Digital resonant laser printing: Bridging nanophotonic science and consumer products

Zhu, Xiaolong; Keshavarz Hedayati, Mehdi; Raza, Søren; Levy, Uriel; Mortensen, N. Asger; Kristensen, Anders

Published in:
Nano Today

Link to article, DOI:

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
News and opinions

Digital resonant laser printing: Bridging nanophotonic science and consumer products

Xiaolong Zhu a, Mehdi Keshavarz Hedayati a, Søren Raza a, Uriel Levy b, N. Asger Mortensen c, Anders Kristensen a, b, *  

a Department of Micro and Nanotechnology, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark  
b Department of Applied Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel  
c Center for Nano Optics & Danish Institute for Advanced Study, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark

A R T I C L E   I N F O  
Article history:  
Received 1 September 2017  
Accepted 16 October 2017  
Available online xxx

Keywords:  
Laser-printing  
Structural colors  
Metasurfaces  
High-index dielectrics  
Resonators  
Super-resolution  
Flat optics

A B S T R A C T

Nanophotonics research relies heavily on state-of-the-art and costly nano and microfabrication technologies. While such technologies are fairly mature, their implementation in large-scale manufacturing of photonic devices is not straightforward. This is a major roadblock for integrating nanophotonic functionalities, such as flat optics or high definition, ink-free color printing, into real life applications. In particular, optical metasurfaces – nanoscale textured surfaces with engineered optical properties – hold great potential for a myriad of such applications. Digital laser printing has recently been introduced as a low-cost lithography solution, which allows the fabrication of high-resolution features on optical substrates. By exploiting resonant opto-thermal modification of individual nanoscale elements, laser printing can achieve nanometer-sized resolution. In addition, the concept of digital resonant laser printing at the nanoscale supports mass-customization and may therefore convert nanophotonic science into everyday consumer products.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
[23] without use of expensive and time-consuming electron-beam lithography. Laser-written large-area metasurfaces can also be implemented in solar cells and photodetectors to increase performance without the concomitant dramatic increase in price.

Besides the significant benefits in applied research, DRLP also opens new avenues in fundamental research in nanophotonics. In addition to morphological changes of plasmonic nanostructures [24–26], DRLP allows for changing the crystallinity of the meta-atom material. Nanosecond laser pulses can change silicon meta-atoms from amorphous to crystalline [27], which is accompanied by a large change in the refractive index. This phase change is reversible [28], allowing for rewritable metasurfaces – a topic currently being pursued with more traditional phase-change materials [29]. Fabrication of meta-atoms made from alloys is an alternative approach. Targeting only one of the materials with the laser, the meta-atom composition, and thereby the optical response, can be gradually controlled. Multimaterial meta-atom designs are largely unexplored, but have potential for realizing hyperbolic metasurfaces [30] for quantum-information applications [31].

Looking beyond photonics, we anticipate application wherein the nanoscale manipulation of the structure or constituents of a compound is desired. As an example, the resonant nature of DRLP can be used in polymer welding for expanding the material selection from traditional absorbing polymers [32] or polymer-metal composites [33] to non-absorbing or additive-free counterparts. This allows for polymer welding without toxic elements, important for e.g. bio-medical applications [34]. Localized de-alloying of solid solution alloys – selective corrosion of one or more elements of alloys – can be realized in fraction of seconds by DRLP (contrasting slow chemical methods [35]). Likewise, pre-defined porous substance with extremely high surface area and low refractive index can be realized. The former can be profound for applications in catalysis [36] and surface chemistry [37], while the latter is highly desired e.g. for anti-reflective coatings in solar cells [38]. The high temperature in DRLP can also be exploited to locally oxidize or nitridize metals to locally functionalize otherwise passive films. For instance, localized oxidation of titanium via DRLP can be used to construct smart surfaces where the wettability can be tailored on the nanoscale: Pure titanium is hydrophilic, while DRLP-written titanium oxide areas are hydrophobic. Such surfaces can find application as anti-icing (icephobic) surfaces among others [39].

Post-processing large areas of nanostructures is highly desirable for adaptable and low-cost applications, which can have a strong impact on the industrialization of these devices. The diversity of the nanophotonic products naturally requests the development of efficient, universal and high-quality technologies, which should also be ready for the production-chain in industry. With the sub-diffraction-limited precision and the ultrafast feature, high-performance DRLP may be a game-changer in enabling, controlling, and enhancing the nowadays nanophotonic devices as well as other fundamental and functional applications.

Acknowledgements

This work was supported by the European Commission through the H2020 FET-OPEN project CHROMAVISION (Grant Agreement No. 665233) and H2020-NMP-PILOTS IZADI-NANO2INDUSTRY (Grant Agreement No. 686165), and by the International Network Programme of the Danish Agency for Science, Technology and Innovation (1370-00124B and 4070-00158B). This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 701597. N.A.M. is a VILLUM Investigator (grant No. 16498) and X.Z. is funded by VILLUM Experiment (grant No. 17400), both supported by VILLUM FONDEN.

References

Please cite this article in press as: X. Zhu et al., Digital resonant laser printing: Bridging nanophotonic science and consumer products, Nano Today (2017), https://doi.org/10.1016/j.nantod.2017.10.002
Uriel Levy is a faculty and director of the Center for Nanoscience and Nanotechnology at the Hebrew University of Jerusalem. He obtained his PhD (2002) from Tel Aviv University and he was subsequently a postdoctoral fellow at University of California, San Diego. He is the author of more than 120 papers in peer-review journals, including pioneering works on metasurfaces and plasmonics. He is an ERC grantee and a fellow of OSA.

N. Asger Mortensen is a Villum Investigator at the Center of Nano Optics, while also holding a chair of technical sciences at the Danish Institute for Advanced Study, both at the University of Southern Denmark. He obtained his PhD (2001) and Dr. Techn. (2006) degrees from the Technical University of Denmark. He is the author of more than 220 papers in peer-review journals, including pioneering works on nonlocal plasmonics and plasmonic colors. He is a fellow of APS, OSA and SPIE.

Anders Kristensen is a faculty at the Technical University of Denmark. He obtained his PhD (1994) from University of Copenhagen and he was subsequently a postdoctoral fellow at the Royal Holloway and Bedford New College, University of London. He is the author of more than 180 papers in peer-review journals, including pioneering works on optofluidics and plasmonic colors. He has been heading various national and European projects, including the EU funded http://www.plast4future.eu.