound/Visual production (digital) – Annual report year: 2012
Polymer Solar Cells – Non Toxic Processing and Stable Polymer Photovoltaic Materials

The field of polymer solar cell has experienced enormous progress in the previous years, with efficiencies of small scale devices (~1 mm²) now exceeding 8%. However, if the polymer solar cell is to achieve success as a renewable energy resource, mass production of sufficiently stable and efficient cell must be achieved. For a continuous success it is therefore essential to transfer the accomplishments from the laboratory to large scale facilities for actual production. In order to do so, several issues have to be approached. Among these are more environmentally friendly processing and development of more stable materials.

The field of polymer solar cells has evolved around the use of toxic and carcinogenic solvents like chloroform, benzene, toluene, chlorobenzene, dichlorobenzene and xylene. As large scale production of organic solar cells is envisaged to production volumes corresponding to several GWpeak, this is not a suitable approach from neither a production nor environmental point of view. As a consequence new materials, which can be processed from more environmentally friendly solvents (preferably water), need to be developed. In this thesis, the issue has been approached through synthesis of polymers carrying water coordinating side chains which allow for processing from semi-aqueous solution. A series of different side chains were synthesized and incorporated into the final polymers as thermocleavable tertiary esters. Using a cleavable side chain induces stability to solar cells as it slows down diffusion though the active layer, but just as important it renders the layer insoluble. This allows for further processing, using the same solvent, without dissolving already processed layers, and resulted in the first ever reported solar cells where all layers are processed from aqueous or semi-aqueous solution. As previously mentioned many advantages can be achieved by use of thermocleavable materials. Unfortunately the cleavage temperatures are too high to allow processing on flexible substrates like PET. As a final result, the reduction in cleavage temperature of thermocleavable thiophene polymers with ester side chains, through acid catalysis have been examined. The study shows that substantial lowering of the temperatures can be obtained for tertiary, secondary and primary esters, but further research needs to be performed in order to transfer the reaction to solar cells.

From a stability point of view, the current state of the art polymers are not stable enough to be processed by large area processing methods like roll-to-roll (R2R) coating techniques, as this has to be performed in air. This calls for the development of new materials, which can endure such processing conditions, and in this context it would be preferable to have a guideline towards which properties of a polymer that either induces stability or causes it to degrade. As part of a larger study, aiming at mapping the relative stability influence of different donors and acceptors in low-band-gap polymers, four polymers were synthesized for examination of their photochemical stabilities. Two of these were furthermore optimized for R2R processing and were tested together with other cells, in an outdoor study involving 8 countries. Panels containing the cells encapsulated in polyurethane were manufactured, measured and installed by travelling between the different locations. Following 4½ months outdoor exposure the trip was done again in order to dismount the panels for...
shipment back to Denmark, where final characterization was made. The use of polyurethane for encapsulation showed improved conservations of the cells compared to previous studies.

**General information**
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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Søndergaard, R. (Intern), Krebs, F. C. (Intern)
Number of pages: 346
Publication date: 2012

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**Relations**
Projects:
Polymer Solar Cells – Non Toxic Processing and Stable Polymer Photovoltaic Materials
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**Polymer solar cells / OPV and their perspectives in our future fossil-free energy supply**

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Authors: Lauritzen, H. (Intern)
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Original language: English
Main Research Area: Technical/natural sciences
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**Polymersolceller**

**General information**
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
PROCESS OF ELECTRICAL CONNECTION OF PHOTOVOLTAIC DEVICES

A photovoltaic cell module comprising at least two serially connected photovoltaic cells on a common substrate, wherein the cells each comprise a first electrode layer, a first charge selective layer, a light harvesting layer which comprises an organic conjugated polymer, and a second charge selective layer that selects for an opposite charge to the first charge selective layer, wherein the first electrode layers for each cell are formed such that the first electrode layer of one cell has no direct electrical connection to the first electrode layer of any other cell, and the second charge selective layer is formed such that the second charge selective layer of one cell has no direct electrical connection to the second charge selective layer of any other cell, and wherein the light-harvesting layer is formed such that it is common to at least one pair of adjacent cells of the module; wherein, for the at least one pair of adjacent cells to which the light harvesting layer is common, a metal layer is formed such that an electrical connection is established between the second charge selective layer of a first one of the at least one pair of adjacent cells and the first electrode layer of a second cell of the pair, which connection is made through the light harvesting layer common to the at least one pair of cells, without forming an electrical connection with the first electrode of the first cell or the second charge selective layer of the second cell; and a method of making such a photovoltaic cell module.

Rapid flash annealing of thermally reactive copolymers in a roll-to-roll process for polymer solar cells

Light induced thermocleaving of a thermally reactive copolymer based on dithienylthiazolo[5,4-d]thiazole (DTZ) and silolodithiophene (SDT) in contact with the heat sensitive substrate the heat sensitive substrate polyethylene terephthalate (PET) was effectively demonstrated with the use of high intensity pulsed light, delivered by a commercial photonic sintering system. Thermally labile ester groups are positioned on the DTZ unit of the copolymer that can be eliminated thermally for enhanced photochemical stability and advantages in terms of processing (solubility/insolubility switching).
The photonic sintering system was successfully implemented in a full roll-to-roll process on flexible PET substrates and large-area polymer solar cell modules were prepared by solution processing of five layers under ambient conditions using the photonic sintering system for thermocleaving of the active layer. The PET foil did not show any deformation after exposure to the high intensity light only leaving the insoluble thermocleaved active layer. The active layer remained planar after light exposure thereby allowing the coating of supplementary material on top.
Roll-to-roll coated PBI membranes for high temperature PEM fuel cells

We employed roll-to-roll coating in the preparation of 40 μm thick poly[2,2′(m-phenylene)-5,5′bibenzimidazole] (PBI) films for fuel cells using both knife-coating (KC) and slot-die (SD) coating. The films were coated directly from a 9% (w/w) solution of PBI in dimethylacetamide onto a sacrificial low cost paper or plastic based carrier substrate and dried using a hot air oven with a length of 1 m at 140 °C. A web width of 305 mm, a working width of 250 mm and a web speed of 0.2 m min⁻¹ were explored to ensure efficient drying of the thick wet film. A large air flow was found to efficiently avoid skinning. Films were prepared by a single coating step and by two subsequent coating steps in order to explore whether two coating steps gave films with fewer defects. A significant development towards upscaling the PEM fuel cell technology was that the PBI membrane was coated onto a sacrificial carrier substrate allowing for easy recoating on top of the firstly prepared film. It was thus possible to prepare free-standing films by a simple coating procedure followed by delamination from the carrier substrate post-film formation and drying. We finally carried out systematic membrane characterization with respect to solubility, phosphoric acid doping and fuel cell performance. Our results showed that the PBI membranes prepared in this work have identical properties compared to traditionally cast membranes while enabling an increase of a factor of 100 in manufacturing speed.

General information
State: Published
Organisations: Department of Chemistry, Department of Energy Conversion and Storage, Proton conductors, Functional organic materials
Authors: Steenberg, T. (Intern), Hjuler, H. A. (Intern), Terkelsen, C. (Ekstern), Sanchez, M. T. R. (Intern), Cleemann, L. N. (Intern), Krebs, F. C. (Intern)
Pages: 6076-6080
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Journal: Energy & Environmental Science
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Scopus rating (2016): CiteScore 26.39 SJR 12.283 SNIP 4.325
Roll-to-roll fabrication of polymer solar cells

**General information**

- **State:** Published
- **Organisations:** Department of Energy Conversion and Storage, Functional organic materials
- **Authors:** Søndergaard, R. (Intern), Hösel, M. (Intern), Angmo, D. (Intern), Larsen-Olsen, T. T. (Intern), Krebs, F. C. (Intern)
- **Pages:** 36-49
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- **Volume:** 15
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  - Web of Science (2017): Indexed Yes
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  - Web of Science (2015): Indexed yes
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Roll-to-roll fabrication of polymer solar cells

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Relations
Projects:
Roll-to-roll fabrication of polymer solar cells

Source: dtu
Source-ID: u::3522
Publication: Research - peer-review › Journal article – Annual report year: 2012

Round-Robin Studies as a Method for Testing and Validating High-Efficiency ITO-Free Polymer Solar Cells Based on Roll-to-Roll-Coated Highly Conductive and Transparent Flexible Substrates

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Seneste udvikling indenfor plastsolceller: Plastsolcellerne og fremtidens energiforsyning

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Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Lauritzen, H. (Intern)
Number of pages: 23
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Gå-hjem-møde for IDA, Region Sjælland, DTU Risø Campus, 18/9-2012
Source: dtu
Silver front electrode grids for ITO-free all printed polymer solar cells with embedded and raised topographies, prepared by thermal imprint, flexographic and inkjet roll-to-roll processes

Semitransparent front electrodes for polymer solar cells, that are printable and roll-to-roll processable under ambient conditions using different approaches, are explored in this report. The excellent smoothness of indium-tin-oxide (ITO) electrodes has traditionally been believed to be difficult to achieve using printed front grids, as surface topographies accumulate when processing subsequent layers, leading to shunts between the top and bottom printed metallic electrodes. Here we demonstrate how aqueous nanoparticle based silver inks can be employed as printed front electrodes using several different roll-to-roll techniques. We thus compare hexagonal silver grids prepared using either roll-to-roll inkjet or roll-to-roll flexographic printing. Both inkjet and flexo grids present a raised topography and were found to perform differently due to only the conductivity of the obtained silver grid. The raised topographies were compared with a roll-to-roll thermally imprinted grid that was filled with silver in a roll-to-roll process, thus presenting an embedded topography. The embedded grid and the flexo grid were found to perform equally well, with the flexographic technique currently presenting the fastest processing and the lowest silver use, whereas the embedded grid presents the maximally achievable optical transparency and conductivity. Polymer solar cells were prepared in the same step, using roll-to-roll slot-die coating of zinc oxide as the electron transport layer, poly-3-hexylthiophene:phenyl-C61–butyric acid methyl ester (P3HT:PCBM) as the active layer and poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) as the top electrode, along with a flat bed screen printed silver grid. The power conversion efficiency (PCE) obtained for large area devices (6 cm2) was 1.84%, 0.79% and 1.72%, respectively, for thermally imprinted, inkjet and flexographic silver grids, tested outside under the real sun. Central to all three approaches was that they employed environmentally friendly solvents, i.e. water based nanoparticle silver inks.

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Journal: Nanoscale
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 7.46 SJR 2.789 SNIP 1.441
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.77 SNIP 1.542 CiteScore 7.97
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 2.646 SNIP 1.649 CiteScore 7.64
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Scopus rating (2013): SJR 2.558 SNIP 1.467 CiteScore 6.89
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.769 SNIP 1.349 CiteScore 6.08
Stability and Degradation of Organic and Polymer Solar Cells

Organic photovoltaics (OPV) are a new generation of solar cells with the potential to offer very short energy pay back times, mechanical flexibility and significantly lower production costs compared to traditional crystalline photovoltaic systems. A weakness of OPV is their comparative instability during operation and this is a critical area of research towards the successful development and commercialization of these 3rd generation solar cells.

Covering both small molecule and polymer solar cells, Stability and Degradation of Organic and Polymer Solar Cells summarizes the state of the art understanding of stability and provides a detailed analysis of the mechanisms by which degradation occurs. Following an introductory chapter which compares different photovoltaic technologies, the book focuses on OPV degradation, discussing the origin and characterization of the instability and describing measures for extending the duration of operation.

Stability and degradation of organic photovoltaics fabricated, aged, and characterized by the ISOS 3 inter-laboratory collaboration

Seven distinct sets (n > 12) of state of the art organic photovoltaic devices were prepared by leading research laboratories in a collaboration planned at the Third International Summit on Organic Photovoltaic Stability (ISOS-3). All devices were shipped to DTU and characterized simultaneously up to 1830 h in accordance with established ISOS-3 protocols under three distinct illumination conditions: accelerated full sun simulation; low level indoor fluorescent lighting; and dark storage with daily measurement under full sun simulation. Three nominally identical devices were used in each experiment both to provide an assessment of the homogeneity of the samples and to distribute samples for a variety of post soaking analytical measurements at six distinct laboratories enabling comparison at various stages in the degradation of the devices. Characterization includes current-voltage curves, light beam induced current (LBIC) imaging, dark lock-in thermography (DLIT), photoluminescence (PL), electroluminescence (EL), isu incident photon-to-electron conversion efficiency (IPCE), time of flight secondary ion mass spectrometry (TOF-SIMS), cross sectional electron microscopy (SEM), UV visible spectroscopy, fluorescence microscopy, and atomic force microscopy (AFM). Over 100 devices with more than 300 cells were used in the study. We present here design of the device sets, results both on individual devices and uniformity of device sets from the wide range of characterization methods applied at different stages of aging under the three illumination conditions. We will discuss how these data can help elucidate the degradation mechanisms as well as the benefits and challenges associated with the unprecedented size of the collaboration.
Stability and degradation of organic photovoltaics fabricated, aged, and characterized by the ISOS 3 inter-laboratory collaboration

Stability of Polymer Solar Cells
Organic photovoltaics (OPVs) evolve in an exponential manner in the two key areas of efficiency and stability. The power conversion efficiency (PCE) has in the last decade been increased by almost a factor of ten approaching 10%. A main concern has been the stability that was previously measured in minutes, but can now, in favorable circumstances, exceed many thousands of hours. This astonishing achievement is the subject of this article, which reviews the developments in stability/degradation of OPVs in the last five years. This progress has been gained by several developments, such as inverted device structures of the bulk heterojunction geometry device, which allows for more stable metal electrodes, the choice of more photostable active materials, the introduction of interfacial layers, and roll-to-roll fabrication, which promises fast and cheap production methods while creating its own challenges in terms of stability.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis
Authors: Jørgensen, M. (Intern), Norman, K. (Intern), Gevorgyan, S. (Intern), Tromholt, T. (Intern), Andreasen, B. (Intern), Krebs, F. C. (Intern)
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Web of Science (2015): Indexed yes
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Scopus rating (2014): CiteScore 16.79
Web of Science (2014): Indexed yes
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Scopus rating (2013): CiteScore 15.78
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Degradation, Organic solar cells, Polymer solar cells, Stability

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Relations
Projects:
Stability of Polymer Solar Cells
Stability of Polymer Solar Cells
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Status and perspectives in R&D in PV

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Synthesis and properties of poly(aryl sulfone benzimidazole) and its copolymers for high temperature membrane electrolytes for fuel cells
Poly(aryl sulfone benzimidazole) (SO2PBI) and its copolymers with poly[2,2’-p-(phenylene)-5,5’-bibenzimidazole] (pPBI), termed as Co-SO2PBI, were synthesized with varied feeding ratios of 4,4’-sulfonyldibenzoic acid (SDBA) to terephthalic acid (TPA). Incorporation of the stiff para-phenylene and flexible aryl sulfone linkages in the macromolecular structures resulted in high molecular weight copolymers with good solubility. The chemical stability towards radical oxidation was improved for SO2PBI and its copolymer membranes due to the electron-withdrawing sulfone functional groups. Upon acid doping, the membrane swelling was reduced and the mechanical strength was improved, as compared with their meta structured analogues. At an acid doping level of 11 mol H3PO4 per average molar repeat unit, the Co-20%SO2PBI
membrane exhibited a tensile strength of 16 MPa at room temperature and an H2-air fuel cell peak power density of 346 mW cm−2 at 180 °C at ambient pressure. Durability tests with the membrane under a constant current density of 300 mA cm−2 at 160 °C showed a degradation rate of 6.4 μV h−1 during a period of 2400 h, which was significantly lower than that for meta PBI membranes with a similar acid doping level.

**General information**

State: Published
Organisations: Department of Energy Conversion and Storage, Proton conductors, Energy and Materials, Functional organic materials, Department of Chemistry, Newcastle University, Northeastern University
Authors: Yang, J. (Intern), Li, Q. (Intern), Cleemann, L. N. (Intern), Xu, C. (Ekstern), Jensen, J. O. (Intern), Pan, C. (Intern), Bjerrum, N. (Intern), He, R. (Ekstern)
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Main Research Area: Technical/natural sciences

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ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
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10.1039/c2jm30217a
Source: dtu
Source-ID: n:oat:DTIC-ART:rsc/365036746::16562
Publication: Research - peer-review › Journal article – Annual report year: 2012

**The Different PV Technologies and How They Degrade**

**General information**

State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Krebs, F. C. (Intern)
Pages: 1-16
Publication date: 2012
The role of fuel cells and electrolysers in future efficient energy systems

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Mixed Conductors, Functional organic materials, Management, Aalborg University
Authors: Hendriksen, P. V. (Intern), Vad Mathiesen, B. (Ekstern), Pedersen, A. S. (Intern), Linderoth, S. (Intern)
Pages: 95-101
Publication date: 2012

Host publication information
Title of host publication: DTU International Energy Report 2012: Energy efficiency improvements: A key element in the global transition to non-fossil energy
Publisher: Technical University of Denmark (DTU)
ISBN (Print): 978-87-550-3965-0
Main Research Area: Technical/natural sciences
Electronic versions:
Publication: Research - peer-review › Report chapter – Annual report year: 2012

The use of polyurethane as encapsulating method for polymer solar cells—An inter laboratory study on outdoor stability in 8 countries

A new encapsulation method for organic solar cells has been tested on flexible solar modules and cells embedded in polyurethane, sandwiched between a tempered glass plate and a polycarbonate plate. Panels, each containing 10 organic solar modules/cells, were fabricated and installed for outdoor exposure in eight different countries for 4½ months. In order to minimize potential deviations in procedures and equipment, one person was responsible for the fabrication, installation and initial and final IV-measurements of the panels using the same equipment for all measurements and calibrations. The encapsulated modules/cells showed significantly reduced degradation compared with previous studies, with final average efficiencies around 40% of the original after 4½ months outdoor exposure. Photodegradation was furthermore found not to be the primary source of degradation.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Fraunhofer Gesellschaft, University of Patras, Ben-Gurion University of the Negev, Imperial College London, Energy Research Centre of the Netherlands, Centre d’Investigació en Nanociència i Nanotecnologia, University of Freiburg
Pages: 292-300
Publication date: 2012
Main Research Area: Technical/natural sciences
Encapsulation, Polyurethane, Organic solar cells, Outdoor stability study, Round robin, Inter laboratory study (ILS)

DOIs:

Bibliographical note
This work was supported by:
– The Danish Strategic Research Council (DSF2104-07-0022) and EUDP (64009-0050 and 64011-0002).
Relations
Projects:
The use of polyurethane as encapsulating method for polymer solar cells—An inter laboratory study on outdoor stability in 8 countries

Source: dtu
Source-ID: n:oai:DTIC-ART:elsevier/319942087::15152
Publication: Research - peer-review › Journal article – Annual report year: 2012

TOF-SIMS investigation of degradation pathways occurring in a variety of organic photovoltaic devices – the ISOS-3 Inter-laboratory collaboration

The present work is the fourth (and final) contribution to an inter-laboratory collaboration that was planned at the 3rd International Summit on Organic Photovoltaic Stability (ISOS-3). The collaboration involved six laboratories capable of producing seven distinct sets of OPV devices that were degraded under well-defined conditions in accordance with the ISOS-3 protocols. The degradation experiments lasted up to 1830 hours and involved more than 300 cells on more than 100 devices. The devices were analyzed and characterized at different points of their lifetimes by a large number of non-destructive and destructive techniques in order to identify specific degradation mechanisms responsible for the deterioration of the photovoltaic response. Work presented herein involves time-of-flight secondary ion mass spectrometry (TOF-SIMS) in order to study chemical degradation in-plane as well as in-depth in the organic solar cells. Various degradation mechanisms were investigated and correlated with cell performance. For example, photo-oxidation of the active material was quantitatively studied as a function of cell performance. The large variety of cell architectures used (some with and some without encapsulation) enabled valuable comparisons and important conclusions to be drawn on degradation behaviour. This comprehensive investigation of OPV stability has significantly advanced the understanding of degradation behaviour in OPV devices, which is an important step towards large scale application of organic solar cells.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials, Imaging and Structural Analysis, Centre d'Investigació en Nanociència i Nanotecnologia, Dresden University of Technology, Katholieke Universiteit, National Renewable Energy Laboratory, Holst Center, Fraunhofer Gesellschaft, IMEC, Ilmenau University of Technology, Clermont Université, French National Centre for Scientific Research, Brookhaven National Laboratory, Hasselt University
Pages: 11780-11799
Publication date: 2012
Main Research Area: Technical/natural sciences
Publication information
Journal: Physical Chemistry Chemical Physics
Volume: 14
Issue number: 33
ISSN (Print): 1463-9076
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 1.089 SJR 1.686
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.06 SJR 1.685 SNIP 1.113
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.725 SNIP 1.205 CiteScore 4.45
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.771 SNIP 1.239 CiteScore 4.29
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.72 SNIP 1.207 CiteScore 4.05
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.921 SNIP 1.177 CiteScore 3.67
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.707 SNIP 1.19 CiteScore 3.6
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.817 SNIP 1.199
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.147 SNIP 1.364
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.166 SNIP 1.198
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.845 SNIP 1.123
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.477 SNIP 1.118
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.423 SNIP 1.1
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.191 SNIP 1.012
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.146 SNIP 0.929
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.634 SNIP 0.967
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 1.13 SNIP 1.115
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.948 SNIP 1.079
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 0.121 SNIP 0

Original language: English

Electronic versions:
prod11343859269934.pdf
DOIs:
10.1039/c2cp41787a

Bibliographical note
This work has been supported by the Danish Strategic Research Council (2104-07-0022), EUDP (j.no. 64009-0050, 64009-0051) and the Danish National Research Foundation. Partial financial support was also received from the European
Polymers for organic photovoltaics based on 1,5-bis(2-hexyldecyloxy)-naphthalene, thiophene, and benzothiadiazole

Two new conjugated polymers consisting of the donors 1,5-bis(2-hexyldecyloxy)naphthalene, thiophene, or bithiophene and the acceptor benzothiadiazole has been synthesized and their optical and photovoltaic properties have been characterized. The two polymers were compared with earlier synthesized and characterized polymers containing benzene instead of naphthalene. The two polymers absorb light in the visible spectrum (400 to 700 nm). The naphthalene containing polymers had blueshifted absorption spectra compared to the benzene containing polymers and also higher band gaps. In photovoltaic devices the bithiophene containing polymer gave the best efficiency of 0.6%, whereas the single thiophene only showed efficiency of 0.005%. This is lower than the best benzene incorporated polymer that showed efficiency up to 2.2%.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Carlé, J. E. (Intern), Jørgensen, M. (Intern), Krebs, F. C. (Intern)
Number of pages: 11
Pages: 011111
Publication date: 2011
Main Research Area: Technical/natural sciences

Publication information
Journal: Photonics for Energy and the Environment
Volume: 1
Issue number: 1
ISSN (Print): 1947-7988
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed Yes
Scopus rating (2016): CiteScore 1.8
Scopus rating (2015): CiteScore 1.2
Web of Science (2015): Indexed yes
Scopus rating (2014): CiteScore 1.28
Refined life-cycle assessment of polymer solar cells

A refined life-cycle assessment of polymer solar cells is presented with a focus on critical components, i.e. the transparent conductive ITO layer and the encapsulation components. This present analysis gives a comprehensive sketch of the full environmental potential of polymer-OPV in comparison with other PV technologies. It is shown that on a m² basis the environmental characteristics of polymer-OPV are highly beneficial, while on a watt-peak and on a kWh basis, these benefits are - at the current level of the development - still (over-)compensated by low module efficiency and limited lifetime expectancy. The findings of this study underscore that, from an environmental and sustainability point of view, the replacement of the ITO layer and the optimization of encapsulation concepts should be in the spotlight of any near-term R&D efforts of the OPV community. Solutions to both of these technological issues are actively pursued. Some of these are discussed as examples in this paper.
Study of the behaviour of YSZ dispersions in water

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Ceramic Engineering & Science, Imaging and Structural Analysis, Functional organic materials
Number of pages: 1
Publication date: 2011
Main Research Area: Technical/natural sciences
Electronic versions:
STUDY_OF_THE_BEHAVIOUR.pdf
Source: dtu
Source-ID: u::4380
Publication: Research › Poster – Annual report year: 2012

Fabrication and Processing of Polymer and Organic Solar Cells

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Krebs, F. C. (Intern), Lauritzen, H. (Intern)
Number of pages: 36
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: dtu
Source-ID: u::6438
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Polymer Solar Cells

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Functional organic materials
Authors: Lauritzen, H. (Intern)
Number of pages: 42
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: dtu
Source-ID: u::6439
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Integration of organic based Schottky junctions into crossbar arrays by standard UV lithography

The integration of polymers into microelectronic devices is a challenging task, because the standard processes used in device fabrication, most notably photolithography, are not fully compatible with such materials. In this study, we demonstrate a possible route for the integration of micron size organic based Schottky diodes in a crossbar architecture, by standard UV lithography. The proposed integration route features a limited number of process steps and prevents the exposure of the active materials to UV. This approach was developed using poly(3-hexylthiophene) as a model compound and was successfully applied to different organic semiconductors. The electrical characteristics of the as prepared
junctions reveal the successful patterning and demonstrate the compatibility of the process sequence steps with the organic materials.

**General information**

**State:** Published

**Organisations:** Department of Energy Conversion and Storage, Functional organic materials, Risø National Laboratory for Sustainable Energy, Solar Energy Programme, Laboratorio Nazionale MDM

**Authors:** Katsia, E. (Ekstern), Tallarida, G. (Ekstern), Kutrzeba-Kotowska, B. (Ekstern), Ferrari, S. (Ekstern), Bundgaard, E. (Intern), Sandergaard, R. (Intern), Krebs, F. C. (Intern)

**Pages:** 1044-1050

**Publication date:** 2008

**Main Research Area:** Technical/natural sciences

**Publication information**

**Journal:** Organic Electronics

**Volume:** 9

**Issue number:** 6

**ISSN (Print):** 1566-1199

**Ratings:**

BFI (2018): BFI-level 2

Web of Science (2018): Indexed Yes

BFI (2017): BFI-level 2

Scopus rating (2017): SNIP 0.884 SJR 1.085

Web of Science (2017): Indexed Yes

BFI (2016): BFI-level 2

Scopus rating (2016): CiteScore 3.4 SJR 1.081 SNIP 0.944

BFI (2015): BFI-level 2

Scopus rating (2015): SJR 1.135 SNIP 1.082 CiteScore 3.6

BFI (2014): BFI-level 2

Scopus rating (2014): SJR 1.346 SNIP 1.188 CiteScore 3.85

Web of Science (2014): Indexed yes

BFI (2013): BFI-level 2

Scopus rating (2013): SJR 1.456 SNIP 1.268 CiteScore 3.94

ISI indexed (2013): ISI indexed yes

Web of Science (2013): Indexed yes

BFI (2012): BFI-level 2

Scopus rating (2012): SJR 1.955 SNIP 1.458 CiteScore 4.25

ISI indexed (2012): ISI indexed yes

BFI (2011): BFI-level 2

Scopus rating (2011): SJR 1.941 SNIP 1.466 CiteScore 4.09

ISI indexed (2011): ISI indexed yes

Web of Science (2011): Indexed yes

BFI (2010): BFI-level 2

Scopus rating (2010): SJR 2.028 SNIP 1.395

BFI (2009): BFI-level 1

Scopus rating (2009): SJR 2.046 SNIP 1.268

Web of Science (2009): Indexed yes

BFI (2008): BFI-level 1

Scopus rating (2008): SJR 2.217 SNIP 1.452

Web of Science (2008): Indexed yes

Scopus rating (2007): SJR 2.251 SNIP 1.275

Web of Science (2007): Indexed yes

Scopus rating (2006): SJR 2.704 SNIP 1.868

Scopus rating (2005): SJR 1.81 SNIP 1.2

Scopus rating (2004): SJR 2.968 SNIP 2.078

Web of Science (2004): Indexed yes

Scopus rating (2003): SJR 2.382 SNIP 1.634
Synthesis and structural properties of 5,17-bis (N-methyl-N-arylaminocarbonyl)calix[4]arenes. Directing the substituents toward the cavity by use of the cis-generating property of the N-methylaminocarbonyl linker

A series of cone 5,17-bis(N-arylaminocarbonyl)calix[4]arenes were synthesized and N-methylated using an easy and high-yielding methylation procedure. The structures of the cone 5,17-bis(Nmethyl-N-arylaminocarbonyl)calix[4]arenes were studied in solution by NMR spectroscopy and in the solid state by X-ray structural resolution. The use of the N-methylaminocarbonyl linker between the calix[4]arene and the aromatic substituent was found to have a dominant influence on the molecular structure, forcing the substituent toward the cavity of the calix[4]arene regardless of the size of the substituent. The linker may be a very useful structure generator when considering the design of molecular receptors.

General information
State: Published
Organisations: Solar Energy Programme, Risø National Laboratory for Sustainable Energy, Department of Energy Conversion and Storage, Functional organic materials, Department of Chemistry, University of Copenhagen
Authors: Krebs, F. C. (Intern), Larsen, M. (Intern), Jørgensen, M. (Intern), Jensen, P. R. (Intern), Bielecki, M. (Ekstern), Schaumburg, K. (Ekstern)
Pages: 9872-9879
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Organic Chemistry
Volume: 63
ISSN (Print): 0022-3263
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): SNIP 0.997 SJR 1.846
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.59 SJR 2.001 SNIP 1.035
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.997 SNIP 1.166 CiteScore 4.69
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.007 SNIP 1.219 CiteScore 4.69
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.092 SNIP 1.169 CiteScore 4.51
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.286 SNIP 1.223 CiteScore 4.31
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 2.265 SNIP 1.239 CiteScore 4.43
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.127 SNIP 1.169
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.198 SNIP 1.251
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.349 SNIP 1.217
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.249 SNIP 1.296
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.03 SNIP 1.284
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.956 SNIP 1.299
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.912 SNIP 1.333
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.188 SNIP 1.417
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.048 SNIP 1.36
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.024 SNIP 1.342
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 1.943 SNIP 1.339
Original language: English
DOIs:
10.1021/jo981649d
Source: orbit
Source-ID: 299013
Publication: Research - peer-review › Journal article – Annual report year: 1999

Projects:

**DronEL**
The purpose of this project is to develop and bring to market an aerial drone based automated solution (DronEL) used for a full PV plant survey for more accurate survey in less time. The automatic drone-based inspection method combines IR, EL and PL imaging, and visual images.

Department of Photonics Engineering
Diode Lasers and LED Systems
Coding and Visual Communication
Centre of Excellence for Silicon Photonics for Optical Communications
Department of Energy Conversion and Storage
Organic Energy Materials
Aalborg University
Sky Watch
SiCon
Kenergy
Skive Kommune
Period: 01/01/2017 → 31/12/2019
Number of participants: 8
Project ID: 71001
Project participant:
Thorsteinsson, Sune (Intern)
Forchhammer, Søren (Intern)
Benatto, Gisele Alves dos Reis (Intern)
Riedel, Nicholas (Intern)
Thorseth, Anders (Intern)
Dam-Hansen, Carsten (Intern)
Mantel, Claire (Intern)
Project Manager, organisational:
Poulsen, Peter Behrensdorff (Intern)

Relations
Related projects:
- PV LED ENGINE
- PV BALCONY FENCE – a highly esthetic cost efficient PV integrated balcony

Activities:
- 7th International SpectroRadiometer Comparison (ISRC 2017)
- Activities in the standardisation of light sources and spectroradiometer calibration
- Outdoor Electroluminescence Acquisition Using a Movable Testbed

Publications:
- Optimizing sensitivity of Unmanned Aerial System optical sensors for low zenith angles and cloudy conditions
- Development of outdoor luminescence imaging for drone-based PV array inspection
- New Light Source Setup for Angle Resolved Light Absorption measurement of PV sample
- Indoor measurement of angle resolved light absorption by antireflective glass in solar panels
- Luminescence Imaging Strategies for Drone-Based PV Array Inspection
- Quantification of solar cell failure signatures based on statistical analysis of electroluminescence images
- New dental applications with LEDs

Cost and energy effective all-black solar cell panel | Black Si BIPV | Phase 2
The objective of the EUDP project is to develop and manufacture a novel type of solar panel based on a new type of solar cell (black silicon solar cell), which – apart from a high and preferably improved efficiency and an implementable and cheaper production method – should have several significant advantages in terms of building integration. The black solar cells will be further processed to make the front conducting grid completely black through an electrochemical deposition technology. The tabbing wires interconnecting the cells in the panel will be processed into non-reflecting black strings in a scalable, inorganic electrochemical process step securing a completely black appearance of the solar panel later produced. A compatible panel production process with traditional PV panel process will be demonstrated for the total black silicon BIPV module.

Department of Photonics Engineering
Diode Lasers and LED Systems
Department of Micro- and Nanotechnology
Silicon Microtechnology
Experimental Surface and Nanomaterials Physics
Department of Energy Conversion and Storage
Organic Energy Materials
Gaia Solar A/S
Institute for Product Development
SoliTek
High Current All Printed Transistors
The fast evolution of printed electronics, with the photovoltaic technology in primis, is requiring the presence of a valid transistor alternative to the traditional one. The realization of a high current roll-to-roll transistor will interconnect all the different technologies so far developed with this low cost and high throughput method. Our aim is to develop a roll-to-roll transistor capable to of modulate modulating the current to levels that where has not been achieved so far. The fabrication of the transistor will be done considering the lowest environmental impact possible, and containing energy consumption with a temperature below 150 °C. This high current (~mA) transistor will be able to support and assist other technologies and will also be the base for logics and sensing application.

The optical studies on the organic material will result in a more controllable production process that for the first time will relate polymer crystallinity directly with an optical characterization technique. The realization of such kind of measurements is not trivial, but will give information on polymer nanoscale structures never investigated before. To do so this technique uses femtosecond pulse in subdiffraction-limited area. This will disclose an unprecedented tool to control the polymer morphology as soon as it is deposited, with enormous consequences in performance control and optimization.

The realization of samples and the study of real cases will produce important information regarding this new technology and its real life applications. In addition, life-time and stability studies can be performed. Then the objective of minimizing the environmental impact of the technology life time cycle will be more realistic. These kinds of studies are also important to explain science to the society and to give a technology preview to industries.
**SMARTONICS FP7**
The target of the Smartonics project is the development of Pilot lines that will combine smart technologies with smart nanomaterials for the precision synthesis of Organic Electronic (OE) devices

Department of Energy Conversion and Storage

**Functional organic materials**
**Period:** 01/01/2013 → 01/08/2014
**Number of participants:** 1

Project participant:
Beliatis, Michail (Intern)

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**Hybrid metal-graphene nanostructured materials for innovative plasmonic electrodes**

Department of Energy Conversion and Storage

**Functional organic materials**
**Period:** 01/03/2012 → 01/03/2014
**Number of participants:** 1

Acronym: **UK EPSRC Postdoctoral Prize Fellowship**

Project participant:
Beliatis, Michail (Intern)

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**Solar Hydrogen Fuel Production Station**

Department of Energy Conversion and Storage

**Functional organic materials**
**Period:** 31/10/2011 → 01/09/2012
**Number of participants:** 1

Acronym: **UK Knowledge Transfer Account (KTA)**

Project participant:
Beliatis, Michail (Intern)

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**Adiabatic Liquid Piston Compressed Air Energy Storage**

Traditional Compressed Air Energy Storage (CAES) is seen as one of the most cost effective technologies for the bulk energy storage in the future flexible grid. The project will investigate the possible lift of the round trip efficiency by the introduction of Adiabatic Liquid Piston CAES (ALP-CAES) which is expected to be highly competitive.

Department of Mechanical Engineering

Energy Engineering

Thermal Energy

Risø National Laboratory for Sustainable Energy

Secretariat, IT

Department of Energy Conversion and Storage

Materials Research Division

Nano-Microstructures in Materials

Administration Department

**Functional organic materials**
**Period:** 01/03/2011 → …
**Number of participants:** 6
Large-area Organic and Hybrid Solar Cells
Department of Energy Conversion and Storage

Functional organic materials
Period: 01/09/2010 → 31/08/2014
Number of participants: 2
Acronym: Largecells
Project participant:
Krebs, Frederik C (Intern)
Søndergaard, Roar R. (Intern)

Relations
Publications:
Reversible degradation of inverted organic solar cells by concentrated sunlight
The use of polyurethane as encapsulating method for polymer solar cells—An inter laboratory study on outdoor stability in 8 countries
Interlaboratory outdoor stability studies of flexible roll-to-roll coated organic photovoltaic modules: Stability over 10,000 h
Roll-to-roll fabrication of polymer solar cells
Electrical and Photo-Induced Degradation of ZnO Layers in Organic Photovoltaics
Origin of size effect on efficiency of organic photovoltaics
Scalability and stability of very thin roll-to-roll processed large area indium-tin-oxide free polymer solar cell modules
The OE-A OPV demonstrator anno domini 2011
Solar cells with one-day energy payback for the factories of the future
Large-scale roll-to-roll photonic sintering of flexo printed silver nanoparticle electrodes
The ISOS-3 inter-laboratory collaboration focused on the stability of a variety of organic photovoltaic devices
Investigation of the degradation mechanisms of a variety of organic photovoltaic devices by combination of imaging techniques—the ISOS-3 inter-laboratory collaboration
Rapid flash annealing of thermally reactive copolymers in a roll-to-roll process for polymer solar cells
TOF-SIMS investigation of degradation pathways occurring in a variety of organic photovoltaic devices – the ISOS-3 inter-laboratory collaboration
Roll-to-Roll fabrication of large area functional materials
Polymer and organic solar cells viewed as thin film technologies: What it will take for them to become a success outside academia
On the stability of a variety of organic photovoltaic devices by IPCE and in situ IPCE analyses – the ISOS-3 inter-laboratory collaboration
Enhancing functionality of ZnO hole blocking layer in organic photovoltaics
Comparison of UV-Curing, Hotmelt, and Pressure Sensitive Adhesive as Roll-to-Roll Encapsulation Methods for Polymer Solar Cells
All solution processing of ITO-free organic solar cell modules directly on barrier foil
A rational method for developing and testing stable flexible indium- and vacuum-free multilayer tandem polymer solar cells comprising up to twelve roll processed layers
Economic assessment of solar electricity production from organic-based photovoltaic modules in a domestic environment
Stability of Polymer Solar Cells
Slot-die Coating of a High Performance Copolymer in a Readily Scalable Roll Process for Polymer Solar Cells
Comparison of Fast Roll-to-Roll Flexographic, Inkjet, Flatbed, and Rotary Screen Printing of Metal Back Electrodes for Polymer Solar Cells

Danish-Chinese Center for Organic based Photovoltaic Cells with Morphology Control

Department of Energy Conversion and Storage

Functional organic materials

Imaging and Structural Analysis
Period: 31/08/2010 → 31/08/2016
Number of participants: 12
Number of related Ph.D. students: 1
Project participant:
- Oksbjerg, Birgit (Intern)
- Trofod, Thue (Intern)
- Bundgaard, Eva (Intern)
- Andreasen, Jens Wenzel (Intern)
- Norman, Kion (Intern)
- Krebs, Frederik C (Intern)
- Zawacka, Natalia Klaudia (Intern)
- Jørgensen, Mikkel (Intern)
- Angmo, Dechan (Intern)
- Andersen, Thomas Rieks (Intern)
- Bentzen, Janet Jonna (Intern)
- Rossander, Lea Hildebrandt (Intern)

Relations
Activities:
High resolution ptychographic tomography of soft matter

Publications:
- Spatial degradation mapping and componentwise degradation tracking in polymer-fullerene blends
- Scalable, ambient atmosphere roll-to-roll manufacture of encapsulated large area, flexible organic tandem solar cell modules
- In situ monitoring of structure formation in the active layer of polymer solar cells during roll-to-roll coating
- The influence of additives on the morphology and stability of roll-to-roll processed polymer solar cells studied through ex situ and in situ X-ray scattering
- Enabling Flexible Polymer Tandem Solar Cells by 3D Ptychographic Imaging
- All-Solution-Processed, Ambient Method for ITO-Free, Roll-Coated Tandem Polymer Solar Cells using Solution-Processed Metal Films
- Medium area, flexible single and tandem junction solar cells based on roll coated semi-random copolymers
- Roll-coating fabrication of flexible large area small molecule solar cells with power conversion efficiency exceeding 1%
- Comparison of additive amount used in spin-coated and roll-coated organic solar cells

Polymer Solar Cells for Solar Energy Conversion
DSF sagsnr.: 2104-07-0022, DTU projektnr.: 48010

Department of Energy Conversion and Storage

Functional organic materials
Period: 01/01/2008 → 31/12/2013
Number of participants: 1
Project Manager, academic:
- Krebs, Frederik C (Intern)

Relations
Publications:
Thermally reactive Thiazolo[5,4-d]thiazole based copolymers for high photochemical stability in polymer solar cells
Advanced Functional Polymers for Increasing the Stability of Organic Photovoltaics
Concentrated Light for Accelerated Photo Degradation of Polymer Materials
Non-destructive lateral mapping of the thickness of the photoactive layer in polymer-based solar cells
Aesthetically Pleasing Conjugated Polymer: Fullerene Blends for Blue-Green Solar Cells Via Roll-to-Roll Processing
Ambient fabrication of flexible and large-area organic light-emitting devices using slot-die coating
Application of optical coherence tomography (OCT) as a 3-dimensional imaging technique for roll-to-roll coated polymer solar cells
Comparative studies of photochemical cross-linking methods for stabilizing the bulk hetero-junction morphology in polymer solar cells
Enhancing functionality of ZnO hole blocking layer in organic photovoltaics
Exciton diffusion length in some thermocleavable polythiophenes by the surface photovoltage method
Influence of processing and intrinsic polymer parameters on photochemical stability of polythiophene thin films
Investigation of the degradation mechanisms of a variety of organic photovoltaic devices by combination of imaging techniques—the ISOS-3 inter-laboratory collaboration
Large-scale roll-to-roll photonic sintering of flexo printed silver nanoparticle electrodes
Low-temperature side-chain cleavage and decarboxylation of polythiophene esters by acid catalysis
New Low-Bandgap Materials with Good Stabilities and Efficiencies Comparable to P3HT in R2R-Coated Solar Cells
On the stability of a variety of organic photovoltaic devices by IPCE and in situ IPCE analyses – the ISOS-3 inter-laboratory collaboration
Photochemical stability of conjugated polymers, electron acceptors and blends for polymer solar cells resolved in terms of film thickness and absorbance
Roll-to-roll fabrication of polymer solar cells
Solar cells with one-day energy payback for the factories of the future
Stability of Polymer Solar Cells
The ISOS-3 inter-laboratory collaboration focused on the stability of a variety of organic photovoltaic devices
The use of polyurethane as encapsulating method for polymer solar cells—An inter laboratory study on outdoor stability in 8 countries
TOF-SIMS investigation of degradation pathways occurring in a variety of organic photovoltaic devices – the ISOS-3 inter-laboratory collaboration
A compact multi-chamber setup for degradation and lifetime studies of organic solar cells
A life cycle analysis of polymer solar cell modules prepared using roll-to-roll methods under ambient conditions
An inter-laboratory stability study of roll-to-roll coated flexible polymer solar modules
A self-calibrating led-based solar test platform
A solution process for inverted tandem solar cells
Consensus stability testing protocols for organic photovoltaic materials and devices
Degradation of semiconducting polymers by concentrated sunlight
Economic assessment of solar electricity production from organic-based photovoltaic modules in a domestic environment
Electrical and Photo-Induced Degradation of ZnO Layers in Organic Photovoltaics
Ellipsometry as a Nondestructive Depth Profiling Tool for Roll-to-Roll Manufactured Flexible Solar Cells
Fabrication of Polymer Solar Cells Using Aqueous Processing for All Layers Including the Metal Back Electrode
Fused thiophene/quinoxaline low band gap polymers for photovoltaic's with increased photochemical stability
Life-cycle analysis of product integrated polymer solar cells
Origin of size effect on efficiency of organic photovoltaics
Oxygen- and water-induced degradation of an inverted polymer solar cell: the barrier effect
Photochemical stability and photovoltaic performance of low-band gap polymers based on dithiophene with different bridging atoms
Polymers for organic photovoltaics based on 1,5-bis(2-hexydecyloxy)-naphthalene, thiophene, and benzothiadiazole
Business, market and intellectual property analysis of polymer solar cells
Water and oxygen induced degradation of small molecule organic solar cells
Roll-to-Roll Processing of Inverted Polymer Solar Cells using Hydrated Vanadium(V)Oxide as a PEDOT:PSS Replacement
Printed metal back electrodes for R2R fabricated polymer solar cells studied using the LBIC technique
Degradation Patterns in Water and Oxygen of an Inverted Polymer Solar Cell
Influence of the Annealing Temperature on the Photovoltaic Performance and Film Morphology Applying Novel Thermocleavable Materials
Low band gap polymers based on 1,4-dialkoxybenzene, thiophene, bithiophene donors and the benzothiadiazole acceptor
Low Band Gap Polymers for Roll-to-Roll Coated Polymer Solar Cells
Manufacture, integration and demonstration of polymer solar cells in a lamp for the Lighting Africa initiative
Photovoltaic Performance of Polymers Based on Dithienylthienopyrazines Bearing Thermocleavable Benzoate Esters
Product integration of compact roll-to-roll processed polymer solar cell modules: methods and manufacture using flexographic printing, slot-die coating and rotary screen printing
The effect of post-processing treatments on inflection points in current–voltage curves of roll-to-roll processed polymer photovoltaics
Thermo-cleavable polymers: Materials with enhanced photochemical stability
The teraton challenge. A review of fixation and transformation of carbon dioxide
Ultra Fast and Parsimonious Materials Screening for Polymer Solar Cells Using Differentially Pumped Slot-Die Coating
Upscaling of polymer solar cell fabrication using full roll-to-roll processing
Using Light-Induced Thermocleavage in a Roll-to-Roll Process for Polymer Solar Cells
All solution roll-to-roll processed polymer solar cells free from indium-tin-oxide and vacuum coating steps
A roll-to-roll process to flexible polymer solar cells: model studies, manufacture and operational stability studies
A round robin study of flexible large-area roll-to-roll processed polymer solar cell modules
Fabrication and processing of polymer solar cells: A review of printing and coating techniques
"Hairy" Poly(3-hexylthiophene) Particles Prepared via Surface-Initiated Kumada Catalyst-Transfer Polycondensation
Investigation of optical spacer layers from solution based precursors for polymer solar cells using X-ray reflectometry
Pad printing as a film forming technique for polymer solar cells
Polymer solar cell modules prepared using roll-to-roll methods: Knife-over-edge coating, slot-die coating and screen printing
Roll-to-roll fabrication of monolithic large-area polymer solar cells free from indium-tin-oxide
Study of hybrid solar cells made of multilayer nanocrystalline titania and poly(3-octylthiophene) or poly-(3-(2-methylhex-2-yl)-oxy-carbonyldithiophene)
Thermocleavable Materials for Polymer Solar Cells with High Open Circuit Voltage-A Comparative Study
Thermo-cleavable solvents for printing conjugated polymers: Application in polymer solar cells
Water-Induced Degradation of Polymer Solar Cells Studied by (H2O)-O-18 Labeling
Air stable polymer photovoltaics based on a process free from vacuum steps and fullerenes
All solution processed tandem polymer solar cells based on thermocleavable materials
An explanation for the high stability of polycarboxythiophenes in photovoltaic devices—A solid-state NMR dipolar recoupling study
Applicability of X-ray reflectometry to studies of polymer solar cell degradation
A setup for studying stability and degradation of polymer solar cells
A simple nanostructured polymer/ZnO hybrid solar cell - preparation and operation in air
Biodegradable polymer solar cells
Bulk heterojunctions based on native polythiophene
Thermocleavable Low Band Gap Polymers and Solar Cells Therefrom with Remarkable Stability toward Oxygen
Structural and chemical investigation of CdSe crystals deposited in a nanoporous sol–gel: Effect of chemistry and defects on photovoltaic properties
Analysis of the failure mechanism for a stable organic photovoltaic during 10 000 h of testing
The OE-A OPV demonstrator anno domini 2011
Ultra high open circuit voltage (>1 V) of poly-3-hexylthiophene based organic solar cells with concentrated light
Polymer Solar Cells – Non Toxic Processing and Stable Polymer Photovoltaic Materials
Stability and Degradation of Organic and Polymer Solar Cells
Polymeric solar cells; materials, design, manufacture
Polymer photovoltaics: A practical approach
Organic solar cells
Characterization and Reporting of OPV Device Lifetime
Concentrated Light for Organic Photovoltaics
Degradation of Polymer-Based OPV
Polymersolceller
The Different PV Technologies and How They Degrade
Introduction
Manufacture
Market Analysis
Materials and Processing
Patent Overview of OPVs
Stability and Characterization of Devices
Technology Potential and Outlook
Introduction
Lifetime and stability studies
Outlook
Processing and production of large modules
The polymer solar cell
Photovoltaics efficiency improvements
Energy efficient Solid State Lighting
Solar energy
Combined Characterization Techniques to Understand the Stability of a Variety of Organic Photovoltaic Devices - the ISOS-3 inter-laboratory collaboration
Optical coherence tomography (OCT) as a 3-dimensional imaging technique for non-destructive testing of roll-to-roll coated polymer solar cells
Edge sealing for low cost stability enhancement of roll-to-roll processed flexible polymer solar cell modules
Interlayer adhesion in roll-to-roll processed flexible inverted polymer solar cells
Quality control of roll-to-roll processed polymer solar modules by complementary imaging methods
Simple roll coater with variable coating and temperature control for printed polymer solar cells
Stability and degradation of organic photovoltaics fabricated, aged, and characterized by the ISOS 3 inter-laboratory collaboration
Economical assessment of solar electricity from organic photovoltaic systems
Large area modules based on low band gap polymers
Polymer solar cells for solar energy conversion
Solar energy – new photovoltaic technologies
Improved adhesion of metal oxide layer
Improved electron transport layer
PROCESS OF ELECTRICAL CONNECTION OF PHOTOVOLTAIC DEVICES
Photovoltaic device
Air Stable Photovoltaic Device
Method of Testing Solar Cells
Method of Thermocleaving a Polymer Layer
Editorial for the special issue on ISOS-3 (Third International Summit on OPV Stability)
Video editorial for the special issue on ISOS-3 (3rd international summit on OPV stability)
Editorial for the special issue on EMRS-A
Editorial: Reporting solar cell efficiencies in Solar Energy Materials and Solar Cells
Solceller lavet af plast
Low band gap polymers for organic solar cells
Solar Test Platform

Activities:

Advanced Concepts in Photovoltaics
Period: 10 Oct 2017 → 13 Oct 2017
Peter Behrensdorff Poulsen (Organizer)
Description
Top Danish Researchers within photovoltaics was lecturing in this 4 day summer school along with Professor Peter Würfel, who is one of the international leading researchers within photovoltaics and author of the book Physics of Solar Cells: From Basic Principles to Advanced Concepts. The summer school was tailored towards PhD students within photovoltaics, but other interested in the program could join.
Degree of recognition: International

Related event
Advanced Concepts in Photovoltaics: A Summer School in Photovoltaics
10/10/2017 → 13/10/2017
Roskilde, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Description
For the conference we had assembled all the top researchers in Denmark within Photovoltaics to tell about their latest results. Furthermore, some of the highly innovative companies within photovoltaics in Denmark did elaborate on their newest achievements.
Degree of recognition: International

Related event
Progress in Photovoltaic Research in Denmark 2017: Conference i Photovoltaics
09/10/2017 → …
Roskilde, Denmark
Activity: Attending an event › Participating in or organising a conference

ISOS-8
Period: 1 Oct 2015
Michael Corazza (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Description
ISOS-8
Links:

Related event
ISOS-8
29/09/2015 → 01/10/2015
Rio de Janeiro, Brazil
Activity: Talks and presentations › Conference presentations
IN SITU SMALL ANGLE STUDIES OF ROLL-TO-ROLL COATED PEROVSKITE SOLAR CELLS
Period: 14 Sep 2015
Lea Hildebrandt Rossander (Speaker)
Department of Energy Conversion and Storage
Organic Energy Materials

Related event
16th Conference on Small Angle Scattering (SAS 2015)
13/09/2015 → 18/09/2015
Berlin, Germany
Activity: Talks and presentations › Conference presentations

In situ GISAXS/GIWAXS studies of roll-to-roll coated perovskite solar cells
Period: 10 Sep 2015
Lea Hildebrandt Rossander (Speaker)
Department of Energy Conversion and Storage
Organic Energy Materials

Related event
GISAS2015: 3rd International GISAS Conference
08/09/2015 → …
Nice, France
Activity: Talks and presentations › Conference presentations

Optical antennas, optical cavity and photonic crystals to enhance the performance of organic solar cells
Period: 2014
Francesco Pastorelli (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Related event
E-MRS 2014 Spring Meeting
25/05/2014 → 30/05/2014
Lille, France
Activity: Talks and presentations › Conference presentations

Semitransparent Organic Solar Cell toward Opaque Performances
Period: 2014 → …
Francesco Pastorelli (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Related event
2014 MRS Spring Meeting
21/04/2014 → 25/04/2014
San Francisco, United States
Activity: Talks and presentations › Conference presentations

Scalable Roll-to-Roll Fabrication for Fully Solution-Processed Polymer Solar Cells from Small-Scale Test Devices to Multi Square Meter Large Modules for Energy Production
Period: 3 Dec 2014
Description
The majority of lab-scale organic and polymer solar cells (OPV) are very small with <<0.5 cm² using ITO glass, spin coating, evaporation, inert atmosphere, and optimum conditions. Obviously, the cells can lead to record efficiencies - but they are far beyond real world applications due to miniscule power output. Transfer to large-scale devices with an appropriate power output is hardly possible.

Here, we present the route from roll and roll-to-roll processed test devices to multi square meter large polymer solar cell modules with hundreds of Watts output - fully roll-to-roll (R2R) produced under vacuum-free and ambient conditions without using indium tin oxide (ITO) as transparent conductive electrode. ITO has the highest impact on the embodied energy in OPV devices and is replaced by an all additive printed and coated electrode based on flexo printed silver grid, rotary screen printed PEDOT:PSS, and slot-die coated zinc oxide (Flextrode). The production speed for each layer is beyond 10 m/min independently of the individual layout for different devices.

Model cells with at least 1 cm² are fabricated on a rollcoater, which allows easy transfer to the R2R line for larger test modules with e.g. 8 serially connected cells and the size of a postcard (freeOPV, active area >50 cm²). Both routes allow the testing of new polymers, functional inks, and device structures such as tandem stacks with minimum amount of material input but large number of devices for statistical analyses.

Finally, OPV modules with high power output for real-world applications and grid-connection can be easily produced based on the Infinity concept developed in our group. Virtually infinite large solar cell modules are based on thousands of serially connected cells entirely fabricated using very fast R2R printing and coating processes. No manual labour or proprietary processes are required for bussing and interconnection of submodules. The serial connection is completed throughout the print run due to an optimized pattern layout. The advantage of the Infinity concept is the fabrication of high-voltage OPV modules with active areas beyond several square meters (21000 cells = 14.7 m², 100 m long) and stabilized power outputs of >220 W using the standard active layer material P3HT:PCBM. The module has only two terminal connectors for minimized wiring during the setup of module arrays. The installation of a 100 m long module takes less than one minute. A parallel-connected array with outputs >1.3 kW and rather low efficient material (<2%) was built. An entire solarpark based on such OPV modules has a low energy payback time of just 0.5 years.
Functional organic materials

**Related event**

**EOS Annual Meeting 2014 (EOSAM)**  
15/09/2014 → 19/09/2014  
Berlin Adlershof, Germany  
Activity: Talks and presentations › Conference presentations  

**International Summer School on OPV**  
Period: 4 Sep 2014  
Michael Corazza (Speaker)  
Department of Energy Conversion and Storage  
Functional organic materials  

**Description**  
Presentation of a poster  
International summer school on OPV  
Documents:  
Program summer school RHIN-SOLAR 2014  
Poster_strasburg

**Related event**

**International Summer School on OPV**  
31/08/2014 → 04/09/2014  
Strasbourg, France  
Activity: Talks and presentations › Guest lectures, external teaching and course activities at other universities  

*Will organic photovoltaic technology render benefits in a near future of a 30 years horizon?*  
Period: 12 May 2014  
Nieves Espinosa Martinez (Lecturer)  
Department of Energy Conversion and Storage  
Functional organic materials

**Related event**

**SETAC Europe 24th Annual Meeting**  
11/05/2014 → 15/05/2014  
Basel, Switzerland  
Activity: Talks and presentations › Conference presentations  

**Infinitely Large Organic Solar Cell Modules: At The Edge Of Traditional Territories For Power Supply**  
Period: 16 Apr 2014  
Nieves Espinosa Martinez (Invited speaker)  
Department of Energy Conversion and Storage  
Functional organic materials

**Related event**

**2nd International Conference on Clean Energy**  
13/04/2014 → 16/04/2014  
Qingdao, China  
Activity: Talks and presentations › Conference presentations
Fully printed multi square meter large organic solar cell modules for real energy production  
Period: 15 Apr 2014  
Markus Hösel (Speaker)  
Department of Energy Conversion and Storage  
Functional organic materials  

Related event  
2nd International Conference on Clean Energy  
13/04/2014 → 16/04/2014  
Qingdao, China  
Activity: Talks and presentations › Conference presentations

Outdoor Operational Stability of Indium-free Polymer Solar Cell Modules Investigated over 1 year  
Period: 15 Apr 2014  
Dechan Angmo (Speaker)  
Department of Energy Conversion and Storage  
Functional organic materials  

Related event  
2nd International Conference on Clean Energy  
13/04/2014 → 16/04/2014  
Qingdao, China  
Activity: Talks and presentations › Conference presentations

What is a solar cell  
Period: 27 Mar 2014  
Michael Corazza (Lecturer)  
Department of Energy Conversion and Storage  
Functional organic materials  
Documents:  
Program 27 3 HTX Roskilde- intro  
What is a Solar Cell_v3  

Related event  
High school talk  
27/03/2014 → 27/03/2014  
Denmark  
Activity: Talks and presentations › Conference presentations

Eurotech participants meeting  
Period: 23 Jan 2014  
Michael Corazza (Speaker)  
Department of Energy Conversion and Storage  
Functional organic materials  
Documents:  
140124 - EuroTech - Summary  

Related event  
Eurotech participants meeting  
23/01/2014 → 24/01/2014  
Neuchatel, Switzerland  
Activity: Talks and presentations › Conference presentations
**Light trapping with plasmonic oligomers and photonic crystals to enhance the performance of organic solar cells devices**

Period: 2013 → …

Francesco Pastorelli (Speaker)

Department of Energy Conversion and Storage

Functional organic materials

**Related event**

**Complex nanophotonics**

27/08/2013 → 31/08/2013

London, United Kingdom

Activity: Talks and presentations › Conference presentations

**Plasmonic Oligomers studies to Enhance the Performance of Organic Solar Cells devices**

Period: 2013 → …

Francesco Pastorelli (Speaker)

Department of Energy Conversion and Storage

Functional organic materials

**Related event**

**Plasmonica 2013**

01/07/2013 → 03/07/2013

Milano, Italy

Activity: Talks and presentations › Conference presentations

**Eurotech participants meeting**

Period: 17 Jul 2013

Michael Corazza (Speaker)

Department of Energy Conversion and Storage

Functional organic materials

**Description**

Eurotech participants meeting

**Related event**

**Eurotech participants meeting**

17/07/2013 → 18/07/2013

Munich, Germany

Activity: Talks and presentations › Conference presentations

**Self assembled dimers of metallic nano-particles for enhanced light harvesting in organic solar cells**

Period: 2012 → …

Francesco Pastorelli (Speaker)

Department of Energy Conversion and Storage

Functional organic materials

**Related event**

**5th Mediterranean Conference on NanoPhotonics**

05/11/2012 → 06/11/2012

Barcelona, Spain

Activity: Talks and presentations › Conference presentations
Self assembled dimers of metallic nano-particles for enhanced light harvesting in organic solar cells
Period: 2012 → …
Francesco Pastorelli (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Related event

Conferencia Española de Nanofotonica 2012
01/10/2012 → 04/10/2012
Sevilla, Spain
Activity: Talks and presentations › Conference presentations

Design and fabrication of broadband anti-reflection sub-wavelength periodic structure for solar cells
Period: 2010 → …
Francesco Pastorelli (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Related event

Renewable energy
27/06/2010 → 02/07/2010
Yokoama, Japan
Activity: Talks and presentations › Conference presentations

Cimtec 2010
Period: 18 Jun 2010
Hanne Lauritzen (Speaker)
Department of Energy Conversion and Storage
Functional organic materials

Description
Fabrication and Processing of Polymer and Organic Solar Cells
Documents:
Fabrication and Processing of Polymer and Organic Solar Cells

Related event

Cimtec 2010: 5th Forum on New Materials
13/06/2010 → 18/10/2010
Montecatini Terme, Italy
Activity: Talks and presentations › Conference presentations

Prizes:

Best Poster Award at the Sustain 2017
Gisele Alves dos Reis Benatto (Recipient), Nicholas Riedel (Recipient), Claire Mantel (Recipient), Sune Thorsteinsson (Recipient), Peter Behrensdrorff Poulsen (Recipient), Søren Forchhammer (Recipient), Kenn H. B. Frederiksen (Recipient), Jan Vedde (Recipient), Harsh Parikh (Recipient), Sergiu Spataru (Recipient) & Dezso Sera (Recipient)
Department of Photonics Engineering, Photovoltaic Materials and Systems, Organic Energy Materials, Coding and Visual Communication, Centre of Excellence for Silicon Photonics for Optical Communications

Description
Outdoor luminescence imaging strategies for drone-based PV array inspection

Details
Awarded date: 6 Dec 2017
Degree of recognition: International
Press clippings:

Article in ComputerWorld (DK)
Michael Corazza
02/01/2015
Department of Energy Conversion and Storage, Functional organic materials

Media contribution (1)

Article in ComputerWorld (DK)
02/01/2015
Print
http://www.computerworld.dk/art/232794/risoe-forsker-open-source-er-et-lystvaerk
Michael Corazza
Department of Energy Conversion and Storage, Functional organic materials

Press / Media