Deep-UV to Mid-IR Supercontinuum Generation driven by Mid-IR Ultrashort Pulses in a Gas-filled Hollow-core Fiber

Supercontinuum (SC) generation based on ultrashort pulse compression constitutes one of the most promising technologies towards ultra-wide bandwidth, high-brightness, and spatially coherent light sources for applications such as spectroscopy and microscopy. Here, multi-octave SC generation in a gas-filled hollow-core antiresonant fiber (HC-ARF) is reported spanning from 200 nm in the deep ultraviolet (DUV) to 4000 nm in the mid-infrared (mid-IR) having an output energy of 5 μJ. This was obtained by pumping at the center wavelength of the first anti-resonant transmission window (2460 nm) with ~100 fs pulses and an injected pulse energy of ~8 μJ. The mechanism behind the extreme spectral broadening relies upon intense soliton-plasma nonlinear dynamics which leads to efficient soliton self-compression and phase-matched dispersive wave (DW) emission in the DUV region. The strongest DW is observed at 275 nm which corresponds to the calculated phase-matching wavelength of the pump. Furthermore, the effect of changing the pump pulse energy and gas pressure on the nonlinear dynamics and their direct impact on SC generation was investigated. This work represents another step towards gas-filled fiber-based coherent sources, which is set to have a major impact on applications spanning from DUV to mid-IR.

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Real-time high-resolution mid-infrared optical coherence tomography

The potential for improving the penetration depth of optical coherence tomography systems by using light sources with longer wavelengths has been known since the inception of the technique in the early 1990s. Nevertheless, the development of mid-infrared optical coherence tomography has long been challenged by the maturity and fidelity of optical components in this spectral region, resulting in slow acquisition, low sensitivity, and poor axial resolution. In this work, a mid-infrared spectral-domain optical coherence tomography system operating at a central wavelength of 4 µm and an axial resolution of 8.6 µm is demonstrated. The system produces two-dimensional cross-sectional images in real time enabled by a high-brightness 0.9- to 4.7-µm mid-infrared supercontinuum source with a pulse repetition rate of 1 MHz for illumination and broadband upconversion of more than 1-µm bandwidth from 3.58–4.63 µm to 820–865 nm, where a standard 800-nm spectrometer can be used for fast detection. The images produced by the mid-infrared system are compared with those delivered by a state-of-the-art ultra-high-resolution near-infrared optical coherence tomography system operating at 1.3 µm, and the potential applications and samples suited for this technology are discussed. In doing so, the first practical mid-infrared optical coherence tomography system is demonstrated, with immediate applications in real-time non-destructive testing for the inspection of defects and thickness measurements in samples that exhibit strong scattering at shorter wavelengths.

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Amplitude noise and coherence degradation of femtosecond supercontinuum generation in all-normal-dispersion fibers

Supercontinuum (SC) generation via femtosecond (fs) pumping in all-normal-dispersion (ANDi) fiber is predicted to offer completely coherent broadening mechanisms, potentially allowing for substantially reduced noise levels in comparison to those obtained when operating in the anomalous dispersion regime. However, previous studies of SC noise typically treat only the quantum noise, typically in the form of one-photon-per-mode noise, and do not consider other technical noise contributions, such as the stability of the pump laser, which become important when the broadening mechanism itself is coherent. In this work, we discuss the influence of the amplitude and pulse length noise of the pump laser, both added separately and combined. We show that for a typical mode-locked laser, in which the peak power and pulse duration are anticorrelated, their combined impact on the SC noise is generally smaller than in isolation. This means that the supercontinuum noise is smaller than the noise of the mode-locked pump laser itself, a fact that was recently observed in experiments but not explained. Our detailed numerical analysis shows that the coherence of ANDi SC generation is considerably reduced on the spectral edges when realistic pump laser noise levels are taken into account.

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Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Universite de Franche-Comte, NKT Group
Directional supercontinuum generation: The role of the Soliton
In this paper we numerically study supercontinuum generation by pumping a silicon nitride waveguide, with two zero-dispersion wavelengths, with femtosecond pulses. The waveguide dispersion is designed so that the pump pulse is in the normal-dispersion regime. We show that because of self-phase modulation, the initial pulse broadens into the anomalous-dispersion regime, which is sandwiched between the two normal-dispersion regimes, and here a soliton is formed. The interaction of the soliton and the broadened pulse in the normal-dispersion regime causes additional spectral broadening through formation of dispersive waves by non-degenerate four-wave mixing and cross-phase modulation. This broadening occurs mainly towards the second normal-dispersion regime. We show that pumping in either normal-dispersion regime allows broadening towards the other normal-dispersion regime. This ability to steer the continuum extension towards the direction of the other normal-dispersion regime beyond the sandwiched anomalous-dispersion regime underlies the directional supercontinuum notation. We numerically confirm the approach in a standard silica microstructured fiber geometry with two zero-dispersion wavelengths.

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Noise of supercontinuum sources in spectral domain optical coherence tomography
In this paper, we investigate the effect of pulse-to-pulse fluctuations of supercontinuum sources on the noise in spectral domain optical coherence tomography (OCT) images. The commonly quoted theoretical expression for the OCT noise is derived for a thermal light source, which is not suitable if a supercontinuum light source is used. We therefore propose a new, measurement-based OCT noise model that predicts the noise without any assumptions on the type of light source.
We show that the predicted noise values are in excellent agreement with the measured values. The spectral correlation evaluated for the photodetected signal when using a supercontinuum determines the shape of the OCT noise floor, which must be taken into account when characterizing the sensitivity roll-off of a supercontinuum-based OCT system. The spectral correlations using both conventional supercontinuum sources and low-noise all-normal dispersion supercontinuum sources are investigated, and the fundamental physical effects that cause these correlations are discussed.

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Potential of contrast agents to enhance in vivo confocal microscopy and optical coherence tomography in dermatology

Distinction between normal skin and pathology can be a diagnostic challenge. This systematic review summarizes how various contrast agents, either topically delivered or injected into the skin, affect distinction between skin disease and normal skin when imaged by optical coherence tomography (OCT) and confocal microscopy (CM). A systematic review of in vivo OCT and CM studies using exogenous contrast agents on healthy human skin or skin disease was performed. In total, nine CM studies and one OCT study were eligible. Four contrast agents aluminum chloride (AlCl) n = 2, indocyanine green (ICG) n = 3, sodium fluorescein n = 3 and acetic acid n = 1 applied to CM in variety of skin diseases. ICG, acetic acid and AlCl showed promise to increase contrast of tumor nests in keratinocyte carcinomas. Fluorescein and ICG enhanced contrast of keratinocytes and adnexal structures. In OCT of healthy skin gold nanoshells, increased contrast of natural skin openings. Contrast agents may improve delineation and diagnosis of skin cancers: ICG, acetic acid and AlCl have potential in CM and gold nanoshells facilitate visualization of adnexal skin structures in OCT. However, as utility of bedside optical imaging increases, further studies with robust methodological quality are necessary to implement contrast agents into routine dermatological practice.

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Effects of Solvent Etching on PMMA Microstructured Optical Fiber Bragg Grating
Polymer Optical Fiber Bragg Gratings (POFBGs) can be solvent etched to achieve higher sensitivity sensors. To analyze the influence of etch on the mechanical and thermal performance of PMMA based microstructured POFBGs (mPOFBGs), we etched annealed and unannealed samples in pure acetone, while at the same time monitoring the induced Bragg wavelength shifts. Optical-thermodynamical interpretation of these shifts together with thermal and mechanical testing of etched fibers, reveal that solvent etching can lead to trapping of residual plasticizing solvent in the polymer matrix and consequently to change of Young's modulus and thermal instability of the etched mPOFBG. Removal of these solvent residuals by thermal treatment results in a stable linear response with a thermal sensitivity indistinguishable of that of the unetched mPOFBG. The maximum found change of Young's modulus due to acetone plasticization during etch is ~5\% for both unannealed and annealed mPOFBGs. The mPOFBG force sensitivity increases greatly with reduced diameter and the relatively small changes in strain sensitivity and Young's modulus introduced by the etching process in this case do not have a big effect.

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GLS and GLSSe ultrafast laser inscribed waveguides for mid-IR supercontinuum generation
Using the ultrafast laser inscription technique, buried channel waveguides have been fabricated in gallium lanthanum sulfide and gallium lanthanum sulfide selenide glasses to demonstrate the suitability of the materials for supercontinuum generation in the mid-IR. Supercontinuum generation was performed using 100 femtosecond pump pulses with microJoule pulse energies and a center wavelength of 4.6 \mu m, which is in the anomalous dispersion regime for these waveguides. Under such pump conditions, supercontinuum was obtained covering a 25-dB-bandwidth of up to 6.1 \mu m with a long-wavelength edge of 8 \mu m. To our knowledge, this represents the broadest and the longest-wavelength IR supercontinuum generated from an ultrafast laser inscribed waveguide to date.

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Monitoring of ammonia in an aqueous environment using a supercontinuum-based photoacoustic sensing system

We demonstrate a robust photoacoustic medium for measuring the concentration of ammonia in an aqueous solution. We target the near-infrared (NIR) overtone absorption band (1540 nm) of ammonia with a supercontinuum (SC) laser-based excitation system and an immersion-based acoustic transducer as the detection system. We further present how such a simple system can be used to perform effective in-situ measurements of ammonia over a range of concentrations with a sensitivity of parts per million (ppm) by volume and linearity of >96%. We demonstrate how the sensing system can be readily tailored to monitor the concentrations of other miscible gases in the aqueous solution.

Multispectral photoacoustic sensing for accurate glucose monitoring using a supercontinuum laser

Accurate monitoring of glucose levels constitutes the most important parameter for diabetes management and treatment planning. In this work, we report on an in vitro glucose monitoring system based on multispectral photoacoustic sensing (MSPAS) using a cost-effective supercontinuum (SC) laser. We demonstrate for the first time, to the best of our knowledge, how the use of a broadband SC source allows the identification of distinct absorption characteristics of two major analytes (glucose and cholesterol) present in the human body in the extended near-infrared 1540–1840 nm spectral range. Employing the reported SC-based MSPAS system with a ratiometric analysis, we were able to accurately (coefficient of determination ≥0.938) measure a wide range of glucose concentration levels in vitro. We further demonstrate clinically accurate prediction of glucose concentrations over commonly encountered physiological levels inside the human body (0–400 mg/dL) with reference to a Clarke error grid analysis. These findings pave the way for devising potentially noninvasive and label-free continuous glucose monitoring systems.

Polymer Optical Fiber Tip Mass Production Etch Mechanism to Achieve CPC Shape for Improved Biosensor Performance

We report on a simple chemical etching method that enables nonlinear tapering of Polymer Optical Fiber (POF) tips to manufacture Compound Parabolic Concentrator (CPC) fiber tips. We show that, counter-intuitively, nonlinear tapering can be achieved by first etching the core and not the cladding. The etching mechanism is modelled and etched tips are characterized both geometrically and optically in a fluorescence glucose sensor chemistry. A Zemax model of the CPC tipped sensor predicts an optimal improvement in light capturing efficiency of a factor of 3.96 compared to the conventional sensor with a plane-cut fiber tip. A batch of eight CPC fiber tips has been manufactured by the chemical etching method. The batch average showed an increase of a factor of 3.16, which is only 20% less than the predicted value. The method is reproducible and can be up-scaled for mass production.

Scaling power, bandwidth, and efficiency of mid-infrared supercontinuum source based on a GeO2-doped silica fiber

We demonstrate a supercontinuum source with a 20 dB bandwidth from ~1 to ~3 μm with output power exceeding 6 W based on a GeO2-doped silica fiber. This is the highest output power reported for a 3 μm supercontinuum source based on germania-doped silica fiber in an all-fiberized and compact size device. We further demonstrate a spectrum spanning from ~1.7 to ~3.4 μm (~10 dB bandwidth from ~1.8 to ~3.2 μm) at a low power of tens of milliwatts with more than 50%
power fraction above 2400 nm, which makes this source suitable for several applications where a broadband source at low power is required to avoid damage of the samples. Our investigations reveal the unexploited potential of germania-doped fiber for mid-infrared supercontinuum generation and surpass the current state-of-the-art results.

Small and Robust All-Polymer Fiber Bragg Grating based pH Sensor

The smallest all-polymer optical fiber Bragg grating based transducer element for pH sensing is presented. We show that, considering its size and robustness, it out-performs similar state-of-the-art fiber Bragg grating based pH sensors regarding both sensitivity and response time. A 5 μm - 10 μm thick pH sensitive hydrogel coating is placed on a PMMA based microstructured Polymer Optical Fiber Bragg Grating (mPOFBG). The hydrogel expands or contracts depending on the pH and thus changes in pH are monitored by following the fiber strain induced changes in the reflected Bragg wavelength \( \lambda_B \). Prior to applying the hydrogel coating the mPOF is etched from 150 μm to 80 μm to enhance sensitivity and surface crazing is introduced with a 50/50 vol% solution of acetone and methanol to enhance spreading of the hydrogel during the application and adhesion after cure. With this design we achieved a sensitivity of \( \Delta \lambda_B = 73 \text{ pm/pH} \pm 2 \text{ pm/pH} \) and response times below 4.5 mins. for pH 5 - 7 and 4 - 7 respectively and a thermal cross sensitivity of 31.4 pm/°C ± 0.4 pm/°C.
Supercontinuum noise reduction by fiber undertapering
We demonstrate that the Relative Intensity Noise (RIN) of a supercontinuum source can be significantly reduced using the new concept of undertapering, where the fiber is tapered to a diameter that is smaller than the diameter that gives the shortest blue edge, which is typically regarded as the optimum. We show that undertapering allows to control the second zero dispersion wavelength and use it as a soliton barrier to stop the red shifting solitons at a pre-defined wavelength, and thereby strongly reduce the RIN. We demonstrate how undertapering can reduce the spectrally averaged RIN in the optical coherence tomography bands, 500 – 800 nm and 1150 – 1450 nm, by more than a factor two.

Towards Accurate and Label-free Monitoring of Bio-analytes using Supercontinuum based Multispectral Photoacoustic Spectroscopy in the Extended Near-infrared Wavelength regime
In this work, we report a cost-effective supercontinuum (SC) laser-based multispectral photoacoustic spectroscopy (MSPAS) system for studying spectral characteristics of various analytes. We demonstrate an in vitro label-free monitoring of the analytes in the extended near-infrared (NIR) (1540–1840 nm) spectral range. We further demonstrate how a simple ratiometric analysis in conjunction with linear regression can be used for accurate prediction of glucose over commonly encountered physiological levels inside the human body (0–400 mg/dL). Looking forward, the proposed SC-based MSPAS system provides a framework for the development of label-free and non-invasive monitoring multiple bio-analytes accurately, with potential translation to clinical in vivo applications.
Multi-stage generation of extreme ultraviolet dispersive waves by tapering gas-filled hollow-core anti-resonant fibers

In this work, we numerically investigate an experimentally feasible design of a tapered Ne-filled hollow-core anti-resonant fiber and we report multi-stage generation of dispersive waves (DWs) in the range 90-120 nm, well into the extreme ultraviolet (UV) region. The simulations assume a 800 nm pump pulse with 30 fs 10 µJ pulse energy, launched into a 9 bar Ne-filled fiber with a 34 µm initial core diameter that is then tapered to a 10 µm core diameter. The simulations were performed using a new model that provides a realistic description of both loss and dispersion of the resonant and anti-resonant spectral bands of the fiber, and also importantly includes the material loss of silica in the UV. We show that by first generating solitons that emit DWs in the far-UV region in the pre-taper section, optimization of the following taper structure can allow re-collision with the solitons and further up-conversion of the far-UV DWs to the extreme-UV with energies up to 190 nJ in the 90-120 nm range. This process provides a new way to generate light in the extreme-UV spectral range using relatively low gas pressure.

Role of the Raman gain in the noise dynamics of all-normal dispersion silica fiber supercontinuum generation

We theoretically and numerically study the influence of the Raman gain profile on the noise dynamics of the supercontinuum (SC) generation in a standard all-normal dispersion silica fiber using the scalar generalized nonlinear Schrödinger equation. In particular, we investigate the effect of the different secondary resonance gain peaks on the evolution of the SC coherence by comparing the coherence obtained when using the measured Raman gain of silica with that obtained using different analytical approximations. We demonstrate that the strongest secondary peak at 14.8 THz has a significant influence in that it leads to an early development of a decoherence band on the long wavelength side of the SC. In contrast, the decoherence is strongly dominated by the short wavelength side below the pump for all analytical models not taking this 14.8 THz gain peak into account. We demonstrate that this is due to the 14.8 THz peak being spectrally much narrower than the other gain peaks.
Dynamic mechanical characterization with respect to temperature, humidity, frequency and strain in mPOFs made of different materials

This paper presents a dynamic mechanical analysis (DMA) of polymer optical fibers (POFs) to obtain their Young modulus with respect to the variation of strain, temperature, humidity and frequency. The POFs tested are made of polymethyl methacrylate (PMMA), Topas grade 5013, Zeonex 480R and Polycarbonate (PC). In addition, a step index POF with a core composed of Topas 5013 and cladding of Zeonex 480R is also analyzed. Results show a tradeoff between the different fibers for different applications, where the Zeonex fiber shows the lowest Young modulus among the ones tested, which makes it suitable for high-sensitivity strain sensing applications. In addition, the fibers with Topas in their composition presented low temperature and humidity sensitivity, whereas PMMA fibers presented the highest Young modulus variation with different frequencies. The results presented here provide guidelines for the POF material choice for different applications and can pave the way for applications involving the combination of different polymer materials.

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Fast Inscription of Long Period Gratings in Microstructured Polymer Optical Fibers

We demonstrate 20 dB long period grating (LPG) fast inscription in microstructured polymer optical fibers (mPOFs) using a point-by-point technique obtaining an LPG total length of 25 mm. Two 248 nm UV laser pulses of 15 ns duration have been employed for every inscription point, which means a time reduction by over 21 times compared with the fastest inscription time already reported in literature. The device has been fabricated in a single-mode mPOF with a core that has been doped with benzyl dimethyl ketal for photosensitivity enhancement. Moreover, we characterize the strain and temperature responses and the stability of the fabricated gratings response under different conditions in order to assess the viability for different applications.

General information
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Fast and stable gratings inscription in POFs made of different materials with pulsed 248 nm KrF laser

This paper presents fiber Bragg grating (FBG) inscription with a pulsed 248 nm UV KrF laser in polymer optical fibers (POFs) made of different polymers, namely polymethyl methacrylate (PMMA), cyclic-olefin polymer and co-polymer, and Polycarbonate. The inscribed gratings and the corresponding inscription parameters are compared with grating inscribed in POFs made of the aforementioned materials but with the hitherto most used laser for inscription, which is a continuous wave 325 nm UV HeCd laser. Results show a reduction of the inscription time of at least 16 times. The maximum time reduction is more than 130 times. In addition, a reflectivity and a bandwidth close to or higher than the ones with the 325 nm laser were obtained. The polymer optical fiber Bragg gratings (POFBGs) inscribed with the 248 nm laser setup present high stability with small variations in their central wavelength, bandwidth, and reflectivity after 40 days.

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Chirped mPOF Bragg grating for strain sensing
We demonstrate a chirped microstructured polymer fiber Bragg grating based on taper technology for strain sensing application. The effective bandwidth of the grating is dependent on strain and remains practically constant irrespective of humidity changes. Besides wavelength shift measurement in temperature and humidity stable conditions with 9.02 pm/µε sensitivity, faster measurements under humidity fluctuations condition can be done by measuring the effective bandwidth of the grating.

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High power mid-infrared fiber based supercontinuum sources: Current status and future perspectives
Mid-infrared fiber based supercontinuum sources have great potential for several applications. This paper reviews their current status of power scaling and discusses the challenges and future development in power scaling.

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Corresponding author: Jain, D.
Contributors: Jain, D., Bang, O.
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Supercontinuum laser for spectroscopic photoacoustic imaging of lipids in the extended near-infrared region
The ability of spectroscopic photoacoustic imaging to enable functional information on top of the structural information of the tissue makes it a promising tool for detection and monitoring of numerous diseases. In the current work, we demonstrate a cost-efficient high-power supercontinuum laser source based on a telecom range diode laser system and few meters of a standard optical fiber for spectroscopic photoacoustic imaging of lipids in the extended near-infrared region.
All-depth dispersion cancellation in spectral domain optical coherence tomography using numerical intensity correlations

In ultra-high resolution (UHR-) optical coherence tomography (OCT) group velocity dispersion (GVD) must be corrected for in order to approach the theoretical resolution limit. One approach promises not only compensation, but complete annihilation of even order dispersion effects, and that at all sample depths. This approach has hitherto been demonstrated with an experimentally demanding 'balanced detection' configuration based on using two detectors. We demonstrate intensity correlation (IC) OCT using a conventional spectral domain (SD) UHR-OCT system with a single detector. IC-SD-OCT configurations exhibit cross term ghost images and a reduced axial range, half of that of conventional SD-OCT. We demonstrate that both shortcomings can be removed by applying a generic artefact reduction algorithm and using analytic interferograms. We show the superiority of IC-SD-OCT compared to conventional SD-OCT by showing how IC-SD-OCT is able to image spatial structures behind a strongly dispersive silicon wafer. Finally, we question the resolution enhancement of root 2 that IC-SD-OCT is often believed to have compared to SD-OCT. We show that this is simply the effect of squaring the reflectivity profile as a natural result of processing the product of two intensity spectra instead of a single spectrum.
All-Polymer Fiber Bragg Grating based pH Sensor.
The first all-polymer optical fiber Bragg grating pH sensor is presented. We show that it outperforms similar state-of-the-art glass fiber Bragg grating-based pH sensors regarding both sensitivity and response time.

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Bragg Grating Inscription With Low Pulse Energy in Doped Microstructured Polymer Optical Fibers
We demonstrate that fiber Bragg gratings (FBGs) can be written in a doped polymer optical fiber (POF) in a low ultraviolet (UV) pulse energy regime (60J pulse) using a 248-nm krypton fluoride excimer laser system. The total energy density per inscription necessary to obtain Bragg gratings is between 493.6 and 3825mJcm⁻², depending on the number of pulses and the pulse energy. The impact of the pulse energy on the growth of the Bragg grating is investigated, and it is shown that the 248-nm light induces a positive refractive index change. This article demonstrates that the FBGs can be obtained in the POFs without high pulse energy (μJ level) at 248-nm wavelength, which reduces maintenance costs. Furthermore, we can consider it as a solution to increase the lifetime of the laser system without high energy still allowing fast and efficient production of the FBGs for sensing applications.

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Direct nanoimprinting of moth-eye structures in chalcogenide glass for broadband antireflection in the mid-infrared
Fresnel reflection at the boundary between two media of differing refractive indices is a major contributing factor to the overall loss in mid-infrared optical systems based on high-index materials such as chalcogenide glasses. In this paper, we present a study of broadband antireflective moth-eye structures directly nanoimprinted on the surfaces of arsenic triselenide (As₂Se₃)-based optical windows. Using rigorous coupled-wave analysis, we identify a relief design optimized for high transmittance (<1% reflectance) at 6 μm, which when nanoimprinted features a transmittance improvement (ΔT > 12%) in the 5.9–7.3 μm spectral range as well as improved omnidirectional properties. Finally, we demonstrate the adaptability of nanoimprinted surface reliefs by tailoring the nanostructure pitch and height, achieving both extremely broadband antireflective and highly efficient antireflective surface reliefs. The results and methods presented herein provide an efficient and scalable solution for improving the transmission of bulk optics, waveguides, and photonic devices.
in the mid-infrared.

**Effects of Solvent Etching on PMMA Microstructured Optical Fiber Bragg Grating**

Polymer Optical Fiber Bragg Gratings (POFBG) can be solvent etched to achieve higher sensitivity sensors. We demonstrate that removal of solvent residuals in the POFBG by annealing ensures stable linear thermal response of such sensors.

**Ge22As20Se58 glass ultrafast laser inscribed waveguides for mid-IR integrated optics**

Ultrafast laser inscription has been used to produce channel waveguides in Ge22As20Se58 glass (GASIR-1, Umicore N.V). The mode field diameter and waveguide losses at 2.94 µm were measured along with the waveguide dispersion in the 1 to 4.5 µm range, which is used to estimate the zero-dispersion wavelength. Z-scan measurements of bulk samples have also been performed to determine the nonlinear refractive index. Finally, midIR supercontinuum generation has been shown when pumping the waveguides with femtosecond pulses centered at 4.6 µm. Supercontinuum spanning approximately 4 µm from 2.5 to 6.5 µm was measured which, to the best of the authors' knowledge, represents the broadest and the deepest IR supercontinuum from an ultrafast laser inscribed waveguide to date. This work, combined with the long wavelength transmission of GASIR-1 up to 15 µm, paves the way for realizing further ultrafast laser inscribed waveguide devices in GASIR-1 for mid-IR integrated optics applications. Published by The Optical Society under the terms of the Creative Commons Attribution 4.0 License.
High-pulse energy supercontinuum laser for high-resolution spectroscopic photoacoustic imaging of lipids in the 1650-1850 nm region

We propose a cost-effective high-pulse energy supercontinuum (SC) source based on a telecom range diode laser-based amplifier and a few meters of standard single-mode optical fiber, with a pulse energy density as high as ~25 nJ/nm in the 1650-1850 nm regime (factor >3 times higher than any SC source ever used in this wavelength range). We demonstrate how such an SC source combined with a tunable filter allows high-resolution spectroscopic photoacoustic imaging and the spectroscopy of lipids in the first overtone transition band of C-H bonds (1650-1850 nm). We show the successful discrimination of two different lipids (cholesterol and lipid in adipose tissue) and the photoacoustic cross-sectional scan of lipid-rich adipose tissue at three different locations. The proposed high-pulse energy SC laser paves a new direction towards compact, broadband and cost-effective source for spectroscopic photoacoustic imaging.

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Hot water-assisted fabrication of chirped polymer optical fiber Bragg gratings

We obtained chirped gratings by performing hot water gradient thermal annealing of uniform poly (methylmethacrylate) (PMMA) microstructured polymer optical fiber Bragg gratings (POFBGs). The proposed method’s simplicity is one of its main advantages because no special phase mask or additional etching are needed. It not only enables easy control tuning of the central wavelength and chirp characteristics, but it also leads to obtain flexible grating response, compared with tapered chirped POFBGs. Therefore, a flexible and low-cost chirped POFBG devices fabrication technique has been presented by using a single uniform phase mask.

Influence of the Cladding Structure in PMMA mPOFs Mechanical Properties for Strain Sensors Applications

This paper presents a dynamic mechanical analysis (DMA) of a microstructured polymer optical fiber (mPOF). The fiber material is polymethyl methacrylate (PMMA), which is widely available commercially. The DMA is made by means of sequential strain cycles produced with an oscillatory load with controlled frequency to obtain the variation of the Young’s Modulus with respect to temperature, frequency and humidity for mPOFs with 2, 3 and 5-ring hexagonal microstructured cladding. Results show that the 3 different cladding structures have similar Young’s modulus on the stress-strain tests performed. Furthermore, the 3-ring structure presents the lowest Young’s Modulus variation with temperature among the samples tested, whereas the 5-ring structure presents a Young’s Modulus variation with frequency 25% lower than the 2 and 3-rings cladding structures. Regarding the humidity sensitivity, the 2-ring structure presented a 30% lower Young’s...
Modulus variation for a 25% humidity increase. The results obtained provide guidelines for the cladding structure choice for strain or stress sensors applications when low cross-sensitivity with temperature, humidity and frequency is desired.

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Largely tunable dispersion chirped polymer FBG

We demonstrate a largely tunable dispersion fiber Bragg grating (FBG) inscribed in a microstructured polymer optical fiber (mPOF). The bandwidth of the chirped FBG (CFBG) was achieved from 0.11 to 4.86 nm, which corresponds to a tunable dispersion range from 513.6 to 11.15 ps/nm. Furthermore, thermal sensitivity is used to compensate for the wavelength shift due to the applied strain. These results demonstrate that a CFBG in a POF is a promising technology for future optical systems. 

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LPG inscription in mPOF for optical sensing

We demonstrate a long period grating (LPG) inscription in microstructured polymer optical fibers (mPOFs) using a single 248 nm UV laser pulse of 15 ns duration for every inscription point using a point by point technique with total length of 25 mm. The fabrication time indicates shortening for a single coupling point (15 ns against 42 s reported in literature). A grating with 20 dB transmission dip has been fabricated by using two UV pulses for each coupling point. The device has been fabricated in mPOF with a core that has been doped with benzyl dimethyl ketal (BDK) for photosensitivity increase. The strain and temperature responses of the fabricated gratings under different conditions have been characterized in order to assess the viability for sensing applications. Better performance was achieved with suitable post annealing process of the gratings.

Mechanical characterization of drawn Zeonex, Topas, polycarbonate and PMMA microstructured polymer optical fibres

The mechanical stress-strain behaviour of polymer optical fibres (POFs) drawn from various materials was measured, both before and after temperature annealing of the POFs. The POFs were drawn from PMMA (GEHR), Zeonex (480R), PC (Makrolon LED2245) and two different grades of Topas (8007S-04 and 5013S-04). With fibre drawing stresses at or above the elastic (uniaxial extensional) plateau modulus, the polymer chains in the POFs have a high degree of alignment, which has a large impact on fibre mechanical behaviour. The testing was performed at straining rates ranging from 0.011 s, to 1.1 s for the un-annealed fibres and a straining rate of 1.1 s for the annealed ones. The elastic modulus of the tested POFs showed no sensitivity toward variation of straining rate. In the case of Topas 5013S-04 and PMMA, the producer-reported values are the same as the one obtained here for the POFs both before and after annealing. The drawn POFs made of Zeonex, PC, and Topas 8007S-04 exhibit larger elastic modulus than the respective materials in the bulk form. The elastic modulus of these fibres is reduced upon annealing by 10–15 but still remains above the producer-reported values for the bulk polymers. In the nonlinear elastic region, only the PC POF is statistically unaffected by the changes in the straining rate, while Topas 8007S-04 POF shows insensitivity to the straining rate until 3% strain. All other changes affect the stress-strain curves. The annealing flattens all stress-strain curves, making the fibres more sensitive to yield.
Microstructured PMMA POF chirped Bragg gratings for strain sensing

We demonstrate a chirped microstructured polymer fiber Bragg grating based on taper technology for strain sensing application. The effective bandwidth of the grating is dependent on strain and remains practically constant with respect to temperature and humidity changes. We report a sensitivity of 0.90 pm/µε for the central wavelength under stable temperature and humidity values. The 3-dB bandwidth of the grating has been measured under different temperature and humidity conditions.

Mid-infrared fiber-coupled supercontinuum spectroscopic imaging using a tapered chalcogenide photonic crystal fiber

We present the first demonstration of mid-infrared spectroscopic imaging of human tissue using a fiber-coupled supercontinuum source spanning from 2-7.5 μm. The supercontinuum was generated in a tapered large mode area chalcogenide photonic crystal fiber in order to obtain broad bandwidth, high average power, and single-mode output for good imaging properties. Tissue imaging was demonstrated in transmission by raster scanning over a sub-mm region of paraffinized colon tissue on CaF2 substrate, and the signal was measured using a fiber-coupled grating spectrometer. This demonstration has shown that we can distinguish between epithelial and surrounding connective tissues within a paraffinized section of colon tissue by imaging at discrete wavelengths related to distinct chemical absorption features.
Mid-infrared multispectral tissue imaging using a chalcogenide fiber supercontinuum source

We present the first demonstration of mid-infrared supercontinuum tissue imaging at wavelengths beyond 5 μm using a fiber-coupled supercontinuum source spanning 2-7.5 μm. The supercontinuum was generated in a tapered large mode area chalcogenide photonic crystal fiber in order to obtain broad bandwidth, high average power, and single-mode output for diffraction-limited imaging performance. Tissue imaging was demonstrated in transmission at selected wavelengths between 5.7μm (1754 cm⁻¹) and 7.3μm (1370 cm⁻¹) by point scanning over a sub-mm region of colon tissue, and the results were compared to images obtained from a commercial instrument.

Mid-IR Supercontinuum Generation In Ultrafast Laser Inscribed Waveguides

Supercontinuum from 2.5 to 6.5 μm has been generated in ULI waveguides pumped with femtosecond pulses centered at 4.6 μm. Dispersion measurements show the zero dispersion wavelength for the waveguides to be around 5.3 μm.
Moiré phase-shifted fiber Bragg gratings in polymer optical fibers

We demonstrate a simple way to fabricate phase-shifted fiber Bragg grating in polymer optical fibers as a narrowband transmission filter for a variety of applications at telecom wavelengths. The filters have been fabricated by overlapping two uniform fiber Bragg gratings with slightly different periods to create a Moiré grating with only two pulses (one pulse is 15 ns) of UV power. Experimental characterization of the filter is provided under different conditions where the strain and temperature sensitivities were measured.

Optical fiber

An anti-resonant hollow-core optical fiber with a waveguide structure having a longitudinal direction. The optical fiber comprises an outer cladding region extending in the longitudinal direction, the outer cladding region having a substantially tubular inner wall forming an internal volume, and a core region comprising a central void. The fiber further comprising an inner cladding region comprising an optical material, the inner cladding region being arranged around the core region within the internal volume and extending in the longitudinal direction, the inner cladding region comprising a plurality of anti-resonance elements being arranged adjacent to the inner wall, each having an elongated cross-sectional geometry with a minor axis and a major axis, wherein the major axis is arranged along a radial direction of the fiber and the minor axis is arranged along a tangential direction of the fiber, and wherein the anti-resonance elements are further arranged in a distance from their neighboring elements, and wherein the anti-resonance elements have a negative curvature where they are proximal to the core region.
Polarization noise places severe constraints on coherence of all-normal dispersion femtosecond supercontinuum generation

Supercontinuum (SC) generated with all-normal dispersion (ANDi) fibers has been of special interest in recent years due to its potentially superior coherence properties when compared to anomalous dispersion-pumped SC. However, care must be taken in the design of such sources since too long pump pulses and fiber length has been demonstrated to degrade the coherence. To assess the noise performance of ANDi fiber SC generation numerically, a scalar single-polarization model has so far been used, thereby excluding important sources of noise, such as polarization modulational instability (PMI). In this work we numerically study the influence of pump power, pulse length and fiber length on coherence and relative intensity noise (RIN), taking into account both polarization components in a standard ANDi fiber for SC generation pumped at 1064 nm. We demonstrate that the PMI introduces a power dependence not found in a scalar model, which means that even with short ~120 fs pump pulses the coherence of ANDi SC can be degraded at reasonable power levels above ~40 kW. We further demonstrate how the PMI significantly decreases the pump pulse length and fiber length at which the coherence of the ANDi SC is degraded. The numerical predictions are confirmed by RIN measurements of fs-pumped ANDi fiber SC.

Polymer optical fiber Bragg grating inscription with a single Nd:YAG laser pulse

We experimentally demonstrate the first polymer optical fiber Bragg gratings inscribed with only one Nd:YAG laser (266 nm) pulse. The gratings have been inscribed in a single-mode poly (methyl methacrylate) optical fiber, with a core doped with benzyl dimethyl ketal for photosensitivity enhancement. One laser pulse with a duration of 8 ns and energy of 72 µJ is adequate to introduce a refractive index change of 0.5 × 10⁻⁴ in the fiber core. The stability of the gratings has been confirmed and the strain and temperature sensitivity measurements demonstrate their tunable properties.
Prospective on using fibre mid-infrared supercontinuum laser sources for in vivo spectral discrimination of disease

Mid-infrared (MIR) fibre-optics may play a future role in in vivo diagnosis of disease, including cancer. Recently, we reported for the first time an optical fibre based broadband supercontinuum (SC) laser source spanning 1.3 to 13.4 μm wavelength to cover the spectral 'fingerprint region' of biological tissue. This work has catalysed the new field of fibre MIR-SC and now very bright sources equivalent to a 'few synchrotrons' have been demonstrated in fibre. In addition, we have made record transparency MIR fibre for routeing the MIR light and reported first-time MIR photoluminescence (with long lifetime) in small-core, rare earth ion doped, MIR fibre - an important step towards MIR fibre lasing at >4 μm wavelength for pumping fibre MIR-SC. First time fibre MIR-SC spectroscopic imaging of colon tissue is described at wavelengths in the 'fingerprint region'.

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Recovering distance information in spectral domain interferometry

This work evaluates the performance of the Complex Master Slave (CMS) method, that processes the spectra at the interferometer output of a spectral domain interferometry device without involving Fourier transforms (FT) after data acquisition. Reliability and performance of CMS are compared side by side with the conventional method based on FT, phase calibration with dispersion compensation (PCDC). We demonstrate that both methods provide similar results in terms of resolution and sensitivity drop-off. The mathematical operations required to produce CMS results are highly parallelizable, allowing real-time, simultaneous delivery of data from several points of different optical path differences in the interferometer, not possible via PCDC.
Resolution dependence on phase extraction by the Hilbert transform in phase calibrated and dispersion compensated ultrahigh resolution spectrometer-based OCT

Ultrahigh resolution optical coherence tomography (UHR-OCT) is enabled by using a broad band source. Simultaneously, this makes the OCT image more sensitive to dispersion mismatch in the interferometer. In spectral domain OCT, dispersion left uncompensated in the interferometer and detector non-linearities lead together to an unknown chirp of the detected interferogram. One method to compensate for the chirp is to perform a pixel-wavenumber calibration versus phase that requires numerical extraction of the phase. Typically a Hilbert transform algorithm is employed to extract the optical phase versus wavenumber for calibration and dispersion compensation. In this work we demonstrate UHR-OCT at 1300 nm using a Super continuum source and highlight the resolution constraints in using the Hilbert transform algorithm when extracting the optical phase for calibration and dispersion compensation. We demonstrate that the constraints cannot be explained purely by the numerical errors in the data processing module utilizing the Hilbert transform but must be dictated by broadening mechanisms originating from the experimentally obtained interferograms.
Supercontinuum applications in high resolution non invasive optical imaging
Progress will be presented in adapting supercontinuum sources to a variety of applications with emphasis on signal processing procedures. These are customised to alleviate noise and take full advantage of the large bandwidth and large power spectral density of modern supercontinuum sources.

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The Application of Hansen Solubility Parameters for Local Etching of TOPAS Polymer Optical Fibers.
Solvents are used in Polymer Optical Fiber (POF) etching for sensors. We present a general approach, use of Hansen Solubility Parameters (HSPs), for identifying usable solvents and first results on etching of TOPAS POFs.

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Thermal profile detection through high-sensitivity fiber optic chirped Bragg grating on microstructured PMMA fiber
In this work, a linearly chirped fiber Bragg grating (CFBG) inscribed in a microstructured polymer optical fiber (mPOF) has been demonstrated for detecting temperature profiles during thermal treatments. A CFBG of 10 mm length and 0.98 nm bandwidth has been inscribed in a mPOF fiber by means of a KrF laser and uniform phase mask. The CFBG has a high temperature sensitivity of -191.4 pm/°C). The CFBG has been used as a semi-distributed temperature sensor, capable of detecting the temperature profile along the grating length, for scenarios that account minimally invasive biomedical treatments. Two experiments have been designed to validate the CFBG temperature reconstruction, using a linear gradient, and a research-grade radiofrequency ablation (RFA) setup to apply Gaussian-shaped temperature spatial profiles. The result is that the higher sensitivity of the CFBG supports the detection of spatially non-uniform temperature fields by means of spectral reconstruction.

General information
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Thermal stability of fiber Bragg gratings inscribed in microstructured polymer optical fibers with a single UV laser pulse

We report on a pioneer thermal stability study of polymer optical fiber Bragg gratings (POFBGs) inscribed with a single laser pulse. The POFBG thermal decay follows a typical power-law function, which allowed us to simulate and predict POFBG lifetime for a maximum working temperature of 70 ºC, for a working period up-to 1000 years.

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The value of ultrahigh resolution OCT in dermatology - delineating the dermo-epidermal junction, capillaries in the dermal papillae and vellus hairs

Optical coherence tomography (OCT) imaging of the skin is gaining recognition and is increasingly applied to dermatological research. A key dermatological parameter inferred from an OCT image is the epidermal (Ep) thickness as a thickened Ep can be an indicator of a skin disease. Agreement in the literature on the signal characters of Ep and the subjacent skin layer, the dermis (D), is evident. Ambiguities of the OCT signal interpretation in the literature is however seen for the transition region between the Ep and D, which from histology is known as the dermo-epidermal junction (DEJ); a distinct junction comprised of the lower surface of a single cell layer in epidermis (the stratum basale) connected to an even thinner membrane (the basement membrane). The basement membrane is attached to the underlying dermis. In this work, we investigate the impact of an improved axial and lateral resolution on the applicability of OCT for imaging of the skin. To this goal, OCT images are compared produced by a commercial OCT system (Vivosight from Michaelson Diagnostics) and by an in-house built ultrahigh resolution (UHR-) OCT system for dermatology. In 11 healthy volunteers, we investigate the DEJ signal characteristics. We perform a detailed analysis of the dark (low) signal band clearly seen for UHR- OCT in the DEJ region where we, by using a transition function, find the signal transition of axial sub-resolution character, which can be directly attributed to the exact location of DEJ, both in normal (thin/hairy) and glabrous (thick) skin. To our knowledge no detailed delineating of the DEJ in the UHR- OCT image has previously been
reported, despite many publications within this field. For selected healthy volunteers, we investigate the dermal papillae and the vellus hairs and identify distinct features that only UHR-OCT can resolve. Differences are seen in tracing hairs of diameter below 20 µm, and in imaging the dermal papillae where, when utilising the UHR-OCT, capillary structures are identified in the hand palm, not previously reported in OCT studies and specifically for glabrous skin not reported in any other in vivo optical imaging studies. (c) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement.

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Towards a table-top synchrotron based on supercontinuum generation
Recently, high brightness and broadband supercontinuum (SC) sources reaching far into the infrared (IR) have emerged with the potential to rival traditional broadband sources of IR radiation. Here, the brightness of these IR SC sources is compared with that of synchrotron IR beamlines and SiC thermal emitters (Globars). It is found that SC sources can deliver a brightness that is 5-6 orders of magnitude higher than Globars and 1-2 orders of magnitude higher than typical IR beamlines, matching the beamlines at least out to 10.6 µm (940 cm⁻¹). This means that these sources can now cover nearly all of the 800-5000 cm⁻¹ spectrum (2-12.5 µm) which is frequently used in IR spectroscopy and microscopy. To demonstrate applicability, such an IR SC source was used for transmission spectroscopy of highly scattering filtration membranes from 3500-1300 cm⁻¹, and transmission microscopy of colon tissue at 1538 cm⁻¹.

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Two optical coherence tomography systems detect topical gold nanoshells in hair follicles, sweat ducts and measure epidermis

Optical coherence tomography (OCT) is an optical imaging technology that enables real time, high-resolution, cross-sectional and en face investigation of skin by detecting reflected broad-spectrum near-infrared light from tissue. OCT provides micron-scale spatial resolution and millimeter-scale depth of penetration [1]. Several commercial OCT systems with handheld probes targeted for Dermatology are now available [2].

Ultra-low noise supercontinuum source for ultra-high resolution optical coherence tomography at 1300 nm

Supercontinuum (SC) sources are of great interest for many applications due to their ultra-broad optical bandwidth, good beam quality and high power spectral density [1]. In particular, the high average power over large bandwidths makes SC light sources excellent candidates for ultra-high resolution optical coherence tomography (UHR-OCT) [2-5]. However, conventional SC sources suffer from high pulse-to-pulse intensity fluctuations as a result of the noise-sensitive nonlinear effects involved in the SC generation process [6-9]. This intensity noise from the SC source can limit the performance of OCT, resulting in a reduced signal-to-noise ratio (SNR) [10-12]. Much work has been done to reduce the noise of the SC sources for instance with fiber tapers [7,8] or increasing the repetition rate of the pump laser for averaging in the spectrometer [10,12]. An alternative approach is to use all-normal dispersion (ANDi) fibers [13,14] to generate SC light from well-known coherent nonlinear processes [15-17]. In fact, reduction of SC noise using ANDi fibers compared to anomalous dispersion SC pumped by sub-picosecond pulses has been recently demonstrated [18], but a cladding mode was used to stabilize the ANDi SC. In this work, we characterize the noise performance of a femtosecond pumped ANDi based SC and a commercial SC source in an UHR-OCT system at 1300 nm. We show that the ANDi based SC presents exceptional noise properties compared to a commercial source. An improvement of ~5 dB in SNR is measured in the UHR-OCT system, and the noise behavior resembles that of a superluminiscent diode. This preliminary study is a step forward towards development of an ultra-low noise SC source at 1300 nm for ultra-high resolution OCT.
Optical measuring system with an interrogator and a polymer-based single-mode fibre optic sensor system

The present invention relates to an optical measuring system comprising a polymer-based single-mode fibre-optic sensor system (102), an optical interrogator (101), and an optical arrangement (103) interconnecting the optical interrogator (101) and the polymer-based single-mode fibre-optic sensor system (102). The invention further relates to an optical interrogator adapted to be connected to a polymer-based single-mode fibre-optic sensor system via an optical arrangement. The interrogator comprises a broadband light source arrangement (104) and a spectrum analysing arrangement which receives and analyses light reflected from the polymer-based single-mode fibre-optic sensor system.

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A comparative study of noise in supercontinuum light sources for ultra-high resolution optical coherence tomography

Supercontinuum (SC) light is a well-established technology, which finds applications in several domains ranging from chemistry to material science and imaging systems [1-2]. More specifically, its ultra-wide optical bandwidth and high average power make it an ideal tool for Optical Coherence Tomography (OCT). Over the last 5 years, numerous examples have demonstrated its high potential [3-4] in this context. However, SC light sources present pulse-to-pulse intensity variation that can limit the performance of any OCT system [5] by degrading their signal to noise ratio (SNR). To this goal, we have studied and compared the noise of several SC light sources and evaluated how their noise properties affect the performance of Ultra-High Resolution OCT (UHR-OCT) at 1300 nm. We have measured several SC light sources with different parameters (pulse length, energy, seed repetition rate, etc.). We illustrate the different noise measurements and their impact on a state of the art UHR-OCT system producing images of skin. The sensitivity of the system was higher than 95 dB, with an axial resolution below 4μm.

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Annealing and etching effects on strain and stress sensitivity of polymer optical fibre Bragg grating sensors
Thermal annealing and chemical etching effects on the strain and stress sensitivity of polymer optical fibre based sensors are investigated. Bragg grating sensors have been photo-inscribed in PMMA optical fibre and their strain and stress sensitivity has been characterised before and after any annealing or etching process. The annealing and etching processes have been tried in different sequence in order to investigate their impact on the sensor's performance. Results show with high confidence that fibre annealing can improve both strain and stress sensitivities. The fibre etching can also provide stress sensitivity enhancement, however the strain sensitivity changes seems to be random.

Bandpass transmission filters based on phase shifted fiber Bragg gratings in microstructured polymer optical fibers
In this contribution we report on the fabrication of novel bandpass transmission filters based on PS-FBGs in microstructured polymer fibers at telecom wavelengths. The phase mask technique is employed to fabricate several superimposed gratings with slight different periods in order to form Moiré structures with a single or various π phase shifts along the device. Simulations and experimental results are included in order to demonstrate very narrowband transmission filters. Experimental characterization under strain and temperature variations is provided in a non-annealed fiber and time stability of the fabricated devices has been also measured under different pre-strain conditions.
BDK-doped core microstructured PMMA optical fiber for effective Bragg grating photo-inscription

An endlessly single-mode doped microstructured poly(methyl methacrylate) (PMMA) optical fiber is produced for effective fiber Bragg grating (FBG) photo-inscription by means of a 400 nm femtosecond pulsed laser and the phase mask technique. The fiber presents a uniform benzyl dimethyl ketal (BDK) distribution in its core without drastic loss increase. It was produced using the selected center hole doping technique, and the BDK dopant acts as a photoinitiator. In this Letter, we report a rapidly growing process of the grating reflection band. For an 11 mW mean laser power, the FBG reflectivity reaches 83% in only 40 s.

Compact multichannel high-resolution micro-electro-mechanical systems-based interrogator for Fiber Bragg grating sensing

We propose a novel type of compact high-resolution multichannel micro-electro-mechanical systems (MEMS)-based interrogator, where we replace the linear detector with a digital micromirror device (DMD). The DMD is typically cheaper and has better pixel sampling than an InGaAs detector used in the 1550 nm range, which leads to cost reduction and better performance. Moreover, the DMD is a 2D array, which means that multichannel systems can be implemented without any additional optical components in the interrogator. This makes the proposed interrogator highly cost-effective, particularly for multichannel systems. The digital nature of the DMD also provides opportunities for advanced programmable Hadamard spectroscopy, which, without significant penalties, can greatly improve the wavelength fit resolution. Our results show that DMDs can be used in high-resolution spectroscopy and for Fiber Bragg grating (FBG) interrogation.
Compact multichannel MEMS based spectrometer for FBG sensing

We propose a novel type of compact multichannel MEMS based spectrometer, where we replace the linear detector with a Digital Micromirror Device (DMD). The DMD is typically cheaper and has better pixel sampling than an InGaAs detector used in the 1550 nm range, which leads to cost reduction and better performance. Moreover, the DMD is a 2D array, which means that multichannel systems can be implemented without any additional optical components in the spectrometer. This makes the proposed interrogator highly cost-effective. The digital nature of the DMD also provides opportunities for advanced programmable spectroscopy.
Curvature and position of nested tubes in hollow-core anti-resonant fibers

Hollow-core anti-resonant (HC-AR) fibers where a symmetric distribution of cladding tubes compose a "negative-curvature" core boundary have extraordinary optical properties, such as low transmission loss, wide transmission bands and weak power overlap between the core modes and the silica parts [1], especially when smaller tubes are "nested" inside the larger tubes [2, 3]. Here we investigate the role of curvature and position of the nested tube and we show that the position of the nested tube has a much more pronounced effect compared to the curvature on the overall performance and single-mode operation of the fiber.

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Dispersion free full range spectral intensity optical coherence tomography
Optical coherence tomography (OCT) is a non-invasive imaging technique with many applications and widespread use in ophthalmology [1]. The axial resolution in OCT is inversely proportional to the bandwidth of the optical source used, but the improved axial resolution comes at the price of more significant effects of dispersion stemming from the imaging system and the imaged medium. In recent years, spectral intensity (SI) OCT has been shown, as a classical realisation of quantum OCT, to remove even orders of dispersion intrinsically [2, 3]. One major drawback of SI OCT is however halving of the imaging range which is crucial in spectrometer based OCT which is limited by the spectral resolution, and hence number of pixels of the spectrometer. In this work we demonstrate SI OCT with the full imaging range.

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Effects of pre-strain on the intrinsic pressure sensitivity of polymer optical fiber Bragg-gratings
We experimentally demonstrate a scheme for improving the intrinsic pressure sensitivity of fiber Bragg-gratings (FBGs) inscribed in polymer optical fibers by applying pre-strain in order to suppress the pressure induced mechanical contraction of the fiber. This contraction would otherwise contribute to a blueshift of the Brag-wavelength, counteracting the dominant redshift caused by the stress-optic effect, which effectively reduces the pressure sensitivity of the FBG. By applying this technique we are able to improve the sensitivity of the FBG from 2.8 pm/bar to 7.3 pm/bar. © (2017) COPYRIGHT Society
Efficient Mid-Infrared Supercontinuum Generation in Tapered Large Mode Area Chalcogenide Photonic Crystal Fibers

Mid-infrared supercontinuum spanning from 1.8-9 μm with an output power of 41.5 mW is demonstrated by pumping tapered large mode area chalcogenide photonic crystal fibers using a 4 μm optical parametric source.

Fast Bragg grating inscription in PMMA polymer optical fibers: Impact of thermal pre-treatment of preforms

In this work, fibre Bragg gratings (FBGs) were inscribed in two different undoped poly- (methyl methacrylate) (PMMA) polymer optical fibres (POFs) using different types of UV lasers and their inscription times, temperature and strain sensitivities are investigated. The POF Bragg gratings (POFBGs) were inscribed using two UV lasers: a continuous UV HeCd @325 nm laser and a pulsed UV KrF @248 nm laser. Two PMMA POFs are used in which the primary and secondary preforms (during the two-step drawing process) have a different thermal treatment. The PMMA POFs drawn in which the primary or secondary preform is not specifically pre-treated need longer inscription time than the fibres drawn where both preforms have been pre-annealed at 80 °C for 2 weeks. Using both UV lasers, for the latter fibre much less
inscription time is needed compared to another homemade POF. The properties of a POF fabricated with both preforms thermally well annealed are different from those in which just one preform step process is thermally treated, with the first POFs being much less sensitive to thermal treatment. The influence of annealing on the strain and temperature sensitivities of the fibres prior to FBG inscription is also discussed, where it is observed that the fibre produced from a two-step drawing process with well-defined pre-annealing of both preforms did not produce any significant difference in sensitivity. The results indicate the impact of preform thermal pre-treatment before the PMMA POFs drawing, which can be an essential characteristic in the view of developing POF sensors technology.

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**Femtosecond laser micromachining of compound parabolic concentrator fiber tipped glucose sensors**
We report on highly accurate femtosecond (fs) laser micromachining of a compound parabolic concentrator (CPC) fiber tip on a polymer optical fiber (POF). The accuracy is reflected in an unprecedented correspondence between the numerically predicted and experimentally found improvement in fluorescence pickup efficiency of a Förster resonance energy transfer-based POF glucose sensor. A Zemax model of the CPC-tipped sensor predicts an optimal improvement of a factor of 3.96 compared to the sensor with a plane-cut fiber tip. The fs laser micromachined CPC tip showed an increase of a factor of 3.5, which is only 11.6% from the predicted value. Earlier state-of-the-art fabrication of the CPC-shaped tip by fiber tapering was of so poor quality that the actual improvement was 43% lower than the predicted improvement of the ideal CPC shape.

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This paper describes the application of the Gabor filtering protocol to a Master/Slave (MS) swept source optical coherence tomography (SS)-OCT system at 1300 nm. The MS-OCT system delivers information from selected depths, a property that allows operation similar to that of a time domain OCT system, where dynamic focusing is possible. The Gabor filtering processing following collection of multiple data from different focus positions is different from that utilized by a conventional swept source OCT system using a Fast Fourier transform (FFT) to produce an A-scan. Instead of selecting the bright parts of A-scans for each focus position, to be placed in a final B-scan image (or in a final volume), and discarding the rest, the MS principle can be employed to advantageously deliver signal from the depths within each focus range only. The MS procedure is illustrated on creating volumes of data of constant transversal resolution from a cucumber and from an insect by repeating data acquisition for 4 different focus positions. In addition, advantage is taken from the tolerance to dispersion of the MS principle that allows automatic compensation for dispersion created by layers above the object of interest. By combining the two techniques, Gabor filtering and Master/Slave, a powerful imaging instrument is demonstrated. The master/slave technique allows simultaneous display of three categories of images in one frame: multiple depth en-face OCT images, two cross-sectional OCT images and a confocal like image obtained by averaging the en-face ones. We also demonstrate the superiority of MS-OCT over its FFT based counterpart when used with a Gabor filtering OCT instrument in terms of the speed of assembling the fused volume. For our case, we show that when more than 4 focus positions are required to produce the final volume, MS is faster than the conventional FFT based procedure.
Generation of multiple VUV dispersive waves using a tapered gas-filled hollow-core anti-resonant fiber

Hollow-core anti-resonant (HC-AR) fibers are perhaps the best platform for ultrafast nonlinear optics based on light-gas interactions because they offer broadband guidance and low-loss guidance. The main advantage of using gases inside HC fibers is that both the dispersion and nonlinearity can be tuned by simply changing the pressure of the gas [1]. The emission of efficient dispersive wave (DW) in the deep-UV has been already observed in a uniform Ar-filled hollow-core fiber with tunability from 200 to 320 nm by changing the gas pressure and pulse energy [2]. In the quest of optimizing the nonlinear process to further blue-shift the generated DWs towards vacuum ultra-violet (VUV), here we numerically demonstrate for the first time (to the best of our knowledge) how the use of a tapered Ar-filled HC-AR fiber leads to multiple DWs in the extreme wavelength region from 143 to 280 nm.

High power, ultra-broadband supercontinuum source based on highly GeO2 doped silica fiber

We demonstrate a 74 mol % GeO2 doped fiber for mid-infrared supercontinuum generation. Experiments ensure a highest output power for a broadest spectrum from 700nm to 3200nm from this fiber, while being pumped by a broadband 4 stage Erbium fiber based MOPA. The effect of repetition rate of pump source and length of Germania-doped fiber has also been investigated. Further, Germania doped fiber has been pumped by conventional Silica based photonic crystal fiber supercontinuum source. At low power, a considerable broadening of 200-300nm was observed. Further broadening of spectrum was limited due to limited power of pump source. Our investigations reveal the unexploited potential of Germania doped fiber for mid-infrared supercontinuum generation. This measurement ensures a possibility of Germania based photonic crystal fiber or a step-index fiber supercontinuum source for high power ultra-broad band emission being pumped a 1060nm or a 1550nm laser source. To the best of our knowledge, this is the record power, ultra-broadband, and all-fiberized SC light source based on Silica and Germania fiber ever demonstrated to the date.
High-quality phase-shifted Bragg grating sensor inscribed with only one laser pulse in a polymer optical fiber

We present the first phase-shifted polymer optical fiber Bragg grating sensor inscribed with only one KrF laser pulse. The phase shift defect was created directly during the grating inscription process by placing a very narrow blocking aperture, in the center of the UV beam. One laser pulse with a duration of 15 ns and energy 6.3 mJ is adequate to introduce a refractive index change of $0.69 \times 10^{-4}$ in the fiber core. The high-quality produced Bragg grating structure rejects 16.3 dB transmitted power, thus providing 97.6% reflectivity, which is well suited for photonic applications. The transmission notch depth is about 10 dB and very sharp notches of 3 dB width ranging from 14 pm is reported. The temperature, strain, and pressure response of the sensor has been characterized showing promising results in applications that require high-precision measurements. The ability to inscribe these high-quality sensors effectively can significantly reduce their production cost in industry.

Hybrid photonic-crystal fiber

This article offers an extensive survey of results obtained using hybrid photonic-crystal fibers (PCFs) which constitute one of the most active research fields in contemporary fiber optics. The ability to integrate novel and functional materials in solid- and hollow-core PCFs through various postprocessing methods has enabled new directions toward understanding fundamental linear and nonlinear phenomena as well as novel application aspects, within the fields of optoelectronics, material and laser science, remote sensing, and spectroscopy. Here the recent progress in the field of hybrid PCFs is reviewed from scientific and technological perspectives, focusing on how different fluids, solids, and gases can significantly extend the functionality of PCFs. The first part of this review discusses the efforts to develop tunable linear and nonlinear fiber-optic devices using PCFs infiltrated with various liquids, glasses, semiconductors, and metals. The second part concentrates on recent and state-of-the-art advances in the field of gas-filled hollow-core PCFs. Extreme ultrafast gas-based nonlinear optics toward light generation in the extreme wavelength regions of vacuum ultraviolet, pulse propagation, and compression dynamics in both atomic and molecular gases, and novel soliton-plasma interactions are reviewed. A discussion of future prospects and directions is also included. Optical fibers provide much more than a means to transport light between different locations. This article reviews how integration of functional fluid, solid, and gaseous materials in photonic-crystal fibers enables control of their linear and nonlinear properties with applications in optoelectronics, sensing, and laser-matter interactions.
Increased mid-infrared supercontinuum bandwidth and average power by tapering large-mode-area chalcogenide photonic crystal fibers

The trade-off between the spectral bandwidth and average output power from chalcogenide fiber-based mid-infrared supercontinuum sources is one of the major challenges towards practical application of the technology. In this paper we address this challenge through tapering of large-mode-area chalcogenide photonic crystal fibers. Compared to previously reported step-index fiber tapers the photonic crystal fiber structure ensures single-mode propagation, which improves the beam quality and reduces losses in the taper due to higher-order mode stripping. By pumping the tapered fibers at 4 μm using a MHz optical parametric generation source, and choosing an appropriate length of the untapered fiber segments, the output could be tailored for either the broadest bandwidth from 1 to 11.5 μm with 35.4 mW average output power, or the highest output power of 57.3 mW covering a spectrum from 1 to 8 μm. (C) 2017 Optical Society of America
Influence of dispersion of nonlinearity on coherent supercontinuum generation bandwidth in photonic crystal fibers pumped at 2 μm

Sources of spectrally broadband and coherent light are necessary for frequency metrology and ultrashort pulse generation. Near-infrared (NIR) wavelengths are practical for such devices because of the emergence of robust and reasonably priced femtosecond lasers operating in this part of spectrum. This further enabled pulse preserving and coherent, so called all-normal dispersion supercontinuum (ANDi SC), covering over a full octave of around 600–1600 nm with pulse duration post-compressed down to single optical cycles [1]. When using the new erbium (1560 nm) or thulium (around 2000 nm) femtosecond lasers as pump sources, exceeding the 2400 nm barrier has proved a challenge. ANDi SC requires strong nonlinear response of the optical material, since self-phase modulation (SPM) and optical wave breaking (OWB) mediated four-wave mixing (FWM) are almost exclusively shaping the ANDi SC pulses. Flatness of the normal dispersion profile is also important, because FWM in this case is not phase-matched and takes place at the instance of the temporal overlap of the OWB components. Here we investigate and explain the bandwidth limitation of NIR pulse-preservation coherent SC by confronting ANDi SC generation performance in two types of photonic crystal fibers (PCFs) — Fig. 1(a, b) [2]. One type (NC21 series) has a flat NIR dispersion profile at the cost of nonlinearity, due to low nonlinear refractive index n2 the glasses forming the PCF lattice. The other type (NC38 series) features weaker dependence of the effective mode area Aeff on wavelength and much higher nonlinearity, albeit at the cost of flatness of the engineered normal dispersion profile.

Long-term strain response of polymer optical fiber FBG sensors

We report on the viscoelastic response of PMMA microstructured polymer optical fibers (mPOFs) when exposed to long periods of strain and relaxation, with the strain period ranging from 0.5 min to 50 min. The behavior of the fibers was monitored by inscribing a fiber Bragg grating (FBG) in them and tracking the reflection peak. We demonstrate that the fiber, when relaxing from strains of up to 0.9%, has a two-phase recovery: initially linear (elastic driven) and subsequently nonlinear (viscoelastic driven) contraction. The linear (elastic) relaxation wavelength range depends both on the strain level and on the strain duration. For short strain durations, this wavelength range stays the same, but with increasing strain duration, it decreases, which will influence the operation range of mPOF and POF-based FBG sensors.
Low Loss Polycarbonate Polymer Optical Fiber for High Temperature FBG Humidity Sensing

We report the fabrication and characterization of a polycarbonate (PC) microstructured polymer optical fiber (mPOF) Bragg grating (FBG) humidity sensor that can operate beyond 100°C. The PC preform, from which the fiber was drawn, was produced using an improved casting approach to reduce the attenuation of the fiber. The fiber loss was found reduced by a factor of two compared to the latest reported PC mPOF [20], holding the low loss record in PC based fibers. PC mPOFBG was characterized to humidity and temperature, and a relative humidity (RH) sensitivity of 7.31± 0.13 pm/% RH in the range 10–90% RH at 100°C and a temperature sensitivity of 25.86±0.63 pm/°C in the range 20–100 °C at 90% RH were measured.

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Master/slave: A better tool for Gabor filtering optical coherence tomography imaging instruments

In this report, the benefits that the Master/Slave (MS) implementation of optical coherence tomography (OCT) can bring to a Gabor filtering (GF) imaging instrument are illustrated. The MS allows simultaneous display of three categories of images in one frame: multiple depth en-face OCT images, two B-scan OCT and a confocal like image. The power of MS is illustrated here by showing 3D images of constant transversal resolution from different objects, obtained by merging sub-volumes collected for four different focus positions. By combining the two techniques, GF and MS, a powerful imaging instrument is demonstrated. We show that when more than four focus positions are required, MS can produce fused volumes faster than the conventional FT based procedure.

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Multiple soliton compression stages in mid-IR gas-filled hollow-core fibers

The light confinement inside hollow-core (HC) fibers filled with noble gases constitutes an efficient route to study interesting soliton-plasma dynamics [1]. More recently, plasma-induced soliton splitting at the self-compression point was observed in a gas-filled fiber in the near-IR [2]. However, the role of the plasma is so far not investigated in the mid-IR. This range is interesting because the photon energy is much lower, and thereby the plasma formation dynamics will be different, and because the mid-IR is currently being explored for generating few-cycle pulses and for supercontinuum generation. Here we investigate the soliton-plasma dynamics in a mid-IR pumped Xe-filled HC silica fiber based on the so-called anti-resonant (AR) effect. We find a novel soliton dynamics scenario where multiple soliton self-compression stages are observed.
which the dispersion is normal for all the wavelengths of interest. Pumping these types of fibers with short enough femtosecond pulses allows to suppress stimulated Raman scattering (SRS), which is known to be a noisy process as modulation instability (MI), and coherent SC is generated through self-phase modulation (SPM) and optical wave breaking (OWB). In this study, we show the importance of the pump laser and fiber parameters in the design of low-noise ANDi based SC sources, for application in OCT. We numerically investigate the pulse-to-pulse fluctuations of the SC, calculating the relative intensity noise (RIN) as a function of the pump pulse duration and fiber length. Furthermore, we experimentally demonstrate the role of the fiber length on the RIN of the ANDi SC, validating the results calculated numerically. In the end, we compare the RIN of a commercial SC source based on MI and the ANDi SC source developed here, which shows better noise performance when it is carefully designed.

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Non-destructive testing of layer-to-layer fusion of a 3D print using ultrahigh resolution optical coherence tomography
Within the last decade, 3D printing has moved from a costly approach of building mechanical items to the present state-of-the-art phase where access to 3D printers is now common, both in industry and in private places. The plastic printers are the most common type of 3D printers providing prints that are light, robust and of lower cost. The robustness of the structure printed is only maintained if each layer printed is properly fused to its previously printed layers. In situations where the printed component has to accomplish a key mechanical role there is a need to characterize its mechanical strength. This may only be revealed by in-depth testing in order to discover unwanted air-gaps in the structure. Optical coherence tomography (OCT) is an in-depth imaging method, that is sensitive to variations in the refractive index and therefore can resolve with high resolution translucid samples. We report on volume imaging of a 3D printed block made with 100% PLA fill. By employing ultrahigh resolution OCT (UHR-OCT) we show that some parts of the PLA volume reveal highly scattering interfaces which likely correspond to transitions from one layer to another. In doing so, we document that UHR-OCT can act as a powerful tool that can be used in detecting fractures between layers stemming from insufficient fusion between printed structure layers. UHR-OCT can therefore serve as an useful assessment method of quality of 3D prints.

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Phase estimation for global defocus correction in optical coherence tomography
In this work we investigate three techniques for estimation of the non-linear phase present due to defocus in optical coherence tomography, and apply them with the angular spectrum method. The techniques are: Least squares setting the of unwrapped phase of the angular spectrum, iterative optimization, and sub-aperture correlations. The estimated phase of a single en-face image is used to extrapolate the non-linear phase at all depths, which is the end can be used to correct the entire 3-D tomogram, and any other tomogram from the same system.

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Phase-shifted Bragg grating inscription in PMMA microstructured POF using 248 nm UV radiation
In this work we experimentally validate and characterize the first phase-shifted polymer optical fiber Bragg gratings (PS-POFBGs) produced using a single pulse from a 248 nm krypton fluoride laser. A single-mode poly (methyl methacrylate) optical fiber with a core doped with benzyl dimethyl ketal for photosensitivity improvement was used. A uniform phase mask customized for 850 nm grating inscription was used to inscribe these Bragg structures. The phase shift defect was created directly during the grating inscription process by placing a narrow blocking aperture in the center of the UV beam. The produced high-quality Bragg grating structures, presenting a double dips, reject 16.3 dB (97.6% reflectivity) and 13.2 dB (95.2% reflectivity) of the transmitted power, being therefore appropriate for sensing or other photonic applications. Its transmission spectrum possesses two sharp transmission notches, allowing a significant increase in measurement resolution compared to direct interrogation of a single grating. The reflection and transmission spectra when multiple phase shifts are introduced in the FBG structure are also shown. The PS-POFBG's strain, temperature, pressure, and humidity characteristics have been experimentally analyzed in detail to assess their potential usage as sensors.

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We investigate the polarization of supercontinuum generated in nominally non-birefringent silica photonic crystal fibers over the entire spectrum of the source (450-2400 nm). We demonstrate that the degree of polarization varies over the spectrum but that some parts of the spectrum show stable polarization extinction ratios (PER) of over 10 dB. We experimentally demonstrate how the spectrally resolved polarization develops with increasing power and along the length of the nonlinear fiber. The experimental results are compared to numerical simulations of coupled polarization states mimicking the experimental conditions. Subsequently, a single-shot pulse-to-pulse polarization dependent relative intensity noise (PD-RIN) was measured and the noise characteristics were analyzed using long-tailed and rogue wave statistics. To do this, we used a range of 10 nm narrow bandpass filters (BPF) between 550 nm to 2200 nm, and fast photo detectors, to record 800 consecutive pulses. Peaks from these pulses are first extracted, then distribution of their pulse height histogram (PHH) is constructed. Analysis using higher-order moments about the mean (variance, skewness and kurtosis) showed that: (1) around the pump wavelength of 1064nm, the PD-RIN is lowest, PHH exhibits a Gaussian distribution, and higher order moments are zero, (2) further away from pump, PD-RIN increases in parabolic fashion, PHH follows a left-skewed long-tailed Gamma distribution, and higher-order moments increase. Spectrally, the difference of the PD-RIN in the two orthogonal axes increases with PER.

Polymer optical fiber Bragg grating inscription with a single UV laser pulse
We experimentally demonstrate the first polymer optical fiber Bragg grating inscribed with only one krypton fluoride laser pulse. The device has been recorded in a single-mode poly(methyl methacrylate) optical fiber, with a core doped with benzyl dimethyl ketal for photosensitivity enhancement. One laser pulse with a duration of 15 ns, which provide energy density of 974 mJ/cm², is adequate to introduce a refractive index change of 0.74×10⁻⁴ in the fiber core. After the exposure, the reflectivity of the grating increases for a few minutes following a second order exponential saturation. The produced Bragg grating structure rejects 17.9 dB transmitted power, thus providing 98.4% reflectivity, which is well suited for sensing applications. In addition, we report the importance of the fiber thermal treatment before or after the inscription,
showing its effects on the lifetime and quality of the grating structures. Optimizing the irradiation conditions and the material chemical composition, a higher refractive index change in the fiber core is feasible. This demonstration significantly improves the potential for commercial exploitation of the technology.

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**Q-switch-pumped supercontinuum for ultra-high resolution optical coherence tomography**
In this Letter, we investigate the possibility of using a commercially available Q-switch-pumped supercontinuum (QS-SC) source, operating in the kilohertz regime, for ultrahigh resolution optical coherence tomography (UHR-OCT) in the 1300 nm region. The QS-SC source proves to be more intrinsically stable from pulse to pulse than a mode-locked-based SC (ML-SC) source while, at the same time, is less expensive. However, its pumping rate is lower than that used in ML-SC sources. Therefore, we investigate here specific conditions to make such a source usable for OCT. We compare images acquired with the QS-SC source and with a current state-of-the-art SC source used for imaging. We show that comparable visual contrast obtained with the two technologies is achievable by increasing the readout time of the camera to include a sufficient number of QS-SC pulses.

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Simultaneous measurement of temperature and humidity with microstructured polymer optical fiber Bragg gratings
A microstructured polymer optical fiber (mPOF) Bragg grating sensor system for the simultaneous measurement of temperature and relative humidity (RH) has been developed and characterized. The sensing head is based on two in-line fiber Bragg gratings recorded in a mPOF. The sensor system has a root mean square deviation of 1.04 % RH and 0.8 °C in the range 10 to 90% RH and 20 to 80 °C. The proposed sensor system is easy to fabricate, cheap and compact.

Soliton-plasma nonlinear dynamics in mid-IR gas-filled hollow-core fibers
We investigate numerically soliton-plasma interaction in a noble-gas-filled silica hollow-core anti-resonant fiber pumped in the mid-IR at 3.0 μm. We observe multiple soliton self-compression stages due to distinct stages where either the self-focusing or the self-defocusing nonlinearity dominates. Specifically, the parameters may be tuned so the competing plasma self-defocusing nonlinearity only dominates over the Kerr self-focusing nonlinearity around the soliton self-compression stage, where the increasing peak intensity on the leading pulse edge initiates a competing self-defocusing plasma nonlinearity acting nonlocally on the trailing edge, effectively preventing soliton formation there. As the plasma switches off after the self-compression stage, self-focusing dominates again, initiating another soliton self-compression stage in the trailing edge. This process is accompanied by supercontinuum generation spanning 1-4 μm. We find that the spectral coherence drops as the secondary compression stage is initiated. (C) 2017 Optical Society of America
Soliton-plasma nonlinear dynamics in mid-IR gas-filled hollow-core fibers
This publisher's note corrects Eq. (1) of Opt. Lett.42, 2232 (2017)OPLEDP0146-959210.1364/OL.42.002232.

Solution-Mediated Annealing of Polymer Optical Fiber Bragg Gratings at Room Temperature
In this letter, we investigate the response of poly(methylmethacrylate) (PMMA) microstructured polymer optical fiber Bragg gratings (POFBGs) after immersion in methanol/water solutions at room temperature. As the glass transition temperature of solution-equilibrated PMMA differs from the one of solvent-free PMMA, different concentrations of methanol and water lead to various degrees of frozen-in stress relaxation in the fiber. After solvent evaporation, we observe a permanent blue-shift in the grating resonance wavelength. The main contribution in the resonance wavelength shift arises from a permanent change in the size of the fiber. The results are compared with conventional annealing. The proposed methodology is cost-effective as it does not require a climate chamber. Furthermore, it enables an easy-to-control tuning of the resonance wavelength of POFBGs.
Thermal and chemical treatment of polymer optical fiber Bragg grating sensors for enhanced mechanical sensitivity

An investigation of the thermal annealing effects on the strain, stress, and force sensitivities of polymer optical fiber Bragg grating sensors is performed. We demonstrate for the first time that the fiber annealing can enhance both stress and force sensitivities of Bragg grating sensors, with the possible cause being the molecular relaxation of the polymer when fiber is raised above the β-transition temperature. A simple, cost-effective, but well controlled method for fiber annealing is also presented in this work. In addition, the effects of chemical etching on the strain, stress, and force sensitivities have been investigated. Results show that fiber etching too can increase the force sensitivity, and it can also affect the strain and stress sensitivities of the Bragg grating sensors.

Toward single-mode UV to near-IR guidance using hollow-core antiresonant silica fiber

Hollow-core anti-resonant (HC-AR) fibers with a "negative-curvature" of the core-cladding boundary have been extensively studied over the past few years owing to their low loss and wide transmission bandwidths. The key unique feature of the HC-AR fiber is that the coupling between the core and cladding modes can be made anti-resonant (strongly inhibited) by suitably arranging the anti-resonant tubes in the cladding, which results in low loss and broad spectral bandwidths. HC-AR fibers have been fabricated aimed at visible, near or mid-IR transmission [1-4]. Here we fabricate and characterize a silica HC-AR fiber having a single ring of 7 non-touching capillaries, designed to have effectively single-mode operation and low loss from UV to near-IR.
Zeonex microstructured polymer optical fiber: fabrication friendly fibers for high temperature and humidity insensitive Bragg grating sensing

In the quest of finding the ideal polymer optical fiber (POF) for Bragg grating sensing, we have fabricated and characterized an endlessly single mode microstructured POF (mPOF). This fiber is made from cyclo-olefin homopolymer Zeonex grade 480R which has a very high glass transition temperature of 138 °C and is humidity insensitive. It represents a significant improvement with respect to the also humidity insensitive Topas core fibers, in that Zeonex fibers are easier to manufacture, has better transmittance, higher sensitivity to temperature and better mechanical stability at high temperature. Furthermore, Zeonex has very good compatibility with PMMA in terms of dilatation coefficients for co-drawing applications. The Zeonex mPOF has a core and cladding diameter of 8.8 µm and 150 µm, respectively, with a hole to pitch ratio of 0.4 and a minimum propagation loss of 2.34 ± 0.39 dB/m at 690.78 nm. We have also inscribed and characterized fiber Bragg gratings (FBGs) in Zeonex mPOFs in the low loss 850 nm spectral band.
In this Letter, we report for the first time, to the best of our knowledge, the fabrication and characterization of a Zeonex/PMMA microstructured polymer optical fiber (mPOF) Bragg grating sensor for simultaneous monitoring of relative humidity (RH) and temperature. The sensing element (probe) is based on two separate in-line fiber Bragg gratings (FBGs) inscribed in the fabricated mPOF. A root mean square deviation of 0.8% RH and 0.6°C in the range of 10%-90% RH and 20°C-80°C was found. The developed mPOF sensor constitutes an efficient route toward low-cost, easy-to-fabricate and compact multi-parameter sensing solutions.

3D-printed PMMA Preform for Hollow-core POF Drawing

In this paper we report the first, to our knowledge, 3D-printed hollow-core poly(methyl methacrylate) (PMMA) preform for polymer optical fibre drawing. It was printed of commercial PMMA by means of fused deposition modelling technique. The preform was drawn to cane, proving good enough quality of drawing process and the PMMA molecular weight to be appropriate for drawing. This ascertains that the manufacturing process provides preforms suitable for hollow-core fibre drawing. The paper focuses on maximisation of transparency of PMMA 3D printouts by optimising printing process parameters: nozzle temperature, printing speed and infill.

3-D printed sensing patches with embedded polymer optical fibre Bragg gratings

The first demonstration of a polymer optical fibre Bragg grating (POFBG) embedded in a 3-D printed structure is reported. Its cyclic strain performance and temperature characteristics are examined and discussed. The sensing patch has a repeatable strain sensitivity of 0.38 pm/με. Its temperature behaviour is unstable, with temperature sensitivity
values varying between 30-40 pm/degrees C.

Anisotropic anti-resonant elements gives broadband single-mode low-loss hollow-core fibers
Hollow-core fibers with node-free anisotropic anti-resonant elements give broadband low-loss fibers that are also single-moded. At 1.06 μm silica-based fiber designs show higher-order-mode extinction-ratio >1000 and losses below 10 dB/km over a broad wavelength range.
Annealing effects on strain and stress sensitivity of polymer optical fibre based sensors

The annealing effects on strain and stress sensitivity of polymer optical fibre Bragg grating sensors after their photoinscription are investigated. PMMA optical fibre based Bragg grating sensors are first photo-inscribed and then they were placed into hot water for annealing. Strain, stress and force sensitivity measurements are taken before and after annealing. Parameters such as annealing time and annealing temperature are investigated. The change of the fibre diameter due to water absorption and the annealing process is also considered. The results show that annealing the polymer optical fibre tends to increase the strain, stress and force sensitivity of the photo-inscribed sensor.

Antiresonant hollow core fiber with seven nested capillaries

We report an antiresonant hollow core fiber formed of 7 non-touching capillaries with inner tubes. The fiber has a core diameter of ~33μm and a core wall of ~780nm of thickness. We demonstrate robust single mode operation at 1064nm and broad transmission bandwidth.
Aviation Fuel Gauging Sensor Utilizing Multiple Diaphragm Sensors Incorporating Polymer Optical Fiber Bragg Gratings

A high-performance fuel gauging sensor is described that uses five diaphragm-based pressure sensors, which are monitored using a linear array of polymer optical fiber Bragg gratings. The sensors were initially characterized using water, revealing a sensitivity of 98 pm/cm for four of the sensors and 86 pm/cm for the fifth. The discrepancy in the sensitivity of the fifth sensor has been explained as being a result of the annealing of the other four sensors. Initial testing in JET A-1 aviation fuel revealed the unsuitability of silicone rubber diaphragms for prolonged usage in fuel. A second set of sensors manufactured with a polyurethane-based diaphragm showed no measurable deterioration over a three month period immersed in fuel. These sensors exhibited a sensitivity of 39 pm/cm, which is less than the silicone rubber devices due to the stiffer nature of the polyurethane material used.
Bragg grating photo-inscription in doped microstructured polymer optical fiber by 400 nm femtosecond laser pulses.

In this paper, we report the manufacturing of high-quality endlessly single-mode doped microstructured poly(methyl methacrylate) (PMMA) optical fibers. Bragg gratings are photo-inscribed in such fibers by means of 400 nm femtosecond laser pulses through a 1060-nm-period uniform phase mask. Preliminary results show a rapid growing process of the reflection band. To preserve a good spectral shape, the photo-inscription process was limited to ~20 seconds, yielding an FBG reflectivity close to 40%.

Coherent supercontinuum bandwidth limitations under femtosecond pumping at 2 μm in all-solid soft glass photonic crystal fibers

Two all-solid glass photonic crystal fibers with all-normal dispersion profiles are evaluated for coherent supercontinuum generation under pumping in the 2.0 μm range. Inhouse boron-silicate and commercial lead-silicate glasses were used to fabricate fibers optimized for either flat dispersion, albeit with lower nonlinearity, or with larger dispersion profile curvature but with much higher nonlinearity. Recorded spectra at the redshifted edge reached 2500-2800 nm depending on fiber type. Possible factors behind these differences are discussed with numerical simulations. The fiber enabling the broadest spectrum is suggested as an efficient first stage of an all-normal dispersion cascade for coherent supercontinuum generation exceeding 3000 nm.
Compact multichannel demultiplexer for WDM-POF networks based on spatially overlapped FBGs

The fabrication of spatially overlapped fibre Bragg gratings over microstructured polymer optical fibre allows to demonstrate low-cost and compact multichannel wavelength division demultiplexers. Coarse and dense wavelengths in high-capacity optical systems have been demonstrated for reduced size environments with the advantages of polymer fibres.

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Creation of a microstructured polymer optical fiber with UV Bragg grating inscription for the detection of extensions at temperatures up to 125°C

We describe the fabrication of a polycarbonate (PC) micro-structured polymer optical fiber (mPOF) and the writing of fiber Bragg gratings (FBGs) in it to enable strain and temperature measurements. We demonstrate the photosensitivity of a dopant-free PC fiber by grating inscription using a UV laser. We further show that PC Bragg gratings can be extended up to at least 3% without affecting the initial functionality of the micro-structured fiber. The response of PC FBGs to temperature up to 125°C is also investigated. Polycarbonate has good mechanical properties and its high temperature resistance might extend the range of application of polymeric FBGs.

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Embedding silica and polymer fibre Bragg gratings (FBG) in plastic 3D-printed sensing patches

This paper reports the first demonstration of a silica fibre Bragg grating (SOFBG) embedded in an FDM 3-D printed housing to yield a dual grating temperature-compensated strain sensor. We also report the first ever integration of polymer fibre Bragg grating (POFBG) within a 3-D printed sensing patch for strain or temperature sensing. The cyclic strain performance and temperature characteristics of both devices are examined and discussed. The strain sensitivities of the sensing patches were 0.40 and 0.95 pm/με for SOFBG embedded in ABS, 0.38 pm/με for POFBG in PLA, and 0.15 pm/με for POFBG in ABS. The strain response was linear above a threshold and repeatable. The temperature sensitivity of the SOFBG sensing patch was found to be up to 169 pm/°C, which was up to 17 times higher than for an unembedded silica grating. Unstable temperature response POFBG embedded in PLA was reported, with temperature sensitivity values varying between 30 and 40 pm/°C.

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Fabrication and characterization of polycarbonate microstructured polymer optical fibers for high-temperature-resistant fiber Bragg grating strain sensors
Here we present the fabrication of a solid-core microstructured polymer optical fiber (mPOF) made of polycarbonate (PC), and report the first experimental demonstration of a fiber Bragg grating (FBG) written in a PC optical fiber. The PC used in this work has a glass transition temperature of 145°C. We also characterize the mPOF optically and mechanically, and further test the sensitivity of the PC FBG to strain and temperature. We demonstrate that the PC FBG can bear temperatures as high as 125°C without malfunctioning. In contrast, polymethyl methacrylate-based FBG technology is
Fuel level sensor based on polymer optical fiber Bragg gratings for aircraft applications

Safety in civil aviation is increasingly important due to the increase in flight routes and their more challenging nature. Like other important systems in aircraft, fuel level monitoring is always a technical challenge. The most frequently used level sensors in aircraft fuel systems are based on capacitive, ultrasonic and electric techniques, however they suffer from intrinsic safety concerns in explosive environments combined with issues relating to reliability and maintainability. In the last few years, optical fiber liquid level sensors (OFLLSs) have been reported to be safe and reliable and present many advantages for aircraft fuel measurement. Different OFLLSs have been developed, such as the pressure type, float type, optical radar type, TIR type and side-leaking type. Amongst these, many types of OFLLSs based on fiber gratings have been demonstrated. However, these sensors have not been commercialized because they exhibit some drawbacks: low sensitivity, limited range, long-term instability, or limited resolution. In addition, any sensors that involve direct interaction of the optical field with the fuel (either by launching light into the fuel tank or via the evanescent field of a fiber-guided mode) must be able to cope with the potential build up of contamination – often bacterial – on the optical surface. In this paper, a fuel level sensor based on microstructured polymer optical fiber Bragg gratings (mPOFBGs), including poly (methyl methacrylate) (PMMA) and TOPAS fibers, embedded in diaphragms is investigated in detail. Our new system exhibits a high performance when compared with other previously published in the literature, making it a potentially useful tool for aircraft fuel monitoring.
Keywords: Fibre optic sensors; fibre gyro, Other fibre optical devices and techniques, Spatial variables measurement, Optical polymers and other organic optical materials, Gratings, echelles, Fibre optic sensors, Level, flow and volume measurement, Aerospace instrumentation and equipment, Optical materials, aircraft, Bragg gratings, diaphragms, fibre optic sensors, fuel, fuel systems, level measurement, optical polymers, optical radar, water, fuel level sensor, civil aviation, flight routes, fuel level monitoring, aircraft fuel systems, capacitive techniques, ultrasonic techniques, electric techniques, explosive environments, reliability, maintainability, optical fiber liquid level sensors, OFLLS, aircraft fuel measurement, pressure type, float type, optical radar type, TIR type, side-leaking type, long-term instability, limited resolution, optical field, fuel tank, evanescent field, fiber-guided mode, contamination, optical surface, microstructured polymer optical fiber Bragg gratings, mPOFBG, poly(methyl methacrylate), PMMA fibers, TOPAS fibers, aviation fuel, aircraft fuel monitoring

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High energy supercontinuum sources using tapered photonic crystal fibers for multispectral photoacoustic microscopy

We demonstrate a record bandwidth high energy supercontinuum source suitable for multispectral photoacoustic microscopy. The source has more than 150 nJ/10 nm bandwidth over a spectral range of 500 to 1600 nm. This performance is achieved using a carefully designed fiber taper with large-core input for improved power handling and small-core output that provides the desired spectral range of the supercontinuum source.

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High-power picosecond pulse delivery through hollow core photonic band gap fibers

We demonstrated robust and bend insensitive fiber delivery of high power laser with diffraction limited beam quality for two different kinds of hollow core band gap fibers. The light source for this experiment consists of ytterbium-doped double clad fiber aeroGAIN-ROD-PM85 in a high power amplifier setup. It provided 22ps pulses with a maximum average power of 95W, 40MHz repetition rate at 1032nm (~2.4μJ pulse energy), with M2 <1.3. We determined the facet damage threshold for a 7-cells hollow core photonic bandgap fiber and showed up to 59W average power output for a 5 meters fiber. The damage threshold for a 19-cell hollow core photonic bandgap fiber exceeded the maximum power provided by the light source and up to 76W average output power was demonstrated for a 1m fiber. In both cases, no special attention was needed to mitigate bend sensitivity. The fibers were coiled on 8 centimeters radius spools and even lower bending radii were present. In addition, stimulated rotational Raman scattering arising from nitrogen molecules was measured through a 42m long 19 cell hollow core fiber. © (2016) COPYRIGHT Society of Photo-Optical Instrumentation Engineers (SPIE). Downloading of the abstract is permitted for personal use only.
Hollow-core fibers for high power pulse delivery

We investigate hollow-core fibers for fiber delivery of high power ultrashort laser pulses. We use numerical techniques to design an anti-resonant hollow-core fiber having one layer of non-touching tubes to determine which structures offer the best optical properties for the delivery of high power picosecond pulses. A novel fiber with 7 tubes and a core of 30 μm was fabricated and it is here described and characterized, showing remarkable low loss, low bend loss, and good mode quality. Its optical properties are compared to both a 10 μm and a 18 μm core diameter photonic band gap hollow-core fiber. The three fibers are characterized experimentally for the delivery of 22 picosecond pulses at 1032 nm. We demonstrate flexible, diffraction limited beam delivery with output average powers in excess of 70 W. (C) 2016 Optical Society of America

Intrinsic pressure response of a single mode cyclo olefin polymer fiber Bragg grating

The intrinsic pressure response of a Fibre Bragg Grating (FBG) inscribed in a single-mode cyclo olefin polymer (COP) microstructured polymer optical fibre (mPOF) in the range 0-200 bar is investigated for the first time. In order to efficiently suppress the effects from changes in temperature and relative humidity the pressure calibration is performed in a gas free environment with the FBG submerged in water. As a result of the incompressible nature of water no temperature effects due to rapid pressure changes are observed. We find a highly linear, hysteresis-free response with a sensitivity of 2.982 ±
0.002 pm/bar. The corresponding fractional sensitivity is found to be 34.5·10⁻⁶ MPa⁻¹ which is of the same order of magnitude as the results obtained for a multimode PMMA mPOF-FBG at 1562 nm previously reported in the literature. The resulting pressure resolution of our sensor is estimated to be 2 bar based on a root mean square deviation of 6 pm.

Investigation of the in-solution relaxation of polymer optical fibre Bragg gratings
We investigate the response of PMMA microstructured polymer optical fibre Bragg gratings when immersed in methanol/water solutions. Overall we observe a permanent blue-shift in Bragg grating wavelength after solvent evaporation. The main contribution in the resonance wavelength shift probably arises from a permanent change in the size of the fibre, as already reported for high-temperature annealing of polymer optical fibres. As a consequence of the solution concentration dependence of the glass transition temperature of polymers, different methanol/water solutions lead to various degrees of frozen-in stress relaxation with an overall blue-shift of the Bragg grating wavelength.

Low-Loss Hollow-Core Anti-Resonant Fibers With Semi-Circular Nested Tubes
Hollow-core fibers with a single ring of circular antiresonant tubes as the cladding provide a simple way of getting a negative-curvature hollow core, resulting in broadband low-loss transmission with little power overlap in the glass. These fibers show a significant improvement in loss performance if the antiresonant tubes have nested tubes inside them, and here we investigate the role of the shape and position of these nested elements. By allowing the circular nested elements to become semi-circular, we selectively change the position or curvature of the nested elements. We find that the loss performance is quite insensitive to the curvature of the nested element, while the distance from the core boundary to the outer perimeter of the nested element is much more critical. Interestingly, the additional freedom of the semicircular nested elements allows optimizing them for a better loss performance than the ideal full-circle design.
Low loss mid-IR transmission bands using silica hollow-core anisotropic anti-resonant fibers

In this paper, a node-free anisotropic hollow-core anti-resonant fiber has been proposed to give low transmission loss in the near-IR to mid-IR spectral regime. The proposed silica-based fiber design shows transmission loss below 10 dB/km at 2.94 μm with multiple low loss transmission bands. Transmission loss of 1 dB/m up to 4 μm is also predicted.

Low-loss single-mode hollow-core fiber with anisotropic anti-resonant elements

A hollow-core fiber using anisotropic anti-resonant tubes in the cladding is proposed for low loss and effectively single-mode guidance. We show that the loss performance and higher-order mode suppression is significantly improved by using symmetrically distributed anisotropic antiresonant tubes in the cladding, elongated in the radial direction, when compared to using isotropic, i.e. circular, anti-resonant tubes. The effective single-mode guidance of the proposed fiber is achieved by enhancing the coupling between the cladding modes and higher-order-core modes by suitably engineering the anisotropic anti-resonant elements. With a silicabased fiber design aimed at 1.06 μm, we show that the loss extinction ratio between the higher-order core modes and the fundamental core mode can be more than 1000 in the range 1.0-1.65 μm, while the leakage loss of the fundamental core mode is below 15 dB/km in the same range.
Mid-infrared Spectroscopy/Bioimaging: Moving toward MIR optical biopsy

Limited availability of tests to diagnose cancer in its early stages has contributed to an unfortunate prevalence of late-stage diagnoses and metastatic spread. For this reason, emerging technologies that promise early diagnosis constitute a key focus of research. Mid-infrared imaging (MIR), with its ability to enable in vivo medical diagnosis, is particularly interesting. In fact, the European Commission provides support for a major effort to develop the technology through its Framework Seven (FP7) project called MINERVA (MId-to-NEaR- infrared spectroscopy for improVed medical diAgnostics).
Mid-IR supercontinuum generation beyond 7 μm using a silica-fluoride-chalcogenide fiber cascade

We report on an experimental demonstration of mid-infrared cascaded supercontinuum generation in commercial silica, fluoride, and chalcogenide fibers as a potentially cheap and practical alternative to direct pumping schemes. A pump continuum up to 4.4 μm was generated in cascaded silica and fluoride fibers by an amplified 1.55 μm nanosecond diode laser. By pumping a commercial Ge10As22Se68 single-material photonic crystal fiber with 135.7 mW of the pump continuum from 3.5- 4.4 μm, we obtained a continuum up to 7.2 μm with a total output power after the collimating lens of 54.5 mW, and 3.7 mW above 4.5 μm.

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Modulation-instability biosensing using an As2S3 chalcogenide tapered fiber

We demonstrate an experimentally feasible biosensor design based on As2S3 chalcogenide tapered fiber. Pumping the fiber close to 1064 nm, a record sensitivity up to ~18 nm/nm was predicted.

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M-type fiber for exploiting higher-order-modes dispersion for application in mid-IR supercontinuum generation

We demonstrate an M-type fiber suitable for launching higher-order-modes (such as LP02&LP03) as core-confined-modes, while guiding LP01 and other lower-order-modes in a ring. The M-type fiber can shift the zero-dispersion-wavelength of bulk-material by several 1000 nanometers.
Multimode supercontinuum generation in chalcogenide glass fibres
Mid-infrared supercontinuum generation is considered in chalcogenide fibres when taking into account both polarisations and the necessary higher order modes. In particular we focus on high pulse energy supercontinuum generation with long pump pulses. The modeling indicates that when only a single polarisation in the fundamental mode is considered the obtainable supercontinuum bandwidth is substantially exaggerated compared to when both polarisations are taken into account. Our modeling shows that if the pump pulse is short enough (≤ 10ps) then higher order modes are not important because of temporal walk-off. In contrast long pump pulses (≥ 40ps) will efficiently excite higher order modes through Raman scattering, which will deplete the fundamental mode of energy and limit the possibility of obtaining a broadband supercontinuum.

Performance of low-cost few-mode fiber Bragg grating sensor systems: polarization sensitivity and linearity of temperature and strain response
We evaluate whether 850 nm fiber Bragg grating (FBG) sensor systems can use low-cost 1550 nm telecom fibers; in other words, how detrimental the influence of higher-order modes is to the polarization stability and linearity of the strain and temperature response. We do this by comparing polarization sensitivity of a few-mode 850 nm FBG sensor to a strictly single-mode 850 nm FBG sensor system using 850 nm single-mode fibers. We also compare the performance of the FBGs in strain and temperature tests. Our results show that the polarization stability and the linearity of the response...
degrade due to the presence of the higher-order modes. We demonstrate that, by using simple coiling of the 1550 nm fiber, one can regain the performance of the few-mode system and make it usable for high precision measurements.

**Polymer Optical Fiber Compound Parabolic Concentrator fiber tip based glucose sensor: In-Vitro Testing**

We present in-vitro sensing of glucose using a newly developed efficient optical fiber glucose sensor based on a Compound Parabolic Concentrator (CPC) tipped polymer optical fiber (POF). A batch of 9 CPC tipped POF sensors with a 35 mm fiber length is shown to have an enhanced fluorescence pickup efficiency with an average increment factor of 1.7 as compared to standard POF sensors with a plane cut fiber tip. In-vitro measurements for two glucose concentrations (40 and 400 mg/dL) confirm that the CPC tipped sensors efficiently can detect both glucose concentrations. It sets the footnote at the bottom of this column.
Polymer Optical Fibre Bragg Grating Humidity Sensor at 100ºC
We have demonstrated a polymer optical fibre Bragg grating humidity sensor that can be operated up to 100ºC. The sensor has been fabricated from a polycarbonate (PC) microstructured polymer optical fibre Bragg grating (mPOFBG). PC mPOFBG gave a relative humidity (RH) sensitivity of 6.95±0.83 pm/% RH in the range 10-90% RH at 100ºC and a temperature sensitivity of 25.94±0.47 pm/ºC in the range 20 - 100 ºC at 90% RH. Despite PC mPOFBGs shows smaller humidity sensitivity compared to PMMA mPOFBGs, they can be used to sense humidity beyond the operating temperature limit of PMMA mPOFBGs.

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Record power, ultra-broadband supercontinuum source based on highly GeO2 doped silica fiber
We demonstrate highly germania doped fibers for mid-infrared supercontinuum generation. Experiments ensure a highest output power of 1.44 W for a broadest spectrum from 700 nm to 3200 nm and 6.4 W for 800 nm to 2700 nm from these fibers, while being pumped by a broadband Erbium-Ytterbium doped fiber based master oscillator power amplifier. The effect of repetition frequency of pump source and length of germania-doped fiber has also been investigated. Further, germania doped fiber has been pumped by conventional supercontinuum source based on silica photonic crystal fiber supercontinuum source. At low power, a considerable broadening of 200-300 nm was observed. Further broadening of spectrum was limited due to limited power of pump source. Our investigations reveal the unexploited potential of germania doped fiber for mid-infrared supercontinuum generation. These measurements ensure the potential of germania based photonic crystal fiber or a step-index fiber supercontinuum source for high power ultra-broad band emission being by pumped a 1060 nm or a 1550 nm laser source. To the best of our knowledge, this is the record power, ultra-broadband, and all-fiberized supercontinuum light source based on silica and germania fiber ever demonstrated to the date. (C) 2016 Optical Society of America

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Publication date: 2016
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Refractive index and dispersion control of ultrafast laser inscribed waveguides in gallium lanthanum sulphide for near and mid-infrared applications

The powerful ultrafast laser inscription technique is used to fabricate optical waveguides in gallium lanthanum sulphide substrates. For the first time the refractive index profile and the dispersion of such ultrafast laser inscribed waveguides are experimentally measured. In addition the Zero Dispersion Wavelength of both the waveguides and bulk substrate is experimentally determined. The Zero Dispersion Wavelength was determined to be between 3.66 and 3.71 μm for the waveguides and about 3.61 μm for the bulk. This work paves the way for realizing ultrafast laser inscribed waveguide devices in gallium lanthanum sulphide glasses for near and mid-IR applications. (C) 2016 Optical Society of America

Sensitivity enhancement using annealed polymer optical fibre based sensors for pressure sensing applications

Thermal annealing can be used to induce a permanent negative Bragg wavelength shift for polymer fibre grating sensors and it was originally used for multiplexing purposes. Recently, researchers showed that annealing can also provide additional benefits, such as strain and humidity sensitivity enhancement and augmented temperature operational range. The annealing process can change both the optical and mechanical properties of the fibre. In this paper, the annealing
effects on the stress and force sensitivities of PMMA fibre Bragg grating sensors are investigated. The incentive for that investigation was an unexpected behaviour observed in an array of sensors which were used for liquid level monitoring. One sensor exhibited much lower pressure sensitivity and that was the only one that was not annealed. To further investigate the phenomenon, additional sensors were photo-inscribed and characterised with regard their stress and force sensitivities. Then, the fibres were annealed by placing them in hot water, controlling with that way the humidity factor. After annealing, stress and force sensitivities were measured again. The results show that the annealing can improve the stress and force sensitivity of the devices. This can provide better performing sensors for use in stress, force and pressure sensing applications.

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**Single mode step-index polymer optical fiber for humidity insensitive high temperature fiber Bragg grating sensors**
We have fabricated the first single-mode step-index and humidity insensitive polymer optical fiber operating in the 850 nm wavelength ranges. The step-index preform is fabricated using injection molding, which is an efficient method for cost effective, flexible and fast preparation of the fiber preform. The fabricated single-mode step-index (SI) polymer optical fiber (POF) has a 4.8µm core made from TOPAS grade 5013S-04 with a glass transition temperature of 134°C and a 150 µm cladding made from ZEONEX grade 480R with a glass transition temperature of 138°C. The key advantages of the proposed SIPOF are low water absorption, high operating temperature and chemical inertness to acids and bases and many polar solvents as compared to the conventional poly-methyl-methacrylate (PMMA) and polystyrene based POFs. In addition, the fiber Bragg grating writing time is short compared to microstructured POFs.

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Spectral-temporal composition matters when cascading supercontinua into the mid-infrared

Supercontinuum generation in chalcogenide fibers is a promising technology for broadband spatially coherent sources in the mid-infrared, but it suffers from discouraging commercial prospects, mainly due to a lack of suitable pump lasers. Here, a promising approach is experimentally demonstrated using an amplified 1.55 μm diode laser to generate a pump continuum up to 4.4 μm in cascaded silica and fluoride fibers. We present experimental evidence and numerical simulations confirming that the spectral-temporal composition of the pump continuum is critical for continued broadening in a chalcogenide fiber. The fundamental physical question is concerned with the long-wavelength components of the pump spectrum, which may consist of either solitons or dispersive waves. In demonstrating this we present a commercially viable fiber-cascading configuration to generate a mid-infrared supercontinuum up to 7 μm in commercial chalcogenide fibers.

Study of doping non-PMMA polymer fibre canes with UV photosensitive compounds

We propose a solution doping method for polycarbonate (PC) and TOPAS polymer optical fibre (POF) canes using different UV photosensitive dopants aiming to reduce the fibre Bragg grating inscription time at the typical Bragg grating inscription wavelength (325nm). Three-ring solid-core PC mPOF canes and hollow-core TOPAS canes were doped with a solution of dopants in acetone/methanol and hexane/methanol, respectively. Doping time, solvent mixture concentration and doping temperature were optimised. A long and stepwise drying process was applied to the doped canes to ensure complete solvent removal. This is required to avoid the formation of any bubbles during the fibre drawing process.
Temperature insensitive hysteresis free highly sensitive polymer optical fiber Bragg grating humidity sensor

The effect of humidity on annealing of poly (methyl methacrylate) (PMMA) based microstructured polymer optical fiber Bragg gratings (mPOFBGs) and the resulting humidity responsivity are investigated. Typically annealing of PMMA POFs is done in an oven without humidity control around 80°C and therefore at low humidity. We demonstrate that annealing at high humidity and high temperature improves the performances of mPOFBGs in terms of stability and sensitivity to humidity. PMMA POFBGs that are not annealed or annealed at low humidity level will have a low and highly temperature dependent sensitivity and a high hysteresis in the humidity response, in particular when operated at high temperature. PMMA mPOFBGs annealed at high humidity show higher and more linear humidity sensitivity with negligible hysteresis. We also report how annealing at high humidity can blue-shift the FBG wavelength more than 230 nm without loss in the grating strength.

Towards supercontinuum-driven hyperspectral microscopy in the mid-infrared

The extension of supercontinuum (SC) sources into the mid-infrared, via the use of fluoride and chalcogenide optical fibers, potentially offers the high radiance of a laser combined with spectral coverage far exceeding that of typical tunable lasers and comparable to traditional black-body emitters. Together with advances in mid-IR imaging detectors and novel tunable filter designs, such supercontinua hold considerable potential as sources of illumination for spectrally-resolved microscopy targeting applications such as rapid histological screening. The ability to rapidly and arbitrarily select particular
wavelengths of interest from a broad emission spectrum, covering a wide range of biologically relevant targets, lends itself to image acquisition only at key relevant wavelengths leading to more manageable datasets. However, in addition to offering new imaging modalities, SC sources also present a range of challenges to successful integration with typical spectral microscopy instrumentation, including appropriate utilisation of their high spatial coherence. In this paper the application of SC sources to spectrally-resolved microscopy in the mid-IR is discussed and systems-integration considerations specific to these sources highlighted. Preliminary results in the 3-5 \mu m region, obtained within the European FP7 project MINERVA, are also presented here.

Towards the mid-infrared optical biopsy

We are establishing a new paradigm in mid-infrared molecular sensing, mapping and imaging to open up the mid-infrared spectral region for in vivo (i.e. in person) medical diagnostics and surgery. Thus, we are working towards the mid-infrared optical biopsy ('opsy' look at, bio the biology) in situ in the body for real-time diagnosis. This new paradigm will be enabled through focused development of devices and systems which are robust, functionally designed, safe, compact and cost effective and are based on active and passive mid-infrared optical fibers. In particular, this will enable early diagnosis of external cancers, mid-infrared detection of cancer-margins during external surgery for precise removal of diseased tissue, in one go during the surgery, and mid-infrared endoscopy for early diagnosis of internal cancers and their precision removal. The mid-infrared spectral region has previously lacked portable, bright sources. We set a record in demonstrating extreme broad-band supercontinuum generated light 1.4 to 13.3 microns in a specially engineered, high numerical aperture mid-infrared optical fiber. The active mid-infrared fiber broadband supercontinuum for the first time offers the possibility of a bright mid-infrared wideband source in a portable package as a first step for medical fiber-based systems operating in the mid-infrared. Moreover, mid-infrared molecular mapping and imaging is potentially a disruptive technology to give improved monitoring of the environment, energy efficiency, security, agriculture and in manufacturing and chemical processing. This work is in part supported by the European Commission: Framework Seven (FP7) Large-Scale Integrated Project MINERVA: MId-to-NEaR-infrared spectroscopy for improVed medical DiAgnostics (317803; www.minerva-project.eu).
Zeonex Microstructured Polymer Optical Fibre Bragg Grating Sensor

We fabricated an endlessly single mode and humidity insensitive Zeonex microstructured polymer optical fibre (mPOF) for fibre Bragg grating (FBG) temperature and strain sensors. We inscribed and characterise FBGs in Zeonex mPOF for the first time.

An efficient and fast detection algorithm for multimode FBG sensing

We propose a novel dynamic gate algorithm (DGA) for fast and accurate peak detection. The algorithm uses threshold determined detection window and Center of gravity algorithm with bias compensation. We analyze the wavelength fit resolution of the DGA for different values of signal to noise ratio and different typical peak shapes. Our simulations and
experiments demonstrate that the DGA method is fast and robust with higher stability and accuracy compared to conventional algorithms. This makes it very attractive for future implementation in sensing systems especially based on multimode fiber Bragg gratings.

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Angle dependent Fiber Bragg grating inscription in microstructured polymer optical fibers
We report on an incidence angle influence on inscription of the Fiber Bragg Gratings in Polymethyl methacrylate (PMMA) microstructured polymer optical fibers. We have shown experimentally that there is a strong preference of certain angles, labeled Gamma K, over the other ones. Angles close to Gamma K showed fast start of inscription, rapid inscription and stronger gratings. We have also shown that gratings can be obtained at almost any angle but their quality will be lower if they are not around Gamma K angle. Our experimental results verify earlier numerical and experimental predictions of Marshall et al. (C)2015 Optical Society of America

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Antiresonant guiding in a poly(methyl-methacrylate) hollow-core optical fiber

Strong antiresonant reflecting optical waveguiding is demonstrated in a novel poly (methyl-methacrylate) (PMMA) hollow-core fiber. The transmission spectrum of the fiber was characterized using a supercontinuum source and it revealed distinct resonances with resonant dips as strong as ~20 dB in the wavelength range 480-900 nm, where PMMA has low absorption. The total propagation loss of the fiber was measured to have a minimum of ~45 dB m⁻¹ at around 500 nm. The thermal sensitivity of the fiber is 256 ± 16 pm °C⁻¹, defined as the red-shift of the resonances per °C, which is three times higher than the sensitivity of polymer fiber Bragg gratings.

Coherent multi-octave spanning supercontinuum in tapered sulphide fibres.

A novel frequency comb design is proposed based on a newly developed ultrafast 3µm mid-infrared laser in conjunction with micro-taper chalcogenide fibre. The novel design allows for an all-fibre laser source yielding up to three octave coherent supercontinuum. The design is the first step in realising an all-fibre mid-infrared frequency comb.
Compound parabolic concentrator optical fiber tip for FRET-based fluorescent sensors

The Compound Parabolic Concentrator (CPC) optical fiber tip shape has been proposed for intensity based fluorescent sensors working on the principle of FRET (Förster Resonance Energy Transfer). A simple numerical Zemax model has been used to optimize the CPC tip geometry for a step-index multimode polymer optical fiber for an excitation and emission wavelength of 550 nm and 650 nm, respectively. The model suggests an increase of a factor of 1.6 to 4 in the collected fluorescent power for an ideal CPC tip, as compared to the plane-cut fiber tip for fiber lengths between 5 and 45 mm.

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Contributors: Hassan, H. U., Nielsen, K., Aasmul, S., Bang, O.
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Publication date: 2015

Dielectric tube waveguides with absorptive cladding for broadband, low-dispersion and low loss THz guiding

Research on terahertz waveguides is experiencing a tremendous growth due to their importance for compact and robust THz systems. However, designing compact, broadband, mechanically stable and environmentally shielded THz waveguides is still a challenge due to high losses of both metals and dielectrics in this frequency range. Here we report on a novel twist on the classical tube waveguide where we deliberately introduce a thick and highly lossy cladding layer. By this we attenuate the field in the cladding and thus prevent interference with the core field. This mechanism breaks the well-known ARROW guiding mechanism, and as a result, extremely broad bandwidth and low dispersion can be achieved with a very simple design. Since the main part of the field propagates inside the air-core, the propagation loss is still kept at a very low level. Simulations, analytical modelling and experiments verify our findings. The proposed THz waveguide is robust, insensitive to external perturbation and easy to handle, and thus the design represents a significant advance of the field of THz dielectric waveguides suitable for the 0.3-1 THz band which in the future will be important for ultrafast wireless communication systems.

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Dynamic gate algorithm for multimode fiber Bragg grating sensor systems

We propose a novel dynamic gate algorithm (DGA) for precise and accurate peak detection. The algorithm uses a threshold-determined detection window and center of gravity algorithm with bias compensation. We analyze the wavelength fit resolution of the DGA for different values of the signal-to-noise ratio and different peak shapes. Our simulations and experiments demonstrate that the DGA method is fast and robust with better stability and accuracy than conventional algorithms. This makes it very attractive for future implementation in sensing systems, especially based on multimode fiber Bragg gratings.

Fabry-Perot micro-structured polymer optical fibre sensors for opto-acoustic endoscopy

Opto-Acoustic Endoscopy (OAE) requires sensors with a high sensitivity and small physical dimensions in order to facilitate integration into an endoscope of less than 1mm in diameter. We present fibre Bragg grating (FBG) and Fabry-Perot intrinsic fibre sensors for ultrasound detection. We present a structure profile characterisation setup to analyse tune the fibre sensors in preparation for ultrasonic detection. We evaluate the suitability of the different structures and grating parameters for ultrasonic sensing. By analysing the prepared gratings, we enable the optimisation of the profile and a simplification of the detection regime for an optimal interferometric OAE configuration. © (2015) COPYRIGHT Society of Photo-Optical Instrumentation Engineers (SPIE). Downloading of the abstract is permitted for personal use only.
Fast Fiber Bragg Grating Inscription in the Undoped Microstructured Polymer Optical Fibers

Fiber-based portable optical frequency standard for telecommunication

Fiber-filled hollow-core photonic crystal fibers are used to stabilize a fiber laser to the $13\text{C}_2\text{H}_2 \text{P}(16) (v1 + v3)$ transition at 1542 nm using saturated absorption. The fiber is encapsulated in glass cells for gas handling and compact free-space coupling, and packaged in an easy-to-use configuration. The system is showing a locking-point repeatability within 60 kHz with respect to a conventional acetylene vapor cell reference and an Allan deviation below $8 \times 10^{-11} \text{(s/σ)}^{-1/2}$ for $1 < σ < 1000 \text{ s}$. 
Fiber-optic liquid level monitoring system using microstructured polymer fiber Bragg grating array sensors: performance analysis

A highly sensitive liquid level monitoring system based on microstructured polymer optical fiber Bragg grating (mPOFBG) array sensors is reported for the first time. The configuration is based on five mPOFBGs inscribed in the same fiber in the 850 nm spectral region, showing the potential to interrogate liquid level by measuring the strain induced in each mPOFBG embedded in a silicone rubber (SR) diaphragm, which deforms due to hydrostatic pressure variations. The sensor exhibits a highly linear response over the sensing range, a good repeatability, and a high resolution. The sensitivity of the sensor is found to be 98 pm/cm of water, enhanced by more than a factor of 9 when compared to an equivalent sensor based on a silica fiber around 1550 nm. The temperature sensitivity is studied and a multi-sensor arrangement proposed, which has the potential to provide level readings independent of temperature and the liquid density.

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Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Aston University
Contributors: Marques, C. A. F., Pospori, A., Saez-Rodriguez, D., Nielsen, K., Bang, O., Webb, D. J.
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High performance liquid-level sensor based on mPOFBG for aircraft applications

A high performance liquid-level sensor based on microstructured polymer optical fiber Bragg grating (mPOFBG) array sensors is reported in detail. The sensor sensitivity is found to be 98pm/cm of liquid, enhanced by more than a factor of 9 compared to a reported silica fiber-based sensor.

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High-power picosecond pulse delivery through hollow core photonic band gap fibers

We demonstrated robust and bend insensitive fiber delivery of high power pulsed laser with diffraction limited beam quality for two different kind of hollow core photonic band gap fibers

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Humidity insensitive step-index polymer optical fibre Bragg grating sensors

We have fabricated and characterised a humidity insensitive step index(SI) polymer optical fibre(POF) Bragg grating sensors. The fibre was made based on the injection molding technique, which is an efficient method for fast, flexible and cost effective preparation of the fibre preform. The fabricated SIPOF has a core made from TOPAS with a glass transition temperature of 134 degrees C and a cladding from ZEONEX with a glass transition temperature of 138 degrees C. The main advantages of the proposed SIPOF are the low water absorption and good chemical resistance compared to the conventional poly-methyl-methacrylate (PMMA) based SIPOFs. The fibre has a minimum loss of similar to 6dB/m at 770nm.

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Improved Low-loss Hollow Core Anti-Resonant Silica Mid-IR Fibers

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Long term strain behavior of PMMA based polymer optical fibers
We are reporting on the viscoelasticity of PMMA based Fiber Bragg Grating (FBG) strain sensors when exposed to repeated sequences of long term strain and relaxation with various duty-cycles. In terms of the FBG wavelength and how it follows the strain cycle, we have shown that in the small strain regime (up to 1%) an elastic-dominated fast relaxing range, which is followed by a mainly viscous relaxation, depends both on the strain level and on the strain duration. For a small ratio of the strain-relax durations, this fast relaxation range stays almost the same. However, with increasing strain duration, for the same relaxation time, this range will be shortened, which might influence the sensing capabilities of the fiber sensor.

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Low Loss Double-clad Hollow Core Anti-Resonant Fibers in the Mid-IR

General information
Low-loss hollow-core silica fibers with adjacent nested anti-resonant tubes

We report on numerical design optimization of hollow-core antiresonant fibers with the aim of reducing transmission losses. We show that re-arranging the nested anti-resonant tubes in the cladding to be adjacent has the effect of significantly reducing leakage as well as bending losses, and for reaching high loss extinction ratios between the fundamental mode and higher order modes. We investigate two versions of the proposed design, one optimized for the mid-IR and another scaled down version for the near-IR and compare them in detail with previously proposed antiresonant fiber designs including nested elements. Our proposed design is superior with respect to obtaining the lowest leakage losses and the bend losses are also much lower than for the previous designs. Leakage losses as low as 0.0015 dB/km and bending losses of 0.006 dB/km at 5 cm bending radius are predicted at the ytterbium lasing wavelength 1.06 μm.

When optimizing the higher-order-mode extinction ratio, the low leakage loss is sacrificed to get an effective single-mode behavior of the fiber. We show that the higher-order-mode extinction ratio is more than 1500 in the range 1.0-1.1 µm around the ytterbium lasing wavelength, while in the mid-IR it can be over 100 around λ = 2.94 μm. This is higher than the previously considered structures in the literature using nested tubes.

Mid infrared supercontinuum generation from chalcogenide glass waveguides and fibers

I report work on mid-infrared super-continuum generation in chalcogenide fibers and waveguides pumped by 320fsec pulses at 21MHz in the 3-4.6µm range. Average powers of ≈20mW were produced with spectral coverage from <2µm to >11µm.
Mid-infrared supercontinuum generation in the fingerprint region

The mid-infrared spectral region is of great technical and scientific interest because most molecules display fundamental vibrational absorptions in this region, leaving distinctive spectral fingerprints. Here, we demonstrate experimentally that launching intense ultra-short pulses with a central wavelength of either 4.5 µm or 6.3 µm into short pieces of ultra-high numerical-aperture step-index chalcogenide glass optical fibre generates a mid-infrared supercontinuum spanning 1.5 µm to 11.7 µm and 1.4 µm to 13.3 µm, respectively [1]. This is the first experimental demonstration to truly reveal the potential of fibres to emit across the mid-infrared molecular fingerprint region, which is of key importance for applications such as early cancer diagnostics, gas sensing and food quality control.

Mid-infrared supercontinuum generation spanning more than 11 µm in a chalcogenide step-index fiber

Supercontinuum generation covering an ultra-wide spectrum from 1.5-11.7µm and 1.4-13.3µm is experimentally demonstrated by pumping an 85mm chalcogenide step-index fiber with 100fs pulses at a wavelength of 4.5µm and 6.3µm, respectively.

Mid-infrared supercontinuum generation spanning more than 11 µm in a chalcogenide step-index fiber

Supercontinuum generation covering an ultra-broad spectrum from 1.5-11.7µm and 1.4-13.3µm is experimentally demonstrated by pumping an 85mm chalcogenide step-index fiber with 100fs pulses at a wavelength of 4.5µm and 6.3µm, respectively.
Multi-milliwatt mid-infrared supercontinuum generation in a suspended core chalcogenide fiber

A low-loss suspended core As$_{38}$Se$_{62}$ fiber with core diameter of 4.5 μm and a zero-dispersion wavelength of 3.5 μm was used for mid-infrared supercontinuum generation. The dispersion of the fiber was measured from 2.9 to 4.2 μm and was in good correspondence with the calculated dispersion. An optical parametric amplifier delivering 320 fs pulses with a peak power of 14.8 kW at a repetition rate of 21 MHz was used to pump 18 cm of suspended core fiber at different wavelengths from 3.3 to 4.7 μm. By pumping at 4.4 μm with a peak power of 5.2 kW coupled to the fiber a supercontinuum spanning from 1.7 to 7.5 μm with an average output power of 15.6 mW and an average power >5.0 μm of 4.7 mW was obtained.

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Nonlinear Label-Free Biosensing With High Sensitivity Using As$_2$S$_3$ Chalcogenide Tapered Fiber

We demonstrate an experimentally feasible fiber design, which can act as a highly sensitive, label-free, and selective biosensor using the inherent high nonlinearity of an As$_2$S$_3$ chalcogenide tapered fiber. The surface immobilization of the fiber with an antigen layer can provide the possibility to selectively capture antibody biomolecules. This increase of the layer thickness directly affects the group velocity dispersion of the fiber and, thus, the modulation instability (MI) gain spectrum (location of the anti-Stokes and Stokes wavelengths) when pumping the fiber close to the zero-dispersion wavelength. The sensitivity of the sensor was predicted to be ~18 nm/nm, defined as the shift in resonance wavelength per nanometer biolayer thickness, which is almost twice the current record sensitivity of nonlinear MI-based fiber optical biosensors. Importantly, due to the strong nonlinearity of As$_2$S$_3$, this high sensitivity can be obtained using a low-power 1064-nm microchip laser.

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Optical frequency stabilization using gas-filled hollow-core photonic crystal fibers

Gas-filled hollow-core photonic crystal fibers are used to stabilize a fiber laser to the $^{13}$C$_2$H$_2$ P(16) ($\nu_1+\nu_3$) transition at 1542 nm using saturated absorption. Four hollow-core fibers with different crystal structure are compared in terms of long term lock-point repeatability and fractional frequency instability. The locked fiber laser shows a fractional frequency instability below $4 \times 10^{-12}$ for averaging time up to 104 s. The lock-point repeatability over more than 1 year is $1.3 \times 10^{-11}$, corresponding to a standard deviation of 2.5 kHz. A complete experimental investigation of the light-matter interaction between the spatial modes excited in the fibers and the frequency of the locked laser is presented. A simple theoretical model that explains the interaction is also developed.

Optical frequency standard using acetylene-filled hollow-core photonic crystal fibers

Gas-filled hollow-core photonic crystal fibers are used to stabilize a fiber laser to the $^{13}$C$_2$H$_2$ P(16) ($\nu_1+\nu_3$) transition at 1542 nm using saturated absorption. Four hollow-core fibers with different crystal structure are compared in terms of long term lock-point repeatability and fractional frequency instability. The locked fiber laser shows a fractional frequency instability below $4 \times 10^{-12}$ for averaging time up to 104 s. The lock-point repeatability over more than 1 year is $1.3 \times 10^{-11}$, corresponding to a standard deviation of 2.5 kHz. A complete experimental investigation of the light-matter interaction between the spatial modes excited in the fibers and the frequency of the locked laser is presented. A simple theoretical model that explains the interaction is also developed.
Pmma fiber viscoelasticity in extremely low frequency regime

We are reporting on the viscoelasticity of PMMA based Fiber Bragg Grating (FBG) strain sensors when exposed to repeated sequences of long term strain and relaxation with various duty-cycles and frequencies much smaller than 1 Hz. Monitoring the FBG wavelength and how it follows the applied strain, we have shown that after being strained up to 1%, the fiber will rapidly contract elastically to a certain amount after which a viscous-dominated relaxation takes place. The amount of elastic versus viscous relaxation depends both on the level of applied strain and on the duration of the strain. For a big duration of the strain with respect to relaxation, this fast relaxation wavelength range stays almost the same. However, with increasing relaxation duration and keeping the same strain duration, elastic relaxation wavelength range will be shortened for up to 18% (1%) when strained for 0.5% (1%), which could, in certain applications, influence the sensitivity range of sensors based on plastic fibers.

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Polarization effects in polymer FBGs: study and use for transverse force sensing
Bragg gratings photo-inscribed in polymer optical fibers (POFs) are more sensitive to temperature and pressure than their silica counterparts, because of their larger thermo-optic coefficient and smaller Young's modulus. Polymer optical fiber Bragg gratings (POFBGs) are most often photo-written in poly(methylmethacrylate) (PMMA) based materials using a continuous-wave 325 nm HeCd laser. In this work, we present the first study about birefringence effects in POFBGs manufactured in different types of fiber. To achieve this, highly reflective (> 90%) gratings were produced with the phase mask technique. Their spectral response was then monitored in transmission with polarized light. Polarization dependent loss (PDL) and differential group delay (DGD) were computed from the Jones matrix eigenanalysis using an optical vector analyzer. Maximum values exceeding several dB and a few picoseconds were obtained for the PDL and DGD, respectively. An inverse scattering technique applied to the experimental data provided an estimate of the photo-induced birefringence value arising from the side fabrication process. The response to lateral force was finally investigated for various incident directions using the PDL response of FBGs manufactured in step-index POFs. As the force induced birefringence adds to the photo-induced one, a force dependent evolution of the PDL maximum value was noticed, with a good temperature-insensitivity. (C) 2015 Optical Society of America

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Polymer optical fiber compound parabolic concentrator tip for enhanced coupling efficiency for fluorescence based glucose sensors

We demonstrate that the light excitation and capturing efficiency of fluorescence based fiber-optical sensors can be significantly increased by using a CPC (Compound Parabolic Concentrator) tip instead of the standard plane-cut tip. We use Zemax modelling to find the optimum CPC tip profile and fiber length of a polymer optical fiber diabetes sensor for continuous monitoring of glucose levels. We experimentally verify the improved performance of the CPC tipped sensor and the predicted production tolerances. Due to physical size requirements when the sensor has to be inserted into the body a non-optimal fiber length of 35 mm is chosen. For this length an average improvement in efficiency of a factor of 1.7 is experimentally demonstrated and critically compared to the predicted ideal factor of 3 in terms of parameters that should be improved through production optimization.
Polymer Optical Fibre Sensors for Endoscopic Opto-Acoustic Imaging
Opto-acoustic imaging (OAI) shows particular promise for in-vivo biomedical diagnostics. Its applications include cardiovascular, gastrointestinal and urogenital systems imaging. Opto-acoustic endoscopy (OAE) allows the imaging of body parts through cavities permitting entry. The critical parameter is the physical size of the device, allowing compatibility with current technology, while governing flexibility of the distal end of the endoscope based on the needs of the sensor. Polymer optical fibre (POF) presents a novel approach for endoscopic applications and has been positively discussed and compared in existing publications. A great advantage can be obtained for endoscopy due to a small size and array potential to provide discrete imaging speed improvements. Optical fibre exhibits numerous advantages over conventional piezo-electric transducers, such as immunity from electromagnetic interference and a higher resolution at small sizes. Furthermore, micro structured polymer optical fibres offer over 12 times the sensitivity of silica fibre. We present a polymer fibre Bragg grating ultrasound detector with a core diameter of 125 microns. We discuss the ultrasonic signals received and draw conclusions on the opportunities and challenges of applying this technology in biomedical applications.

Production and Characterization of Polycarbonate Microstructured Polymer Optical Fiber Bragg Grating Sensor
We present the fabrication and characterization of a polycarbonate (PC) microstructured polymer optical fiber (mPOF) and the writing of a fiber Bragg grating (FBG) in it to obtain a polymer optical FBG sen-sor. The manufacturing process of the PC mPOF consists of multiple consecutive stages, such as casting of pol-ymer granulates into a solid rod, machining and drilling of a 3-ring hexagonal lattice of holes into it, and finally drawing into fiber. We demonstrate that the obtained PC mPOF is photosensitive and FBGs can be conveniently inscribed into it, thereby enabling FBG-based temperature and strain sensing. The PC optical fibers are for some applications an attractive alternative to conventional materials used in POF fabrication, such as polymethyl methacrylate (PMMA). In general, PC can be used at temperature up to 120 °C and breaks at considerably higher strains than PMMA.
Robust and accurate detection algorithm for multimode polymer optical FBG sensor system

We propose a novel dynamic gate algorithm (DGA) for robust and fast peak detection. The algorithm uses a threshold determined detection window and center of gravity algorithm with bias compensation. Our experiment demonstrates that the DGA method is fast and robust with better stability and accuracy than conventional algorithms. This makes it very attractive for future implementation in sensing systems especially based on multimode fiber Bragg gratings.

Simple Room Temperature Method for Polymer Optical Fibre Cleaving

In this paper, we report on a new method to cleave polymer optical fibre. The most common way to cut a polymer optical fibre is chopping it with a razor blade; however, in this approach both the fibre and the blade must be preheated in order to turn the material ductile, and thus, prevent crazing. In this paper, we make use of the temperature-time equivalence in polymers to replace the use of heating by an increase of the cleaving time and use a sawing motion to reduce fibre end face damage. In this way, the polymer fibre can be cleaved at room temperature in seconds with the resulting end face being of similar quality to those produced by more complex and expensive heated systems.
Polymer optical fibre (POF), polymer optical fibre cleaving, Polymers, razor blade, room temperature method, Sawing, sawing motion, Stress, temperature 293 K to 298 K, temperature-time equivalence

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**Tapering of Polymer Optical Fibers for Compound Parabolic Concentrator Fiber Tip Fabrication**

We propose a process for Polymer Optical Fiber (POF) Compound Parabolic Compound (CPC) tip manufacturing using a heat and pull fiber tapering technique. The POF, locally heated above its glass transition temperature, is parabolically tapered down in diameter, after which it is cut to the desired output diameter and finally polished to obtain the special CPC tip. The physical mechanism responsible for giving a CPC shape to the POF tip is also investigated. The fabrication process is shown to be sensitive to several manufacturing parameters, such as temperature of the heat source, thermal flux from the heat source, and heating time. We further consider the influence of the heating time latter parameter on the geometry of the obtained CPC fiber tips.

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**The effect of humidity on annealing of polymer optical fibre bragg gratings**

The effect of humidity on annealing of PMMA based microstructured polymer optical fiber (mPOF) Bragg gratings is studied. Polymer optical fibers (POFs) are annealed in order to release stress formed during the fabrication process. Un-annealed fibers will have high hysteresis and low sensitivity to humidity, particularly when operated at high temperature. Typically annealing of PMMA POFs is done at 80°C in an oven with no humidity control and there for at low humidity. The response to humidity of PMMA FBGs annealed at different levels of humidity at the same temperature has also been studied. PMMA FBGs annealed at high humidity have response with no hysteresis and an improved sensitivity which are independent of temperature compared to FBGs annealed at the same temperature but at lower humidity. In addition, PMMA FBG annealed at high humidity showed a permanent blue shift more than 200nm, which is a record of tuning POF FBGs.

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Thermally tunable bandgaps in a hybrid As2S3/silica photonic crystal fiber

We report the fabrication and characterization of a hybrid silica photonic crystal fiber (PCF) with integrated chalcogenide glass layers and we show how the bandgaps of the fiber can be thermally tuned. The formation of the high-index chalcogenide films on the inner surface of the PCF holes revealed resonances as strong as similar to 35 dB both in the visible and infrared regime. Temperature measurements indicate that the transmission windows can be tuned with a sensitivity as high as similar to 3.5 nm/°C. The proposed fiber has potential for all-fiber filtering and temperature sensing.

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Time-dependent variation of fiber Bragg grating reflectivity in PMMA-based polymer optical fibers

In this Letter, we investigate the effects of viscoelasticity on both the strength and resonance wavelength of two fiber Bragg gratings (FBGs) inscribed in microstructured polymer optical fiber (mPOF) made of undoped PMMA. Both FBGs were inscribed under a strain of 1% in order to increase the material photosensitivity. After the inscription, the strain was released, and the FBGs spectra were monitored. We initially observed a decrease of the reflection down to zero after which it began to increase. After that, strain tests were carried out to confirm the results, and finally the gratings were monitored for a further 120 days, with a stable reflection response being observed beyond 50 days. (C) 2015 Optical Society of America

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Two-octave mid-infrared supercontinuum generation in As-Se suspended core fibers
A more than two-octave mid-infrared supercontinuum with an average output power of 15.6 mW covering 1.7-7.5 μm (1,333-5,900 cm\(^{-1}\)) is generated in a low-loss As\(_{38}\)Se\(_{62}\) suspended core fiber with core diameter of 4.5 μm.

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Bragg grating writing in PMMA microstructured polymer optical fibers in less than 7 minutes
We demonstrate fiber Bragg grating (FBG) writing in PMMA microstructured Polymer Optical Fibers (mPOFs) using UV Phase Mask technique with writing times shorter than 10 min. The shortest writing time was 6 minutes and 50 seconds and the longest writing time was 8 min and 50 sec. The FBGs were written in a 125 x00B5;m PMMA mPOF having 3-rings of holes, the reflection peaks were centred at 632.6 nm and have a reflectivity as high as 26 dB. We also demonstrate how the writing dynamics depends on the intensity of the writing beam.

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BFI (2014): BFI-level 2
Broadband Mid-infrared Supercontinuum Generation in Suspended Core Chalcogenide Fibers

We demonstrate a novel polarization maintaining hollow-core photonic bandgap fiber geometry that reduces the impact of surface modes on fiber transmission. The cladding structure is modified with a row of partially collapsed holes to strip away unwanted surface modes. A theoretical investigation of the surface mode stripping is presented and compared to the measured performance of four 7-cells core fibers that were drawn with different collapse ratio of the defects. The varying pressure along the defect row in the cladding during drawing introduces an ellipticity of the core. This, combined with the presence of antiresonant features on the core wall, makes the fibers birefringent, with excellent polarization maintaining properties. (C) 2014 Optical Society of America

Cladding defects in hollow core fibers for surface mode suppression and improved birefringence

We demonstrate a novel polarization maintaining hollow-core photonic bandgap fiber geometry that reduces the impact of surface modes on fiber transmission. The cladding structure is modified with a row of partially collapsed holes to strip away unwanted surface modes. A theoretical investigation of the surface mode stripping is presented and compared to the measured performance of four 7-cells core fibers that were drawn with different collapse ratio of the defects. The varying pressure along the defect row in the cladding during drawing introduces an ellipticity of the core. This, combined with the presence of antiresonant features on the core wall, makes the fibers birefringent, with excellent polarization maintaining properties. (C) 2014 Optical Society of America
Design and Optimization of Air-Doped 3-dB Terahertz Fiber Directional Couplers

We present a thorough practical design optimization of broadband low loss, terahertz (THz) photonic crystal fiber directional couplers in which the two cores are mechanically down-doped with a triangular array of air holes. A figure of merit taking both the 3-dB bandwidth and loss of the coupler into account, is used for optimization of the structure parameters, given by the diameter and pitch of the cladding (d and Λ) and of the core (dc and Λc) air-hole structure. The coupler with Λ = 498.7 μm, dc = 324.2 μm, Λc = 74.8 μm, and dc = 32.5 μm is found to have the best performance at a center frequency of 1THz, with a bandwidth of 0.25 THz and a total device loss of 9.2 dB. The robustness of the optimum coupler to structural changes is investigated. © 2014 Optical Society of America.

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Design and optimization of mechanically down-doped terahertz fiber directional couplers
We present a thorough practical design optimization of broadband low loss, terahertz (THz) photonic crystal fiber directional couplers in which the two cores are mechanically down-doped with a triangular array of air holes. A figure of merit taking both the 3-dB bandwidth and loss of the coupler into account, is used for optimization of the structure parameters, given by the diameter and pitch of the cladding (d and Λ) and of the core (dc and Λc) air-hole structure. The coupler with Λ = 498.7 μm, dc = 324.2 μm, Λc = 74.8 μm, and dc = 32.5 μm is found to have the best performance at a center frequency of 1THz, with a bandwidth of 0.25 THz and a total device loss of 9.2 dB. The robustness of the optimum coupler to structural changes is investigated. © 2014 Optical Society of America.

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High Average Power Mid-infrared Supercontinuum Generation in a Suspended Core Chalcogenide Fiber
Mid-infrared supercontinuum spanning from 2.0 to 6.1 μm is generated in a 9 cm suspended core chalcogenide fiber by pumping close to the fiber zero-dispersion wavelength at 3.5 μm with an OPA system.

Hollow core fiber-based optical frequency standard

Hybrid polymer photonic crystal fiber with integrated chalcogenide glass nanofilms
The combination of chalcogenide glasses with polymer photonic crystal fibers (PCFs) is a difficult and challenging task due to their different thermo-mechanical material properties. Here we report the first experimental realization of a hybrid polymer-chalcogenide PCF with integrated As2S3 glass nanofilms at the inner surface of the air-channels of a poly-methyl-methacrylate (PMMA) PCF. The integrated high refractive index glass films introduce distinct antiresonant transmission bands in the 480-900 nm wavelength region. We demonstrate that the ultra-high Kerr nonlinearity of the chalcogenide glass makes the polymer PCF nonlinear and provides a possibility to shift the transmission band edges as much as 17 nm by changing the intensity. The proposed fabrication technique constitutes a new highway towards all-fiber nonlinear tunable devices based on polymer PCFs, which at the moment is not possible with any other fabrication method.
Increase of the photosensitivity of undoped poly(methylmethacrylate) under UV radiation at 325 nm

In this paper we report, for the first time to our knowledge, an increase of the photosensitivity of a microstructured polymer optical fibre (mPOF) made of undoped PMMA due to applied strain during the fabrication of the gratings. In the work, fibre Bragg gratings (FBGs) have been fabricated in undoped PMMA mPOFs with a hexagonal structure of three rings in the inner cladding. Two sets of FBGs were inscribed at two different resonant wavelengths (827 nm and 1562 nm) at different strains using an UV He-Cd laser at 325 nm focused by a lens and scanned over the fibre. We observed an increase of the reflection of the fibre Bragg gratings when the fabrication strain is higher. The photosensitivity mechanism is discussed in the paper along with the chemical reactions that could underlie the mechanism. Furthermore, the resolution limit of the material was investigated.

Interferometric microstructured polymer optical fiber ultrasound sensor for optoacoustic endoscopic imaging in biomedical applications

We report a characterization of the acoustic sensitivity of microstructured polymer optical fiber interferometric sensors at ultrasonic frequencies from 100kHz to 10MHz. The use of wide-band ultrasonic fiber optic sensors in biomedical ultrasonic and optoacoustic applications is an open alternative to conventional piezoelectric transducers. These kind of sensors, made of biocompatible polymers, are good candidates for the sensing element in an optoacoustic endoscope because of its high sensitivity, its shape and its non-brittle and non-electric nature. The acoustic sensitivity of the intrinsic fiber optic interferometric sensors depends strongly of the material which is composed of. In this work we compare experimentally the intrinsic ultrasonic sensitivities of a PMMA mPOF with other three optical fibers: a singlemode silica optical fiber, a single-mode polymer optical fiber and a multimode graded-index perfluorinated polymer optical fiber. © 2014 SPIE.
Investigations on birefringence effects in polymer optical fiber Bragg gratings

Step-index polymer optical fiber Bragg gratings (POFBGs) and microstructured polymer optical fiber Bragg gratings (mPOFBGs) present several attractive features, especially for sensing purposes. In comparison to FBGs written in silica fibers, they are more sensitive to temperature and pressure because of the larger thermo-optic coefficient and smaller Young's modulus of polymer materials. (M)POFBGs are most often photowritten in poly(methylmethacrylate) (PMMA) materials using a continuous-wave 325 nm HeCd laser. For the first time to the best of our knowledge, we study photoinduced birefringence effects in (m)POFBGs. To achieve this, highly reflective gratings were inscribed with the phase mask technique. They were then monitored in transmission with polarized light. For this, (m)POF sections a few cm in length containing the gratings were glued to angled silica fibers. Polarization dependent loss (PDL) and differential group delay (DGD) were computed from the Jones matrix eigenanalysis using an optical vector analyser. Maximum values exceeding several dB and a few picoseconds were obtained for the PDL and DGD, respectively. The response to lateral force was finally investigated. As it induces birefringence in addition to the photo-induced one, an increase of the PDL and DGD values were noticed.

Mid-infrared supercontinuum covering the 1.4–13.3 μm molecular fingerprint region using ultra-high NA chalcogenide step-index fibre

The mid-infrared spectral region is of great technical and scientific interest because most molecules display fundamental vibrational absorptions in this region, leaving distinctive spectral fingerprints. To date, the limitations of mid-infrared light sources such as thermal emitters, low-power laser diodes, quantum cascade lasers and synchrotron radiation have precluded mid-infrared applications where the spatial coherence, broad bandwidth, high brightness and portability of a supercontinuum laser are all required. Here, we demonstrate experimentally that launching intense ultra-short pulses with a central wavelength of either 4.5 μm or 6.3 μm into short pieces of ultra-high numerical-aperture step-index chalcogenide glass optical fibre generates a mid-infrared supercontinuum spanning 1.5 μm to 11.7 μm and 1.4 μm to 13.3 μm, respectively. This is the first experimental demonstration to truly reveal the potential of fibres to emit across the mid-infrared molecular ‘fingerprint region’, which is of key importance for applications such as early cancer diagnostics, gas sensing and food quality control.
Mid-infrared supercontinuum generation in a suspended core chalcogenide fiber

The mid-infrared spectral region is of great interest because virtually all organic compounds display distinctive spectral fingerprints herein that reveal chemical information about them [1], and the mid-infrared region is therefore of key importance to many applications, including food quality control [2], gas sensing [3] and medical diagnostics [4]. We have used a low-loss suspended core $\text{As}_{38}\text{Se}_{62}$ fiber with core diameter of 4.5 μm and a zero - dispersion wavelength of 3.5 μm to generate mid-infrared supercontinuum by pumping with an optical parametric amplifier delivering 320 fs pulses with a peak power of ~5.5 kW at a repetition rate of 21 MHz at different wavelengths from 3.3 to 4.7 μm. By pumping at 4.4 μm with a peak power of 5.2 kW coupled to the fiber a supercontinuum spanning from 1.7 to 7.5 μm with an average output power of 15.6 mW was obtained. Figure 1 shows the results obtained when pumping at 3.5 μm. We have recently demonstrated a record-breaking supercontinuum spanning from 1.4-13.3 μm in a step - index chalcogenide fiber [5]. The results in this presentation are however to our knowledge the first reported supercontinuum generated beyond 6 μm in a chalcogenide microstructured optical fiber.

Mid-infrared supercontinuum generation in chalcogenide step-index fibers pumped at 2.9 and 4.5μm

The Mid-InfraRed (MIR) spectral range (2-12μm) contains the spectral fingerprint of many organic molecules, which can be probed nondestructively for e.g. detection of skin cancer. For this SuperContinuum (SC) laser sources are good candidates since they can have broadband bandwidths together with high spectral densities. Here we consider a MIR SC laser sources based on chalcogenide step-index fibers with exceptionally high numerical aperture of ~1 pumped either with Er:ZBLAN and Pr:CHALC fiber laser operating at 2.9 and 4.5μm, respectively, having $P_0=1kW$, $T_0=50ps$, $v_R=4MHz$ and $P_{avg}=200mW$. The optical properties of fibers (dispersion, nonlinearity and confinement loss) are modeled using the finite element tools based on measured refractive indices of the core and the cladding chalcogenide compositions.

Generation of MIR SC is investigated using the Generalized Nonlinear Schrödinger Equation using actual measured fiber loss obtained using FTIR spectrometry. Pumping the fiber at 2.9μm and 4.5μm yields a SC spanning the 3-10 and 3-12.5μm range with around 10 and 20mW converted into the 8-10μm band, respectively. Using specially designed CHALC SIF in conjunction with pulsed MIR fiber lasers at 2.9 and 4.5μm it is thus possible to generate a MIR SC spanning almost the entire spectral region of interest with ample power being converted into the MIR.
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**Abstract**

Mid-infrared supercontinuum generation in concatenated fluoride and chalcogenide glass fibers covering more than three octaves

Supercontinuum is generated in concatenated ZBLAN and As2Se3 fibers. Initially, a 0.9-4.1 mm supercontinuum is obtained by pumping the ZBLAN fiber with a Tm laser, which then continues to broaden to 0.9-9.0 mm in As2Se3 fiber.

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**Mid-infrared supercontinuum generation to 12.5μm in large NA chalcogenide step-index fibres pumped at 4.5μm**

We present numerical modeling of mid-infrared (MIR) supercontinuum generation (SCG) in dispersion-optimized chalcogenide (CHALC) step-index fibres (SIFs) with exceptionally high numerical aperture (NA) around one, pumped with mode-locked praseodymium-doped (Pr3+) chalcogenide fibre lasers. The 4.5μm laser is assumed to have a repetition rate of 4MHz with 50ps long pulses having a peak power of 4.7kW. A thorough fibre design optimisation was conducted using measured material dispersion (As-Se/Ge-As-Se) and measured fibre loss obtained in fabricated fibre of the same materials. The loss was below 2.5dB/m in the 3.3-9.4μm region. Fibres with 8 and 10μm core diameters generated an SC out to 12.5 and 10.7μm in less than 2m of fibre when pumped with 0.75 and 1kW, respectively. Larger core fibres with 20μm core diameters for potential higher power handling generated an SC out to 10.6μm for the highest NA considered but required pumping at 4.7kW as well as up to 3m of fibre to compensate for the lower nonlinearities. The amount of power converted into the 8-10 μm band was 7.5 and 8.8mW for the 8 and 10μm fibres, respectively. For the 20μm core fibres up to 46mW was converted.

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Photo-acoustic imaging of coronary arteries with polymer optical fibers

Coronary artery disease (CAD) is one of the most common types of heart disease which happens when the arteries that supply blood to heart muscle become hardened and narrowed. This is caused by the building of cholesterol plaques on the inner walls of arteries. The gradual growth of plaques cause less blood to flow through the arteries hence the heart muscle can't get the blood or oxygen it needs. Worse, a plaque can suddenly rupture. As a result, blood clot over the rapture and suddenly cut off the hearts’ blood supply, causing permanent heart damage or stroke [1]. Photo-acoustic imaging is useful for detection of plaques for prevention of rupture of vulnerable plaques. These vulnerable plaques in the arteries can be distinguished using photo-acoustic imaging based on lipid accumulation with different characteristics of optical absorption. The basic principle of this imaging technique relies on exposing lipids to a laser capable of inducing photo-acoustic effect and a sensor affected by the induced pressure. Polymer optical fibre Bragg grating and Fabry-Perot sensors will be developed for detection of photo-acoustic signal in collaboration of Optoelectronics and Laser technology group, Universidad Carlos III de Madrid under the TRIPOD project. TRIPOD (http://www.tripod-itn.eu) is a Marie Curie Initial Training Network located in the field of optical fibre sensors - an area where Europe has developed internationally competitive research and commercial activity. The aim is to significantly extend the range of application of optical fibre grating sensors by developing a mature version of the technology in polymer optical fibres and thereby increase European competitiveness.

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Photosensitivity mechanism of undoped poly(methyl methacrylate) under UV radiation at 325 nm and its spatial resolution limit

In this Letter, we provide evidence suggesting that the main photosensitive mechanism of an undoped poly(methyl methacrylate)-based microstructured optical fiber under UV radiation at 325 nm is a competitive process of both photodegradation and polymerization. We found experimentally that increasing strain during photo-inscription leads to an increased photosensitivity, which is evidence of photodegradation. Likewise, refractive index change in the fiber was measured to be positive, which provides evidence for further polymerization of the material. Finally, we relate the data obtained to the spatial recording resolution of the samples. © 2014 Optical Society of America.

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Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Aston University
Contributors: Sáez-Rodríguez, D., Nielsen, K., Bang, O., Webb, D.
Fiber Bragg grating (FBG) writing in PMMA microstructured Polymer Optical Fibers (mPOFs) using the UV Phase Mask technique is a time consuming process requiring about 40 minutes to inscribe a grating in an undoped fiber. Here we demonstrate the FBG inscription with the writing times shorter than 10 min. By careful aligning and increasing the beam intensity in the core of the fiber, writing times as short as 6 minutes and 50 second were achieved. The FBGs were written in a 125 μm PMMA mPOF having 3-rings of holes, the reflection peaks were centred at 632.6 nm and have a reflectivity as high as 26 dB. We also demonstrate how the writing dynamics depends on the intensity of the writing beam.

POF based glucose sensor incorporating grating wavelength filters
Medtronic has already developed a plastic fiber based optical sensor to detect the concentration of glucose both in vivo and in-vitro. The glucose sensor is based on a competitive glucose binding affinity assay consisting of a glucose receptor and glucose analog (ligand) contained in a compartment made up of permeable membrane for exchanging of only small molecules such as glucose, salts etc. (Fig 1). The binding between the glucose binding protein labeled with fluorophore and glucose like molecules labelled with dye, is reversible. In the presence of glucose, the glucose analog competes with the glucose on binding to the protein. The system reaches an equilibrium, which correlates with the glucose concentration. The assay chemistry makes donor and acceptor pair for FRET (Förster Resonance Energy Transfer). FRET results in decrease in donor emission intensity. Higher the concentration of glucose, more donor acceptor pairs got separated resulting in high intensity and vice versa. This change in optical signal is correlated to glucose concentration. (Fig.1) Medtronic Diabetes and DTU FOTONIK has been working together under the consortium of Marie Curie Research
Framework called TRAINING AND RESEARCH IN POLYMER OPTICAL DEVICES; TRIPOD. Within the domain of TRIPOD, research is conducted on "Plastic Optical Fiber based Glucose Sensors Incorporating Grating Wavelength Filters". Research will be focused to optimized fiber tips for better coupling efficiency, reducing the response time of sensor, improve the mechanical stabilization of assay compartment by exploring the side excitation and side coupling method, ease of manufacturing and feasibility of Polymer Fiber Bragg gratings as filters. During the project, fibers will be drawn and fiber bragg gratings will be inscribed at DTU Fotonik and they will be characterized for glucose sensor at Medtronic Diabetes.

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Refractive index dispersion of chalcogenide glasses for ultra-high numerical-aperture fiber for mid-infrared supercontinuum generation
We select a chalcogenide core glass, AsSe, and cladding glass, GeAsSe, for their disparate refractive indices yet sufficient thermal-compatibility for fabricating step index fiber (SIF) for mid-infrared supercontinuum generation (MIR-SCG). The refractive index dispersion of both bulk glasses is measured over the 0.4 μm–33 μm wavelength-range, probing the electronic and vibrational behavior of these glasses. We verify that a two-term Sellmeier model is unique and sufficient to describe the refractive index dispersion over the wavelength range for which the experimentally determined extinction coefficient is insignificant. A SIF composed of the glasses is fabricated and calculated to exhibit an ultra-high numerical aperture >0.97 over the entire wavelength range 0.4-33 μm suggesting that the SIF glass pair is a promising candidate for MIR-SCG. Material dispersion characteristics and the zero dispersion wavelength, both critical design parameters for SIF for MIR-SCG, are derived.

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Single-mode pumped high air-fill fraction photonic crystal fiber taper for high-power deep-blue supercontinuum sources

Dispersion control with axially nonuniform photonic crystal fibers (PCFs) permits supercontinuum (SC) generation into the deep-blue from an ytterbium pump laser. In this Letter, we exploit the full degrees of freedom afforded by PCFs to fabricate a fiber with longitudinally increasing air-fill fraction and decreasing diameter directly on the draw-tower. We demonstrate SC generation extending down to 375 nm in one such monolithic fiber device that is single-mode at 1064 nm at the input end.

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Research output: Contribution to journal › Journal article – Annual report year: 2014 › Research › peer-review

Supercontinuum based mid-IR imaging spectroscopy for cancer detection

The mid-infrared (IR) spectral region is of significant technical and scientific interest because most molecules display fundamental vibrational absorptions in this region, leaving distinct spectral fingerprints. To date, the limitations of mid-IR light sources, such as thermal emitters, low-power laser diodes, quantum cascade lasers and synchrotron radiation, have precluded mid-IR applications where the spatial coherence, broad bandwidth, high brightness and portability of a supercontinuum laser are all required. In an international collaboration in the EU project MINERVA [minerva-project.eu] DTU Fotonik has now demonstrated the first optical fiber based broadband so-called supercontinuum light source, which covers 1.4-13.3 μm and thereby most of the molecular fingerprint region [1]. This ultra-fast light source is the basic component in the mid-IR camera developed in MINERVA for early cancer detection with mid-IR imaging spectroscopy.

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**Supercontinuum generation from ultraviolet to mid-infrared**

The advent of photonic crystal fibers (PCFs) has paved the road for commercial high-power supercontinuum light sources. The air-hole structuring in the PCF manipulates the properties of light and gives a tremendous degree of design freedom, which has enabled pushing the properties of PCFs to limits that can never be achieved with standard step index fibers. For example, one can move the zero dispersion wavelength (ZDW) into the visible [1] and make them endlessly single moded [2]. For efficient supercontinuum generation it is of great importance that the pump wavelength is close to the ZDW. We demonstrate how the spectral blue-edge can be manipulated by careful fiber design and tapering of the PCF enabling supercontinuum generation spanning all the way from 380 nm to 2.4μm [3]. We discuss the limiting factors of the supercontinuum bandwidth. Furthermore, we discuss how the fiber tapering influences the intensity noise of the supercontinuum source [4].

Supercontinuum sources based on silica fibers are limited to the material loss edge at 2.4 μm. However, for wavelengths beyond 2.4 μm the attenuation of light in silica fibers is greatly increased making them useless for the mid-infrared region. Instead, other fiber materials such as fluoride-based glasses (ZBLAN) and chalcogenide glasses can be used for mid-infrared supercontinuum generation. We will show supercontinuum generation in ZBLAN fibers covering 1.5-4.5 μm [5] and super-continuum generation in microstructured chalcogenide fibers out to 9 μm. We discuss the prospects for extending the supercontinuum generation beyond 10 μm and highlight useful applications such as cancer detection and food analysis.

**Supercontinuum light sources for food analysis**

In Light & Food, a 30M DKK project funded by Innovationsfonden where DTU Fotonik has joined forces with University of Copenhagen, Aarhus University, FOSS and NKT, the vision is to develop a platform of analytical solutions to optimization of sustainable food production, both in the field and in the factory. These solutions will combine bright and broadband infrared light sources, so-called supercontinuum light sources, with spectroscopy, chemometrics and processing expertise and thereby contribute to increased food quality through faster and more precise analysis of grains, soils and dairy products. One track of Light & Food will target the mid-infrared spectral region. To date, the limitations of mid-infrared light sources, such as thermal emitters, low-power laser diodes, quantum cascade lasers and synchrotron radiation, have precluded mid-IR applications where the spatial coherence, broad bandwidth, high brightness and portability of a supercontinuum laser are all required. DTU Fotonik has now demonstrated the first optical fiber based broadband supercontinuum light source, which covers 1.4-13.3μm and thereby most of the molecular fingerprint region.
The all-fiber cladding-pumped Yb-doped gain-switched laser
Gain-switching is an alternative pulsing technique of fiber lasers, which is power scalable and has a low complexity. From a linear stability analysis of rate equations the relaxation oscillation period is derived and from it, the pulse duration is defined. Good agreement between the measured pulse duration and the theoretical prediction is found over a wide range of parameters. In particular we investigate the influence of an often present length of passive fiber in the cavity and show that it introduces a finite minimum in the achievable pulse duration. This minimum pulse duration is shown to occur at longer active fibers length with increased passive length of fiber in the cavity. The peak power is observed to depend linearly on the absorbed pump power and be independent of the passive fiber length. Given these conclusions, the pulse energy, duration, and peak power can be estimated with good precision.

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Thulium pumped mid-infrared 0.9–9μm supercontinuum generation in concatenated fluoride and chalcogenide glass fibers
We theoretically demonstrate a novel approach for generating Mid-InfraRed SuperContinuum (MiR SC) by using concatenated fluoride and chalcogenide glass fibers pumped with a standard pulsed Thulium (Tm) laser (TFWHM=3.5ps, Pmax=20kW, νR=30MHz, and Pavg=2W). The fluoride fiber SC is generated in 10m of ZBLAN spanning the 0.9–4.1μm SC at the ~30dB level. The ZBLAN fiber SC is then coupled into 10cm of As2Se3 chalcogenide Microstructured Optical Fiber (MOF) designed to have a zero-dispersion wavelength (λZDW) significantly below the 4.1μm InfraRed (IR) edge of the ZBLAN fiber SC, here 3.55μm. This allows the MiR solitons in the ZBLAN fiber SC to couple into anomalous dispersion in the chalcogenide fiber and further redshift out to the fiber loss edge at around 9μm. The final 0.9–9μm SC covers over 3 octaves in the MiR with around 15mW of power converted into the 6–9μm range.

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THz Tube Waveguides With Low Loss, Low Dispersion, and High Bandwidth

We propose, model and experimentally characterize a novel class of terahertz hollow-core tube waveguides with high-loss cladding material, resulting in propagation with low loss, low dispersion, and high useful bandwidth.

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THz waveguides, devices and hybrid polymer-chalcogenide photonic crystal fibers

In this contribution, we review our recent activities in the design, fabrication and characterization of polymer THz waveguides. Besides the THz waveguides, we finally will also briefly show some of our initial results on a novel hybrid polymer photonic crystal fiber with integrated chalcogenide glass layers.

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THz Waveguides, Devices and Hybrid Polymer-chalcogenide Photonic Crystal Fibers

In this contribution, we review our recent activities in the design, fabrication and characterization of polymer THz waveguides. Besides the THz waveguides, we finally will also briefly show some of our initial results on a novel hybrid polymer photonic crystal fiber with integrated chalcogenide glass layers.

UV-Induced prevention of biofilm formation inside medical tubes and catheters

Biofilm formation inside medical tubes and catheters may often cause unwanted infections, illness and impaired wound healing during medical treatment, resulting in extended hospitalization and - in worst case – life-threatening conditions of the patients. In fact, it is estimated, that the infection risk connected with the use of medical tubes and catheters is the direct cause of more than 60% of all infections acquired in European hospitals. Once formed, the biofilm is generally very tough to suppress by either the body's immunity system or by use of antibiotics, which may even favor the population of multi resistant bacterial cultures. Prevention of biofilm formation inside the tube or catheter, without risk of developing multiresistance, may be achieved by creating a UV-exposed environment in the interior. This may be realized by transforming the tube itself into an optical waveguide supporting UV-light propagation or by other means integrating optical fiber technology into the tube walls, such as to gradually release UV-light into the interior, efficiently killing off bacteria present inside.

Coherent and Incoherent Rogue Waves in Seeded Supercontinuum Generation

The shot-to-shot stability of a supercontinuum (SC) can be controlled both in terms of coherence and intensity stability by modulating the input pulse with a weak seed [1-3]. In the long-pulse regime, the SC generation is initiated by noise-seeded modulation instability (MI), which breaks the pump into solitons and dispersive waves. To control the spectral evolution and reduce the noise, it has been proposed to provide a seed, i.e. a weak pulse with a frequency offset relative to the pump, within the MI gain spectrum in order to ensure a deterministic rather than noise-seeded pulse break-up [1,2]. Seeding the pulse break-up has likewise been used to control the generation of otherwise statistically rare large-amplitude rogue solitons [2-4]. In this work, we numerically investigate the influence of the MI gain spectrum on the pulse break-up and rogue wave generation. We find that the results can be clearly divided into a number of distinct dynamical regimes depending on the initial four-wave mixing process and demonstrate that seeding can be used to generate coherent and incoherent rogue waves.

Figure 1 shows simulation results of seeded SC generation in a fiber with a zero-dispersion wavelength (ZDW) at 1054 nm for pump wavelengths of 1055 and 1075 nm, respectively. The MI gain spectrum depends strongly on the pump wavelength and the MI gain bandwidth decreases when the pump is moved away from the ZDW, as seen in the insets in
Fig. 1. The seed causes a beating of the temporal profile, which, if chosen correctly, leads to a deterministic pulse breakup. When the pump is close to the ZDW [Fig. 1(a)], the MI gain is relatively small at the seed wavelength (1070.1 nm) and slowly increasing with wavelength. The temporal profile is therefore only slowly broken up into solitons. This means that the solitons are mainly generated from the pulse center where the peak power is highest. The solitons have time to redshift before the cascade is amplified and the dynamics are relatively turbulent. In contrast to this, pumping further from the ZDW [Fig. 1(b)] gives a much larger gain at the seed wavelength (1090.6 nm) that increases more rapidly with wavelength. This causes a fast breakup of the temporal pulse, where the individual temporal fringes generate fundamental solitons in a controlled fashion that almost resembles soliton fission. The most powerful solitons are still generated near the center of the pulse where the power is highest. These powerful rogue solitons only collide with the smaller solitons generated from the trailing edge of the pulse. Interestingly, a closer inspection reveals that the rogue soliton is generated incoherently when pumping close to the ZDW, but coherently when the pump is shifted away from the ZDW.
TDS system (Picometrix T-Ray 4000). The reference pulse before coupling into the fiber is shown in Fig. 1(a) and the time trace of the THz pulse after propagation through a 5-cm long segment of fiber is shown in Fig. 1(b) (blue curve). After adding some water on the outside of the fiber surface, the transmitted pulse experiences less pronounced oscillations at times later than 20 ps (red curve in Fig. 1(b)). Figs. 1(c) and (d) show the short-time Fourier transforms of the two time-domain traces in Fig. 1(b), overlaid with the calculated group delay in the two bandgaps (black squares). The frequencies below approximately 0.6 THz are attenuated by adding a layer of water on the outside of the fiber surface, while the transmission in the two band gaps in the 0.7-1.1 THz and 1.3-1.7 THz regions are unaffected by the water. This observation demonstrates that the absorptive water layer effectively strips the cladding modes from the fiber. The propagation loss is measured in a cut-back experiment. The fundamental bandgap at 0.75-1.05 THz is found to have losses lower than 1.5 dB/cm, whereas the loss is below 1.0 dB/cm in the reduced bandgap 0.78-1.02 THz, as shown in Fig. 1(g).

**Gain-switched all-fiber laser with narrow bandwidth**

Gain-switching of a CW fiber laser is a simple and cost-effective approach to generate pulses using an all-fiber system. We report on the construction of a narrow bandwidth (below 0.1 nm) gain-switched fiber laser and optimize the pulse energy and pulse duration under this constraint. The extracted pulse energy is 20 μJ in a duration of 135 ns at 7 kHz. The bandwidth increases for a higher pump pulse energy and repetition rate, and this sets the limit of the output pulse energy. A single power amplifier is added to raise the peak power to the kW-level and the pulse energy to 230 μJ while keeping the bandwidth below 0.1 nm. This allows frequency doubling in a periodically poled lithium tantalate crystal with a reasonable conversion efficiency.
Gain-switched, Yb-doped, all-fiber laser with narrow bandwidth

We demonstrate that an all-fiber, narrow bandwidth, high pulse energy pulsed laser can be constructed from commercially available components by applying gain-switching. After single-stage amplification the pulses are frequency doubled in ppSLT with high efficiency.

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Highly photosensitive polymethyl methacrylate microstructured polymer optical fiber with doped core

In this Letter, we report the fabrication of a highly photosensitive, microstructured polymer optical fiber using benzyl dimethyl ketal as a dopant, as well as the inscription of a fiber Bragg grating in the fiber. A refractive index change in the core of at least $3.2 \times 10^{-4}$ has been achieved, providing a grating with a strong transmission rejection of $-23$ dB with an inscription time of only 13 min. The fabrication method has a big advantage compared to doping step index fiber since it enables doping of the fiber without using extra dopants to compensate for the index reduction in the core introduced by the photosensitive agent.

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High-Tg TOPAS mPOF strain sensing at 110 degrees
We demonstrate a mPOF made of high-Tg TOPAS grade 5013 with $T_g = 135^\circ$C. We inscribe FBGs into the fiber and demonstrate strain sensing of 2.5% strain at 98°C, further we also demonstrate strain sensing at a record high temperature of 110°C. The Bragg wavelengths of the FBGs are around 860 nm, where the propagation loss is 5.1dB/m, close to the fiber loss minimum of 3.67dB/m at 787nm.

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High-Tg TOPAS microstructured polymer optical fiber for fiber Bragg grating strain sensing at 110 degrees
We present the fabrication and characterization of fiber Bragg gratings (FBGs) in an endlessly single-mode microstructured polymer optical fiber (mPOF) made of humidity-insensitive high-Tg TOPAS cyclic olefin copolymer. The mPOF is the first made from grade 5013 TOPAS with a glass transition temperature of $T_g = 135^\circ$C and we experimentally demonstrate high strain operation (2.5%) of the FBG at 98°C and stable operation up to a record high temperature of 110°C. The Bragg wavelengths of the FBGs are around 860 nm, where the propagation loss is 5.1dB/m, close to the fiber loss minimum of 3.67dB/m at 787nm.

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Hole-Size Increasing PCFs for Blue-Extended Supercontinuum Generation

Supercontinuum (SC) sources with spectra extending into the deep-blue region below 400 nm are highly desirable in areas such as fluorescent microscopy [1]. Tapering of photonic crystal fibers (PCFs) with high air-fill fractions has proven an effective way of extending the spectra into the deep-blue [1-4]. This facilitates the ideal combination of (1) an initial fiber section to allow a pulse break-up in the vicinity of the zero-dispersion wavelength (ZDW) and an efficient energy transfer into the visible, and (2) a subsequent fiber section with group-velocity match (GVM) from the long wavelength spectral edge to wavelengths in the deep-blue or even UV. Previous reports on blue-extended SC generation were typically achieved in tapered PCFs where the air-hole structure was preserved [1-4], i.e. the relative hole-size constant. However, such PCFs with high air-fill fractions are inevitably (highly) multi moded at the pump, which complicates coupling and interfacing. In [5] this was overcome by increasing the air-hole size in a short section of a single mode PCF using a post processing technique, but only to enhance the visible power. Here we present the first high-power SC generation into the deep-blue in a single mode PCF with varying hole-size and pitch fabricated directly at the draw-tower.

The PCFs in this work are fabricated by increasing the pressure on the air holes during the drawing. However, this process alone will lead to an undesirable structure where both the relative hole-size and pitch increase. The draw speed was therefore increased simultaneously with the increase in pressure to give the optimum structural change with an increasing relative hole-size and decreasing pitch. The resulting fiber structure is shown in Fig. 1(a) for PCF 1: the hole-to-pitch ratio is increased from 0.52 at the input to 0.85 at the output over 7 m, while the pitch is decreased from 3.3 to 2.15 μm. These parameters were chosen to ensure single mode behaviour at 1064 nm at the input and a theoretical blue edge at 365 nm at the output assuming GVM to a long wavelength edge at 2300 nm. An additional target (PCF 2) was drawn to a hole-to-pitch ratio of 0.7 and a pitch of 2.2 μm over 4 m. The SC generated in the two PCFs are shown in Fig. 1(b); both extend well-below 400 nm and PCF 2 shows a record 3 dB spectral flatness over the range 363-628 nm. The higher hole-to-pitch ratio of PCF 1 should yield a more blue shifted spectral edge compared to PCF 2 [2,4], however, a closer inspection showed that the fiber structure deviated from an ideal hexagonal structure when the air holes expand. This resulted in a too small core, which explains why the broadest SC was generated in PCF 2. The results nonetheless clearly demonstrate that deep-blue spectra can be efficiently generated in such PCFs with increasing hole-size and decreasing pitch.

Influence of Phase Coherence on Seeded Supercontinuum Generation

The noise properties of supercontinuum (SC) generation have attracted a lot of attention due to a large application demand for low noise SC sources and in the more fundamental context of clarifying links with instabilities in other systems.
In typical commercial SC sources the pulse break-up is initiated by noise-driven modulational instability (MI). The resulting large spectral shot-to-shot fluctuations can be significantly reduced by modulating the pump with a phase coherent seed [1-2], which leads to a coherent pulse break-up through the amplification of a cascade of four-wave mixing (FWM) sidebands. We demonstrate that the noise properties of the generated SC are highly sensitive to the degree of phase noise of the seed and that a nearly coherent seed pulse is needed to achieve a coherent pulse break-up and low noise SC [3]. This limits the mechanisms that can be used to generate the seed, which is important in designing next-generation low-noise SC sources.

We performed numerical simulations in which the phase noise of the seed was modelled by a physically justified phase-diffusion model. The cross-spectral density (CSD) relative to the pump, i.e. the coherence of the seed relative to the pump, is shown in Fig. 1(a) for varying seed noise linewidths; the seed becomes increasingly incoherent with the pump when the linewidth is increased. Simulation results including ensemble calculated coherence for unseeded and seeded SC generation with varying seed noise linewidths are shown in Fig. 1(b). In the absence of a seed the spectral broadening is initiated by noise-induced MI, where a single set of MI sidebands evolves into solitons and dispersive waves (DWs) with low spectral coherence. By introducing a coherent seed near the pump, the spectral broadening is initiated by the coherent amplification of a cascaded FWM comb, leading to a high spectral coherence over most of the spectral bandwidth. When the seed noise linewidth is increased, the broadening is still initiated by a FWM cascade, but the contrast of the comb is gradually washed out. This leads to a significant reduction of the coherence. For a seed noise linewidth in the GHz range, the noise properties are only marginally better than for an unseeded SC. A closer inspection reveals that the fringe contrast of the FWM comb decreases with increasing seed noise linewidth. This causes an increasingly incoherent amplification of the comb, where only the FWM sidebands closest to the pump are coherently amplified, and results in a significant coherence degradation of the resulting SC.

Our results thus show that there is a stringent requirement on the linewidth of the seed laser for seeding to be effective in reducing the noise of an SC source. Further results show that the specific maximum allowable linewidth decreases with increasing pump power, which means that the noise of high-power SC sources will be difficult to control by seeding.
Intensity Noise of Normal-Pumped Picosecond Supercontinuum Generation

The noise properties of supercontinuum (SC) sources are of importance in many applications. This intensity noise of the SC arises from nonlinear amplification of the input-pulse shot noise and the spontaneous Raman scattering down the fiber [1]. Low noise femtosecond SC generation (SCG) has previously been demonstrated [2]. However, in commercial SC sources, the SC is generated by pumping with picosecond to nanosecond pulses and the SCG is thus initiated by modulation instability (MI). Therefore, the SC is characterized by low coherence and high shot-to-shot fluctuations, in particular at the spectral edges [3–5]. However, the influence of the noise properties when pumping in the normal dispersion regime has so far not been investigated for long pulse pumping. In this work we have measured and compared the relative intensity noise (RIN) properties of long-pulse MI initiated SCG in three different regimes: (i) all-normal SCG, (ii) normal-pumped SCG where higher-order Raman lines occur in the anomalous dispersion regime, and (iii) anomalous-pumped SCG. We show that the noise properties for the three regimes are similar: when increasing the input pump power, the intensity noise will continuously decrease for a given wavelength, and for a given input power the intensity noise will be lowest at the pump wavelength and increase when moving towards the spectral edge [6].

A high-power ytterbium laser, which delivers 10 ps pulses at 1064 nm at a repetition rate of 80 MHz was used to generate the SC in two kinds of photonic crystal fibres (PCFs); 10 m of LMA-15 (ZDW=1240 nm) and 10 m of SC-5.0-1040 (ZDW=1040 nm). The dispersion profiles of the PCFs are shown in Fig. 1(a) and the power spectral density (PSD) as a function of power for normal-pumped SCG is shown in Fig. 1(b). The RIN was measured for different wavelengths (Fig. 1(c)) by passing the SC through bandpass filters (FWHM=10 nm) and detect the filtered SC by a low noise photodetector connected to an electrical spectrum analyzer [4,5]. In Fig. 1 (d-e) the spectra and the RIN of normal pumped SCG are compared to anomalous pumped SCG.

Mid-infrared supercontinuum generation in tapered ZBLAN fiber with a standard Erbium mode-locked fiber laser

Mid-InfraRed (MIR) broadband SuperContinuum (SC) sources are desirable for applications such as pollution monitoring, spectroscopy, and IR countermeasures due to their high spatial coherence and high power density over a broad bandwidth [1]. Conventional silica fibers cannot facilitate this need due to their intrinsic IR transmission edge at 2.4 μm, so instead soft glasses are used for MIR SC sources. The soft glass ZBLAN is in particular interesting as it has low loss out to 4.5 μm [Fig. 1(a)]. Additionally, it has a material Zero Dispersion Wavelength (ZDW) around 1.6 μm that with proper fiber design allows to generate a broadband SC using direct pumping with commercially available Erbium (Er) mode-locked fiber lasers at 1550 nm. Formation of SC is manipulated both in the UV and IR by changing the fiber dispersion and nonlinearity using tapers. This has been much studied in various silica fiber designs and is now also becoming used in ZBLAN [2], and other soft glasses such as chalcogenide [3] and tellurite [4]. The aim of this numerical work is to show how pumping tapered commercially available ZBLAN fibers with an Er mode-locked fiber laser can generate a broadband
SC approaching the ZBLAN long wavelength transmission edge. The taper employed here is a 20 cm long symmetric taper with a down- and up-taper length of 2 cm and a 16 cm long waist [see inset in Fig. 1(c)] and can be easily fabricated on a conventional Vytran taper stage.

Ten meters of uniform ZBLAN Step Index Fiber with NA=0.3 (max. commercially available), core diameter Dc=7 μm, and ZDW=1.5 μm, is pumped with TFWHM=10 ps and P0=10 kW pulses from an Er mode-locked laser with a 40 MHz repetition rate and 4W average power. The resulting MIR SC seen in Fig. 1(b) is based on Modulation Instability breakup of the pump pulse, which generates solitons that undergo Soliton Self Frequency Shift (SSFS). The -30 dB SC IR edge is at 3.06 μm. The increasing dispersion (D) for Dc=7 μm [see Fig. 1(b)] decreases the rate of SSFS, which is why the IR edge is still far away from the ZBLAN transmission edge. This is overcome by tapering the fiber with taper start at 8 m down to Dc=5.5 μm. At the taper waist a region of normal dispersion now appears in between the solitons, which generates MIR Dispersive Waves (DWs) between the second and third ZDW and also accelerates a large number of solitons towards the IR, as we will detail in the presentation. This moves the IR edge to 4.36 μm, close to the ZBLAN transmission edge.

In Fig. 1(c) we show the integrated power above 3.06 μm and the -30 dB IR edge versus the taper waist between 5 and 7 μm for a fixed taper start at 8 m (optimum found through extensive modelling to be presented). Both indicate that a taper waist of 5.5 μm provides the maximum power of 45 mW above 3.06 μm.

The ZBLAN taper in [2] resembling this work is based on very high NA fiber and is 6m long, which can only be made on the draw tower. The resulting SC in [2] covers 1.5-3 μm, where our spectrum covers 0.8-4.4 μm and uses only realistic fiber and laser parameters and a short taper, which can be fabricated on a taper station.

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Mid-infrared supercontinuum generation to 4.5 μm in uniform and tapered ZBLAN step-index fibers by direct pumping at 1064 or 1550 nm

We present a numerical design optimization of step-index ZBLAN fibers for developing mid-infrared (IR) supercontinuum sources with spectra covering the 1–4.5 μm regime using direct pumping with 10 ps pulses (FWHM) from mode-locked Yb (12.5 kW peak power) and Er lasers (10 kW peak power). Even with optimum NA and core diameter to minimize confinement loss and give the most suitable dispersion and nonlinearity, the Yb pump-laser cannot push the spectrum beyond 1.52 μm, whereas the Er laser can push the spectrum to 4.15 μm. We further consider the optimum placement of a 20 cm taper to broaden the spectrum. This does not considerably broaden the Yb-pumped spectrum, whereas the Er-pumped spectrum can be extended to 4.5 μm through mid-IR dispersive waves and tunneling solitons.

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New horizons for Supercontinuum light sources: from UV to mid-IR

Commercially available supercontinuum sources continue to experience a strong growth in a wide range of industrial and scientific applications. In addition, there is a significant research effort focused on extending the wavelength coverage both towards UV and Mid-IR. Broadband sources covering these wavelength regions have received significant attention from potential users, as there is a wide array of applications for which there are few suitable alternative light sources – if any. Our developments in the field of Mid-IR supercontinuum sources have been based on radical approaches; such as soft glasses and novel pumping schemes, whereas shifting the spectrum further towards the UV has been based on sophisticated microstructure fiber designs. Here we present our latest developments in tailoring the power and spectral coverage of spatially coherent broadband supercontinuum sources.

Numerical demonstration of 3-12µm supercontinuum generation in large-core step-index chalcogenide fibers pumped at 4.5µm

We numerically demonstrate the generation of a 3-12µm mid-infrared supercontinuum in a large-core step-index fiber made from highly nonlinear chalcogenide (As2Se3) pumped at 4.5µm with 40ps, 1kW peak power pulses.
Numerical demonstration of 3-12μm supercontinuum generation in large-core step-index chalcogenide fibers pumped at 4.5μm

We numerically demonstrate the generation of a 3-12μm mid-infrared supercontinuum in a large-core (20μm diameter) step-index fiber made from highly nonlinear chalcogenide (As2Se3) pumped at 4.5μm with 40ps, 1kW peak power pulses. © OSA 2013.

Optimized ZBLAN fiber for efficient and broadband mid-infrared supercontinuum generation through direct pumping at 1550nm

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Optimized ZBLAN fiber for efficient and broadband mid-infrared supercontinuum generation through direct pumping at 1550nm

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Selective Serial Multi-Antibody Biosensing with TOPAS Microstructured Polymer Optical Fibers

We have developed a fluorescence-based fiber-optical biosensor, which can selectively detect different antibodies in serial at preselected positions inside a single piece of fiber. The fiber is a microstructured polymer optical fiber fabricated from TOPAS cyclic olefin copolymer, which allows for UV activation of localized sensor layers inside the holes of the fiber. Serial fluorescence-based selective sensing of Cy3-labelled α-streptavidin and Cy5-labelled α-CRP antibodies is demonstrated.

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Zero-dispersion wavelength independent quasi-CW pumped supercontinuum generation
Continuous wave (CW) pumped supercontinuum generation depends strongly on the zero-dispersion wavelength (ZDW) of the fiber due to the low peak power. Here we study several photonic crystal fibers by use of a gain-switched CW pump laser and investigate for what power level the supercontinuum reaches the silica mid-infrared loss edge and the bandwidth becomes independent of the ZDW. We show that for a quasi-CW power of more than 350 W the loss edge limits the broadening, and at 500 W we obtain a variation of only 4% in the achieved bandwidth for fibers with a ZDW in a 50 nm region around the 1064 nm pump wavelength.

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All fiber based supercontinuum light source utilized for IR microscopy

An all-fiber-based supercontinuum light source is demonstrated for infrared microscopy. The high brightness and spatial coherence of the source facilitate fast high-resolution measurements.

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Anomalous interaction of nonlocal solitons in media with competing nonlinearities

We theoretically investigate properties of individual bright spatial solitons and their interaction in nonlocal media with competing focusing and defocusing nonlinearities. We consider the general case with both nonlinear responses characterized by different strengths and degrees of nonlocality. We employ a variational approach to analytically describe soliton properties. In particular, we prove analytically that the interplay of focusing and defocusing nonlocal nonlinearities leads to attraction or repulsion of solitons depending on their separation distance. We then study the propagation and interaction of solitons using numerical simulations of the full model of beam propagation. The numerical simulations fully confirm our analytical results.

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Asymmetric Draw-Tower Tapers for Supercontinuum Generation and Verification of the Novel Concept of Group-Acceleration Matching

We present the first short asymmetrical draw-tower photonic crystal fiber taper for maximizing the power in the blue edge of a supercontinuum. The results clearly emphasize the importance of the taper shape on the spectrum.

Cleaving of TOPAS and PMMA microstructured polymer optical fibers: Core-shift and statistical quality optimization

We fabricated an electronically controlled polymer optical fiber cleaver, which uses a razor-blade guillotine and provides independent control of fiber temperature, blade temperature, and cleaving speed. To determine the optimum cleaving conditions of microstructured polymer optical fibers (mPOFs) with hexagonal hole structures we developed a program for cleaving quality optimization, which reads in a microscope image of the fiber end-facet and determines the core-shift and the statistics of the hole diameter, hole-to-hole pitch, hole ellipticity, and direction of major ellipse axis. For 125μm in diameter mPOFs of the standard polymer PMMA we found the optimum temperatures to be 77.5°C for both blade and fiber. For 280μm in diameter mPOFs of the humidity insensitive polymer TOPAS® (grade 8007) the optimum temperature was 40° for both blade and fiber. A 100μm thick flat-edge blade was found to minimize the core-shift by the cleaving to only 298nm or 5% of the pitch for the PMMA mPOF at the optimal temperature.
Deep-blue supercontinuum sources with optimum taper profiles – verification of GAM

We use an asymmetric 2 m draw-tower photonic crystal fiber taper to demonstrate that the taper profile needs careful optimisation if you want to develop a supercontinuum light source with as much power as possible in the blue edge of the spectrum. In particular we show, that for a given taper length, the downtapering should be as long as possible. We argue how this may be explained by the concept of group-acceleration mismatch (GAM) and we confirm the results using conventional symmetrical short tapers made on a taper station, which have varying downtapering lengths.

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Describing supercontinuum noise and rogue wave statistics using higher-order moments

We show that the noise properties of fiber supercontinuum generation and the appearance of long-tailed “rogue wave” statistics can be accurately quantified using statistical higher-order central moments. Statistical measures of skew and kurtosis, as well as the coefficient of variation provide improved insight into the nature of spectral fluctuations across the supercontinuum and allow regions of long-tailed statistics to be clearly identified. These moments – that depend only on analyzing intensity fluctuations – provide a complementary tool to phase-dependent coherence measures to interpret supercontinuum noise.

Direct Writing of Fiber Bragg Grating in Microstructured Polymer Optical Fiber

We report point-by-point laser direct writing of a 1520-nm fiber Bragg grating in a microstructured polymer optical fiber (mPOF). The mPOF is specially designed such that the microstructure does not obstruct the writing beam when properly aligned. A fourth-order grating is inscribed in the mPOF with only a 2.5-s writing time.
Dynamic Characterization of Polymer Optical Fibers

With the increasing interest in fiber sensors based on polymer optical fibers, it becomes fundamental to determine the real applicability and reliability of this type of sensor. The viscoelastic nature of polymers gives rise to questions about the mechanical behavior of the fibers. In particular, concerns on the response in the nonstatic regime find foundation in the viscoelasticity theory. We investigate the effects of such behavior via analysis of the mechanical properties under dynamic excitations. It is shown that for low strain (0.28%), the Young's modulus is constant for frequencies up to the limit set by our measurement system. A more detailed analysis shows that viscoelastic effects are present and that they increase with both applied strain and frequency. However, the possibility of developing sensors that measure small dynamic deformations is not compromised. A stress-relaxation experiment for larger deformations (2.8%) is also reported and a relaxation time around 5 s is measured, defining a viscosity of 20 GPa·s.

Fabrication and characterization of porous-core honeycomb bandgap THz fibers

We present a numerical and experimental investigation of a low-loss porous-core honeycomb fiber for terahertz wave guiding. The introduction of a porous core with hole size of the same dimension as the holes in the surrounding honeycomb cladding results in a fiber that can be drawn with much higher precision and reproducibility than a corresponding air-core fiber. The high-precision hole structure provides very clear bandgap guidance and the location of the two measured bandgaps agree well with simulations based on finite-element modeling. Fiber loss measurements reveal the frequency-dependent coupling loss and propagation loss, and we find that the fiber propagation loss is much lower than the bulk material loss within the first band gap between 0.75 and 1.05 THz.
Fiber design and realization of point-by-point written fiber Bragg gratings in polymer optical fibers

An increasing interest in making sensors based on fiber Bragg gratings (FBGs) written in polymer optical fibers (POFs) has been seen recently. Mostly microstructured POFs (mPOFs) have been chosen for this purpose because they are easier to fabricate compared, for example, to step index fibers and because they allow to tune the guiding parameters by modifying the microstructure. Now a days the only technique used to write gratings in such fibers is the phase mask technique with UV light illumination. Despite the good results that have been obtained, a limited flexibility on the grating design and the very long times required for the writing of FBGs raise some questions about the possibility of exporting POF FBGs and the sensors based on them from the laboratory bench to the mass production market. The possibility of arbitrary design of fiber Bragg gratings and the very short time required to write the gratings make the point-by-point grating writing technique very interesting and would appear to be able to fill this technological gap. On the other end this technique is hardly applicable for microstructured fibers because of the writing beam being scattered by the air-holes. We report on the design and realization of a microstructured polymer optical fiber made of PMMA for direct writing of FBGs. The fiber was designed specifically to avoid obstruction of the writing beam by air-holes. The realized fiber has been used to point-by-point write a 5 mm long fourth order FBG with a Bragg wavelength of 1518 nm. The grating was inspected under Differential Interferometric Contrast microscope and the reflection spectrum was measured. This is, to the best of our knowledge, the first FBGs written into a mPOF with the point-by-point technique and also the fastest ever written into a polymer optical fiber, with less than 2.5 seconds needed.
Fiber Drawn 2D Polymeric Photonic Crystal THz Filters

In this paper, we report on different polymeric 2D photonic crystal filters for THz frequencies which are fabricated by a standard fiber drawing technique. The bandstop filters were simulated and designed by the generalized multipole technique (GMT). The frequency and angle dependent transmission characteristics of the photonic crystal structures were characterized in a pulsed terahertz (THz) time domain spectrometer.

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Higher-Order Moment Characterisation of Rogue Wave Statistics in Supercontinuum Generation

The noise characteristics of supercontinuum generation are characterized using higher-order statistical moments. Measures of skew and kurtosis, and the coefficient of variation allow quantitative identification of spectral regions dominated by rogue wave like behaviour.

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High power supercontinuum generation in tapered photonic crystal fibers

Tapering of photonic crystal fibers has proven to be an effective way of blueshifting the dispersive wavelength edge of a supercontinuum spectrum down in the deep-blue. In this contribution we will discuss the underlying mechanisms of supercontinuum generation in tapers. We show, by introducing the concept of a group-acceleration mismatch, that for a given taper length, the downtapering section should be as long as possible to enhance the amount of blueshifted light. We also discuss the noise properties of supercontinuum in uniform and tapered fibers and we demonstrate that the amplitude noise at the spectral edges of the generated supercontinuum is at a constant level independent on the pump power in both tapered and uniform fibers.

High Sensitivity Polymer Optical Fiber-Bragg-Grating-Based Accelerometer

We report on the fabrication and characterization of the first accelerometer based on a polymer optical fiber Bragg grating (FBG) for operation at both 850 and 1550 nm. The devices have a flat frequency response over a 1-kHz bandwidth and a resonance frequency of about 3 kHz. The response is linear up to at least 15 g and sensitivities as high as 19 pm/g (shift in resonance wavelength per unit acceleration) have been demonstrated. Given that 15 g corresponds to a strain of less than 0.02% and that polymer fibers have an elastic limit of more than 1%, the polymer FBG accelerometer can measure very strong accelerations. We compare with corresponding silica FBG accelerometers and demonstrate that using polymer FBGs improves the sensitivity by more than a factor of four and increases the figure of merit, defined as the sensitivity times the resonance frequency squared.
Influence of pump power and modulation instability gain spectrum on seeded supercontinuum and rogue wave generation

The noise properties of a supercontinuum can be significantly improved both in terms of coherence and intensity stability by modulating the input pulse with a seed. In this paper, we numerically investigate the influence of the seed wavelength, the pump power, and the modulation instability gain spectrum on the seeding process. The results can be clearly divided into a number of distinct dynamical regimes depending on the initial four-wave mixing process. We further demonstrate that seeding can be used to generate coherent and incoherent rogue waves, depending on the modulation instability gain spectrum. Finally, we show that the coherent pulse breakup afforded by seeding is washed out by turbulent solitonic dynamics when the pump power is increased to the kilowatt level. Thus, our results show that seeding cannot improve the noise performance of a high power supercontinuum source.

Influence of two-photon absorption on soliton self-frequency shift

In this paper, we develop an analytical model for the soliton self-frequency shift, which includes second- and third-order dispersion, self-steepening, the full Raman term, and, for the first time to our best knowledge, the effect of two-photon absorption (TPA). We show that TPA can have a significant effect on soliton dynamics in soft-glass materials such as chalcogenides, by severely depleting a soliton and thereby limiting the achievable redshift. Based on the model, we derive a nonlinear loss length after which the redshift is effectively halted by TPA, which proves to be a useful design tool.
IR microscopy utilizing intense supercontinuum light source
Combining the molecular specificity of the infrared spectral region with high resolution microscopy has been pursued by researchers for decades. Here we demonstrate infrared supercontinuum radiated from an optical fiber as a promising new light source for infrared microspectroscopy. The supercontinuum light source has a high brightness and spans the infrared region from 1400 nm to 4000 nm. This combination allows contact free high resolution hyper spectral infrared microscopy. The microscope is demonstrated by imaging an oil/water sample with 20 μm resolution.

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Modulational instability and solitons in nonlocal media with competing nonlinearities
We investigate propagation and spatial localization of light in nonlocal media with competing nonlinearities. We show that the competing focusing and defocusing nonlinearities enable coexistence of dark or bright spatial solitons in the same medium by varying the intensity of the beam.

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Nonlinear fiber-optic strain sensor based on four-wave mixing in microstructured optical fiber
We demonstrate a nonlinear fiber-optic strain sensor, which uses the shifts of four-wave mixing Stokes and anti-Stokes peaks caused by the strain-induced changes in the structure and refractive index of a microstructured optical fiber. The sensor thus uses the inherent nonlinearity of the fiber and does not require any advanced post-processing of the fiber. Strain sensitivity of -0.23 pm/με is achieved experimentally and numerical simulations reveal that for the present fiber the sensitivity can be increased to -4.46 pm/με by optimizing the pump wavelength and power.

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Nonlinear matching of Solitons - Continued redshift between silica and soft-glass fibers

We present an analysis of nonlinear coupling between fibers. We introduce the nonlinear coupling coefficient and investigate solitons coupling from one fiber into another. We will also present simulated supercontinuum from concatenated fiber systems.

Optical fiber sensors fabricated by the focused ion beam technique

Focused ion beam (FIB) is a highly versatile technique which helps to enable next generation of lab-on-fiber sensor technologies. In this paper, we demonstrate the use application of FIB to precisely mill the fiber taper and end facet of both conventional single mode fiber (SMF) and photonic crystal fiber (PCF). Using this technique we fabricate a highly compact fiber-optic Fabry-Pérot (FP) refractive index sensor near the tip of fiber taper, and a highly sensitive in-line temperature sensor in PCF. We also demonstrate the potential of using FIB to selectively fill functional fluid into desired air holes of PCF.
Optimization of Tapered Photonic Crystal Fibers for Blue-Enhanced Supercontinuum Generation

Tapering of photonic crystal fibers is an effective way of shifting the dispersive wavelength edge of a supercontinuum spectrum down in the deep-blue. We discuss the optimum taper profile for blue-enhanced supercontinuum generation.

Optimum PCF tapers for blue-enhanced supercontinuum sources

Tapering of photonic crystal fibers has proven to be an effective way of bluishifting the dispersive wavelength edge of a supercontinuum spectrum down in the deep-blue. In this article we will review the state-of-the-art in fiber tapers, and discuss the underlying mechanisms of supercontinuum generation in tapers. We show, by introducing the concept of a group-acceleration mismatch, that for a given taper length, the downtapering section should be as long as possible to enhance the amount of blueshifted light. We also discuss the noise properties of supercontinuum generation in uniform and tapered fibers, and we demonstrate that the intensity noise at the spectral edges of the generated supercontinuum is at a constant level independent on the pump power in both tapered and uniform fibers.

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Photonic crystal fibers for supercontinuum generation pumped by a gain-switched CW fiber laser

Supercontinuum generation in photonics crystal fibers (PCFs) pumped by CW lasers yields high spectral power density and average power. However, such systems require very high pump power and long nonlinear fibers. By on/off modulating the pump diodes of the fiber laser, the relaxation oscillations of the laser can be exploited to enhance the broadening process. The physics behind the supercontinuum generation is investigated by sweeping the fiber length, the zero dispersion wavelength, and the fiber nonlinearity. We show that by applying gain-switching a high average output power of up to 30 W can be maintained and the spectral width can be improved by 90%. The zero dispersion wavelength should be close to but below the pump wavelength to achieve the most visible light. By increasing the nonlinearity the fiber length can be reduced from 100 m to 25 m and the efficiency of visible light generation is improved by more than 200%.

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Power dependence of supercontinuum noise in uniform and tapered PCFs
We experimentally investigate the noise properties of picosecond supercontinuum spectra generated at different power levels in uniform and tapered photonic crystal fibers. We show that the noise at the spectral edges of the generated supercontinuum is at a constant level independent on the pump power in both tapered and uniform fibers. At high input power the spectral bandwidth is limited by the infrared loss edge, this however has no effect on the noise properties.

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Power dependence of supercontinuum noise in uniform and tapered PCFs: erratum

An error was made in the calculation of the relative intensity noise (RIN) because of an incorrectly specified value of the photodetector DC transimpedance gain.

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Quadratic solitons for negative effective second-harmonic diffraction as nonlocal solitons with periodic nonlocal response function

We employ the formal analogy between quadratic and nonlocal solitons to investigate analytically the properties of solitons and soliton bound states in second-harmonic generation in the regime of negative diffraction or dispersion of the second harmonic. We show that in the nonlocal description this regime corresponds to a periodic nonlocal response function. We then use the strongly nonlocal approximation to find analytical solutions of the families of single bright solitons and their bound states in terms of Mathieu functions.

Seeded Supercontinuum Generation - Modulation Instability Gain, Coherent and Incoherent Rogue Waves

Deterministic supercontinuum can be generated by seeding the modulation instability-induced pulse break-up. We investigate the influence of the modulation instability gain on seeding and demonstrate the generation of coherent and incoherent rogue waves.
Supercontinuum - broad as a lamp, bright as a laser, now in the mid-infrared

Based on the experience gained developing our market leading visible spectrum supercontinuum sources NKT Photonics has built the first mid-infrared supercontinuum source based on modelocked picosecond fiber lasers. The source is pumped by a ≈ 2 μm laser based on a combination of erbium and thulium and use ZBLAN fibers to generate a 1.75-4.4 μm spectrum. We will present results obtained by applying the source for mid-infrared microscopy where absorption spectra can be used to identify the chemical nature of different parts of a sample. Subsequently, we discuss the possible application of a mid-IR supercontinuum source in other areas including infrared countermeasures.

Supercontinuum Generation in Uniform and Tapered Photonic Crystal Fibers

Supercontinuum generation (SCG) is a striking phenomenon of extreme spectral broadening involving a wealth of beautiful nonlinear physics. The study of SCG and development of today's commercial sources really took off with the invention of the photonic crystal fiber (PCF), in which light can be manipulated by air-hole structuring. SCG is inherently linked to the fundamental field of soliton physics and due to the striking efficiency of SCG in PCFs, researchers have been able to reveal numerous new and important fundamental effects and surprising links with other physical systems. In this work, we describe the underlying mechanisms responsible for SCG in PCFs, and show how the position and power in the spectral edges can be manipulated by tapering the fiber to achieve, e.g., spectra extending into the ultraviolet. This is motivated by the huge commercial potential of blue-extended supercontinuum sources in areas such as fluorescence microscopy.

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Supercontinuum generation in ZBLAN fibers—detailed comparison between measurement and simulation

We present a detailed comparison between modeling and experiments on supercontinuum (SC) generation in a commercial ZBLAN step-index fiber. Special emphasis is put on identifying accurate material parameters by incorporating measurements of the ZBLAN Raman gain, fiber dispersion, and loss. This identification of accurate parameters is of great importance to substantiate numerical simulations of SC generation in soft-glass fibers. Good agreement between measurement and simulation is obtained when pumping both in the normal and anomalous dispersion regimes. © 2012 Optical Society of America
Temperature compensated, humidity insensitive, high-T<sub>g</sub> TOPAS FBGs for accelerometers and microphones

In this paper we present our latest work on Fiber Bragg Gratings (FBGs) in microstructured polymer optical fibers (mPOFs) and their application as strain sensing transducers in devices, such as accelerometers and microphones. We demonstrate how the cross-sensitivity of the FBG to temperature is eliminated by using dual-FBG technology and how mPOFs fabricated from different grades of TOPAS with glass transition temperatures around 135 degrees C potentially allow high-temperature humidity insensitive operation. The results bring the mPOF FBG closer to being a viable technology for commercial applications requiring high sensitivity due to the low Young's Modulus of polymer.

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Temperature Compensated Strain Sensor Based on Cascaded Sagnac Interferometers and All-Solid Birefringent Hybrid Photonic Crystal Fibers

We demonstrate a temperature compensated strain sensor with two cascaded Sagnac interferometers, that provide strain sensing and temperature compensation, respectively. The Sagnac interferometers use an all-solid hybrid photonic crystal fiber with stress-induced birefringence. The stress-induced birefringent fiber is known to offer the maximum strain sensitivity, but also to suffer from temperature crosstalk. Our experimental results show that the cascaded Sagnac sensor can suppress the crosstalk to a temperature upto 0.33 με/ºC, while still providing a high strain sensitivity of ~25.6 pm/με.

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The role of phase coherence in seeded supercontinuum generation
The noise properties of a supercontinuum can be controlled by modulating the pump with a seed pulse. In this paper, we numerically investigate the influence of seeding with a partially phase coherent weak pulse or continuous wave. We demonstrate that the noise properties of the generated supercontinuum are highly sensitive to the degree of phase noise of the seed and that a nearly coherent seed pulse is needed to achieve a coherent pulse break-up and low noise supercontinuum. The specific maximum allowable linewidth of the seed laser is found to decrease with increasing pump power.

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THz Photonic Band-Gap Prisms Fabricated by Fiber Drawing
We suggest a novel form of polymeric based 3D photonic crystal prisms for THz frequencies which could be fabricated using a standard fiber drawing technique. The structures are modeled and designed using a finite element analyzing technique. Using this simulation software we theoretically study their performance.
Tunable Polymer Fiber Bragg Grating (FBG) Inscription: Fabrication of Dual-FBG Temperature Compensated Polymer Optical Fiber Strain Sensors

We demonstrate stable wavelength tunable inscription of polymer optical fiber Bragg gratings (FBGs). By straining the fiber during FBG inscription, we linearly tune the center wavelength over 7 nm with less than 1% strain. Above 1% strain, the tuning curve saturates and we show a maximum tuning of 12 nm with 2.25% strain. We use this inscription method to fabricate a dual-FBG strain sensor in a poly (methyl methacrylate) single-mode microstructured polymer optical fiber and demonstrate temperature compensated strain sensing around 850 nm.

870nm Bragg grating in single mode TOPAS microstructured polymer optical fibre

We report the fabrication and characterization of a fiber Bragg grating (FBG) with 870 nm resonance wavelength in a single-mode TOPAS microstructured polymer optical fiber (mPOF). The grating has been UV-written with the phase-mask technique using a 325 nm HeCd laser. The static tensile strain sensitivity has been measured as 0.64 pm/μstrain, and the temperature sensitivity was -60 pm/°C. This is the first 870nm FBG and the first demonstration of a negative temperature response for the TOPAS FBG, for which earlier results have indicated a positive temperature response. The relatively low material loss of the fiber at this wavelength compared to that at longer wavelengths will considerably enhance the potential utility of the TOPAS FBG.
All-solid birefringent hybrid photonic crystal fiber based interferometric sensor for measurement of strain and temperature
A highly sensitive fiber-optic interferometric sensor based on an all-solid birefringent hybrid photonic crystal fiber (PCF) is demonstrated for measuring strain and temperature. A strain sensitivity of similar to 23.8 pm/με and a thermal sensitivity of similar to -1.12 nm/°C are demonstrated in the experiment.

Dark solitons in nonlinear media with arbitrary degree of nonlocality
Spatial dark optical solitons are localized light intensity dips in the infinite constant background [1]. They exist as a result of a balance between diffraction and nonlinearity of the medium. In recent years there has been strong interest in the so-called nonlocal nonlinearities, in which the nonlinearity in a particular spatial location is determined by the light intensity in a certain neighborhood of this location.
Direct probing of evanescent field for characterization of porous terahertz fibers

We develop a technique based on a micromachined photoconductive probe-tip to characterize a terahertz (THz) porous fiber. Losses less than 0.08 cm⁻¹ are measured in the frequency range from 0.2 to 0.35 THz, with the minimum of 0.003 cm⁻¹ at 0.24 THz. Normalized group velocity greater than 0.8, which corresponds to dispersion values in between −1.3 and −0.5 ps/m/μm for 0.2
Gain-switched CW fiber laser for improved supercontinuum generation in a PCF
We demonstrate supercontinuum generation in a PCF pumped by a gain-switched high-power continuous wave (CW) fiber laser. The pulses generated by gain-switching have a peak power of more than 700 W, a duration around 200 ns, and a repetition rate of 200 kHz giving a high average power of almost 30 W. By coupling such a pulse train into a commercial nonlinear photonic crystal fiber, a supercontinuum is generated with a spectrum spanning from 500 to 2250 nm, a total output power of 12 W, and an infrared flatness of 6 dB over a bandwidth of more than 1000 nm with a power density above 5 dBm/mm (3 mW/mm). This is considerably broader than when operating the same system under CW conditions. The presented approach is attractive due to the high power, power scalability, and reduced system complexity compared to picosecond-pumped supercontinuum sources. © 2011 Optical Society of America.

Group-Acceleration Matching in Tapered Optical Fibers for Maximising the Power in the Blue-Edge of a Supercontinuum
We show that the gradient of a tapered fiber has a major impact on the power actually available in the blueedge of a supercontinuum. We ascribe this to a groupacceleration mismatch induced by the taper.
Higher order moment description of supercontinuum noise and rogue wave statistics
We quantify the noise properties of supercontinuum (SC) generation in optical fibers using higher-order central moments. The higher-order moments quantify not only the mean and variance of a distribution, but also the asymmetry and the presence of long tails, and are thus particularly useful for identifying regions of long-tailed rogue wave like behaviour. By carrying out multiple numerical simulations in the presence of noise, we demonstrate that the statistical moments of Coefficient of Variation, Skew and Kurtosis provide the necessary rigorous measure of the SC histograms to yield a clear means by which SC spectral fluctuations can be quantified under general conditions.

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Contributors: Sørensen, S. T., Bang, O., Dudley, J. M.
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Highly sensitive and simple method for refractive index sensing of liquids in microstructured optical fibers using four-wave mixing
We present both experimental measurements and simulations for a simple fiber-optical liquid refractive index sensor, made using only commercially available components and without advanced postprocessing of the fiber. Despite the simplicity, we obtain the highest sensitivity experimentally demonstrated to date for aqueous solutions (refractive index around 1.33), which is relevant for extensions to biosensing. The sensor is based on measuring the spectral shift of peaks arising from four-wave mixing (FWM), when filling the holes of a microstructured fiber with different liquid samples and propagating nanosecond pulses through the silica-core of the fiber. To the best of our knowledge, this is also the first experiment where a liquid is filled into the holes of a solid-core microstructured fiber to control the phase-match conditions for FWM. (C) 2011 Optical Society of America

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Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Contributors: Frosz, M. H., Stefani, A., Bang, O.
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Humidity insensitive TOPAS polymer fiber Bragg grating sensor

We report the first experimental demonstration of a humidity insensitive polymer optical fiber Bragg grating (FBG), as well as the first FBG recorded in a TOPAS polymer optical fiber in the important low loss 850nm spectral region. For the demonstration we have fabricated FBGs with resonance wavelength around 850 nm and 1550 nm in single-mode microstructured polymer optical fibers made of TOPAS and the conventional poly (methyl methacrylate) (PMMA). Characterization of the FBGs shows that the TOPAS FBG is more than 50 times less sensitive to humidity than the conventional PMMA FBG in both wavelength regimes. This makes the TOPAS FBG very appealing for sensing applications as it appears to solve the humidity sensitivity problem suffered by the PMMA FBG.
Humidity sensitivity of TOPAS optical fibre Bragg grating

**General information**
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Contributors: Kahn, L., Johnson, I. P., Yuan, S. W., Stefani, A., Nielsen, K., Rasmussen, H. K., Webb, D. J., Kalli, K., Bang, O.
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Improved thermal and strain performance of annealed polymer optical fiber Bragg gratings

We report on a detailed study of the inscription and characterization of fiber Bragg gratings (FBGs) in commercial step index polymer optical fibers (POFs). Through the growth dynamics of the gratings, we identify the effect of UV-induced heating during the grating inscription. We found that FBGs in annealed commercial POFs can offer more stable short-term performance at both higher temperature and larger strain. Furthermore, the FBGs' operational temperature and strain range without hysteresis was extended by the annealing process. We identified long-term stability problem of even the annealed POF FBGs.

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Influence of Two Photon Absorption on Soliton Self-Frequency Shift

The creation of mid-infrared supercontinua necessitates the use of soft-glass fibers. However, some materials, like chalcogenide, have a substantial two photon absorption. We introduce a model for soliton self-frequency shift that successfully includes this effect.

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Organisations: Fiber Optics, Devices and Non-linear Effects, Department of Photonics Engineering, Terahertz Technologies and Biophotonics, Fiber Sensors & Supercontinuum
Contributors: Steffensen, H., Rottwitt, K., Jepsen, P. U., Bang, O.
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Label-free biosensing with high sensitivity in dual-core microstructured polymer optical fibers

We present experimentally feasible designs of a dual-core microstructured polymer optical fiber (mPOF), which can act as a highly sensitive, label-free, and selective biosensor. An immobilized antigen sensing layer on the walls of the holes in the mPOF provides the ability to selectively capture antibody biomolecules. The change of the layer thickness of biomolecules can then be detected as a change in the coupling length between the two cores. We compare mPOF structures with 1, 2, and 3 air-holes between the solid cores and show that the sensitivity increases with increasing distance between the cores. Numerical calculations indicate a record sensitivity up to 20 nm/nm (defined as the shift in the resonance wavelength per nm biolayer) at visible wavelengths, where the mPOF has low loss.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, University of Patras, Macquarie University
Contributors: Markos, C., Yuan, W., Vlachos, K., Town, G. E., Bang, O.
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Electronic versions:
Midinfrared optical rogue waves in soft glass photonic crystal fiber
We investigate numerically the formation of extreme events or rogue waves in soft glass tellurite fibers and demonstrate that optical loss drastically diminishes shot-to-shot fluctuations characteristic of picosecond pumped supercontinuum (SC). When loss is neglected these fluctuations include extreme events such as formation of highly energetic pulses located at the red end of the spectrum and we obtain right-skewed heavy-tailed distributions characteristic of extreme events statistics. On the other hand, when loss is included bandwidth fluctuations follow Gaussian-like statistical distributions. Our results thus implicitly show that rogue waves will not occur in any SC spectrum that is limited by loss, such as commercial silica fiber based SC sources. © 2011 Optical Society of America.

Mode profiling of THz fibers with dynamic aperture near-field imaging
We present terahertz near-field mode profiling of different polymer THz fibers. Images with a resolution below the THz wavelength show the fundamental mode profile and higher order modes appearing at higher frequencies.
We investigate analytically and numerically propagation and spatial localization of light in nonlocal media with competing nonlinearities. In particular, we discuss conditions for the modulational instability of plane waves and formation of spatial solitons. We show that the competing focusing and defocusing nonlinearities enable coexistence of dark or bright spatial solitons in the same medium by varying the intensity of the beam.

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Organisations: Ultrafast Nonlinear Optics group, Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Technical University of Denmark, Karlsruhe Institute of Technology, Australian National University
Contributors: Esbensen, B. K., Wlotzka, A., Bache, M., Bang, O., Krolikowski, W.
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review

**Modulational instability and solitons in nonlocal media with competing nonlinearities**
We investigate analytically and numerically propagation and spatial localization of light in nonlocal media with competing nonlinearities. In particular, we discuss conditions for the modulational instability of plane waves and formation of spatial solitons. We show that the competing focusing and defocusing nonlinearities enable coexistence of dark or bright spatial solitons in the same medium by varying the intensity of the beam.
Narrow Bandwidth 850-nm Fiber Bragg Gratings in Few-Mode Polymer Optical Fibers

We report on the inscription and characterization of narrow bandwidth fiber Bragg gratings (FBGs) with 850-nm resonance wavelength in polymer optical fibers (POFs). We use two fibers: an in-house fabricated microstructured POF (mPOF) with relative hole size of 0.5 and a commercial step-index POF, which supports six modes at 850 nm. The gratings have been written with the phase-mask technique and a 325-nm HeCd laser. The mPOF grating has a full-width at half-maximum (FWHM) bandwidth of 0.29 nm and the step-index POF has a bandwidth of 0.17 nm. For both fibers, the static tensile strain sensitivity is measured to be 0.71 pm/$\mu$e at 850 nm and 1.3 pm/$\mu$e at 1550 nm.

Nonlinear soliton matching between optical fibers

In this Letter, we propose a generic nonlinear coupling coefficient, $\eta_2^{NL} = \eta_2^{ fiber_2}/\gamma_2^{ fiber_2}/\beta_2^{ fiber_2}$, which gives a quantitative measure for the efficiency of nonlinear matching of optical fibers by describing how a fundamental soliton couples from one fiber into another. Specifically, we use $\eta_2^{NL}$ to demonstrate a significant soliton selffrequency shift of a fundamental soliton, and we show that nonlinear matching can take precedence over linear mode matching. The nonlinear coupling coefficient depends on both the dispersion ($\beta_2$) and nonlinearity ($\gamma$), as well as on the power coupling efficiency $\eta$. Being generic, $\eta_2^{NL}$ enables engineering of general waveguide systems, e.g., for optimized Raman redshift or supercontinuum generation.
Note: Optical fiber milled by focused ion beam and its application for Fabry-Pérot refractive index sensor

We introduce a highly compact fiber-optic Fabry-Pérot refractive index sensor integrated with a fluid channel that is fabricated directly near the tip of a 32 μm in diameter single-mode fiber taper. The focused ion beam technique is used to efficiently mill the microcavity from the fiber side and finely polish the end facets of the cavity with a high spatial resolution. It is found that a fringe visibility of over 15 dB can be achieved and that the sensor has a sensitivity of ∼1731 nm/RIU (refractive index units) and a detection limit of ∼5.78 × 10⁻⁶ RIU. This miniature integrated all-in-fiber optofludic sensor may find use in minimal-invasive biomedical applications.
Optical Cherenkov radiation by cascaded nonlinear interaction: an efficient source of few-cycle energetic near- to mid-IR pulses

When ultrafast noncritical cascaded second-harmonic generation of energetic femtosecond pulses occur in a bulk lithium niobate crystal optical Cherenkov waves are formed in the near- to mid-IR. Numerical simulations show that the few-cycle solitons radiate Cherenkov (dispersive) waves in the λ = 2.2−4.5 μm range when pumping at λ1 = 1.2−1.8 μm. The exact phase-matching point depends on the soliton wavelength, and we show that a simple longpass filter can separate the Cherenkov waves from the solitons. The Cherenkov waves are born few-cycle with an excellent Gaussian pulse shape, and the conversion efficiency is up to 25%. Thus, optical Cherenkov waves formed with cascaded nonlinearities could become an efficient source of energetic near- to mid-IR few-cycle pulses.

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Optical Cherenkov radiation by cascaded nonlinear interaction: an efficient source of few-cycle near- to mid-IR pulses

Through cascaded second-harmonic generation, few-cycle solitons can form that resonantly emit strongly red-shifted optical Cherenkov radiation. Numerical simulations show that such dispersive waves can be an efficient source of near- to mid-IR few-cycle broadband pulses.

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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review
Optical fibre Bragg grating recorded in TOPAS cyclic olefin copolymer
A report is presented on the inscription of a fibre Bragg grating into a microstructured polymer optical fibre fabricated from TOPAS cyclic olefin copolymer. This material offers two important advantages over poly (methyl methacrylate), which up to now has formed the basis for polymer fibre Bragg gratings: TOPAS has a much lower water affinity and has useful properties for biosensing. The grating had a Bragg wavelength of 1569 nm and a temperature sensitivity of 236.5 ± 0.3 pm/°C.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Manufacturing Engineering, Department of Mechanical Engineering, Cyprus University of Technology, Aston University
Contributors: Johnson, I., Yuan, S. W., Stefani, A., Nielsen, K., Rasmussen, H. K., Khan, L., Webb, D., Kalli, K., Bang, O.
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Optimum fiber tapers for increasing the power in the blue-edge of a supercontinuum - group-acceleration matching
We demonstrate how the gradient of the tapering in a tapered fiber can significantly affect the trapping and blueshift of dispersive waves (DWs) by a soliton. By modeling the propagation of a fundamental 10 fs soliton through tapered fibers with varying gradients, it is shown that the soliton traps and blueshifts an increased fraction of the energy in its DW when the gradient is decreased. This is quantified by the group-acceleration mismatch between the soliton and DW at the entrance of the taper. These findings have direct implications for the achievable power in the blue edge of a supercontinuum generated in a tapered fiber and explain observations of a lack of power in the blue edge.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering
Contributors: Sørensen, S. T., Judge, A., Thomsen, C. L., Bang, O.
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Polymer PCF Bragg grating sensors based on poly(methyl methacrylate) and TOPAS cyclic olefin copolymer

Fibre Bragg grating (FBG) sensors have been fabricated in polymer photonic crystal fibre (PCF). Results are presented using two different types of polymer optical fibre (POF); first multimode PCF with a core diameter of 50μm based on poly(methyl methacrylate) (PMMA) and second, endlessly single mode PCF with a core diameter of 6μm based on TOPAS cyclic olefin copolymer. Bragg grating inscription was achieved using a 30mW continuous wave 325nm helium cadmium laser. Both TOPAS and PMMA fibre have a large attenuation of around 1dB/cm in the 1550nm spectral region, limiting fibre lengths to no longer than 10cm. However, both have improved attenuation of under 10dB/m in the 800nm spectral region, thus allowing for fibre lengths to be much longer. The focus of current research is to utilise the increased fibre length, widening the range of sensor applications. The Bragg wavelength shift of a grating fabricated in PMMA fibre at 827nm has been monitored whilst the POF is thermally annealed at 80°C for 7 hours. The large length of POF enables real time monitoring of the grating, which demonstrates a permanent negative Bragg wavelength shift of 24nm during the 7 hours. This creates the possibility to manufacture multiplexed Bragg sensors in POF using a single phase mask in the UV inscription manufacturing. TOPAS holds certain advantages over PMMA including a much lower affinity for water, this should allow for the elimination of cross-sensitivity to humidity when monitoring temperature changes or axial strain, which is a significant concern when using PMMA fibre.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Department of Mechanical Engineering, Cyprus University of Technology, Technical University of Denmark, Aston University
Contributors: Johnson, I. P., Webb, D. J., Kalli, K., Yuan, S. W., Stefani, A., Nielsen, K., Rasmussen, H. K., Bang, O.
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Porous-core honeycomb bandgap THz fiber

In this Letter we propose a novel (to our knowledge) porous-core honeycomb bandgap design. The holes of the porous core are the same size as the holes in the surrounding cladding, thereby giving the proposed fiber important manufacturing benefits. The fiber is shown to have a 0.35-THz-wide fundamental bandgap centered at 1.05 THz. The calculated minimum loss of the fiber is 0.25 dB/cm.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Manufacturing Engineering, Department of Mechanical Engineering, Terahertz Technologies and Biophotonics
Contributors: Nielsen, K., Rasmussen, H. K., Jepsen, P. U., Bang, O.
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Reduced Amplitude Noise in Supercontinuum Generated in Tapered PCFs

Supercontinuum generation (SCG) in highly nonlinear photonic crystal fibers (PCF) has drawn a lot of attention for the last decade. Pumping such PCFs with high-power picosecond laser pulses enables the creation of broadband and intense light [1]. Picosecond SCG is initiated by modulation instability and as such contains some noise. It is thus of significant interest to reduce the noise. Here we therefore focus on the noise properties of such supercontinuum (SC) generated in tapered PCFs, and that the tapering reduces the noise at the spectral edge.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, NKT Group
Contributors: Møller, U., Sørensen, S. T., Moselund, P. M., Johansen, J., Thomsen, C. L., Bang, O.
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Selective filling of photonic crystal fibers using focused ion beam milled microchannels
We introduce a versatile, robust, and integrated technique to selectively fill fluid into a desired pattern of air holes in a photonic crystal fiber (PCF). Focused ion beam (FIB) is used to efficiently mill a microchannel on the end facet of a PCF before it is spliced to a single-mode fiber (SMF). Selected air holes are therefore exposed to the atmosphere through the microchannel for fluid filling. A low-loss in-line tunable optical hybrid fiber device is demonstrated by using such a technique. (C) 2011 Optical Society of America

Sensing characteristics of birefringent microstructured polymer optical fiber
We experimentally studied several sensing characteristics of a birefringent microstructured polymer optical fiber. The fiber exhibits a birefringence of the order $2 \times 10^{-5}$ at 1.3 μm because of two small holes adjacent to the core. In this fiber, we measured spectral dependence of phase and group modal birefringence, bending losses, polarimetric sensitivity to strain and temperature. The sensitivity to strain was also examined for intermodal interference observed in the spectral range below 0.8 μm. Finally, we showed that the material transmission windows shift as function of the applied strain. This shift has an exponential character and saturates for greater strain.
Stimulated Raman scattering in soft glass fluoride fibers

We have measured the absolute Raman gain spectrum in short fluoride soft glass fibers with a pump wavelength of 1650nm. We found a peak gain of $g_R = 4.02 \times 10^{-14} \text{mW}^{-1}$.

General information

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Supercontinuum generation in a photonic crystal fiber pumped by a gain-switched high-power fiber laser

Supercontinuum (SC) generation in nonlinear photonic crystal fibers (NLF) using continuous-wave (CW) fiber lasers for pumping has been studied before[1,2]. The advantages of CW-SC are high spectral smoothness, high spectral power density, simplicity of the system, and lower noise than the more common picosecond-pumped SC. The cost of these features is increased nonlinear fiber lengths due to less efficient nonlinear processes at the lower power levels. Especially, the generation of light in the visible wavelength range has been a challenge. This has previously been tackled by increasing the nonlinearity of the fiber, zero dispersion shifting along the fiber length, and using 200 m of NLF[1], or
alternatively using extremely high powers of 100's of Watts[2].

Supercontinuum noise in tapered photonic crystal fibers
Supercontinuum generation (SCG) in highly nonlinear photonic crystal fibers (PCF) has drawn a lot of attention for the last decade. Pumping such PCFs with high-power picosecond laser pulses enables the creation of broadband and intense light. Picosecond SCG is initiated by modulation instability and as such contains some noise. It is thus of significant interest to reduce the noise. Here we focus on the noise properties of such supercontinuum (SC) generated in tapered PCFs.

Viscoelastic limit of polymer optical fibers: characterization of the dynamic response
Characterization of polymer optical fibers (POFs) in terms of dynamic behavior is important for many sensors applications for which this type of fibers offers big advantages. We report measurements of the Young's modulus on microstructured and step index polymer optical fibers and their comparison with silica fiber for a frequency range up to 300 Hz. In this range a constant modulus has been measured, allowing the use of polymer fibers for applications like Bragg grating based accelerometers.
ZBLAN supercontinuum generation - detailed comparison between measurement and simulation.
We present a detailed comparison between modeling and experiments on supercontinuum generation in a ZBLAN fiber. Good agreement is obtained when pumping both in the normal and anomalous dispersion regimes.

Analytical theory for the dark-soliton interaction in nonlocal nonlinear materials with an arbitrary degree of nonlocality
We investigate theoretically the interaction of dark solitons in materials with a spatially nonlocal nonlinearity. In particular we do this analytically and for arbitrary degree of nonlocality. We employ the variational technique to show that nonlocality induces an attractive force in the otherwise repulsive soliton interaction.
Analytical theory of dark nonlocal solitons
We investigate properties of dark solitons in nonlocal materials with an arbitrary degree of nonlocality. We employ the variational technique and describe dark solitons, for the first time to our knowledge, in the whole range of degree of nonlocality.

Broadband polymer microstructured THz fiber coupler with downdoped cores
We demonstrate a broadband THz directional coupler based on a dual core photonic crystal fiber (PCF) design with mechanically down-doped core regions. For a center frequency of 1.3 THz we demonstrate a bandwidth of 0.65 THz.
Broadband terahertz fiber directional coupler

We present the design of a short broadband fiber directional coupler for terahertz (THz) radiation and demonstrate a 3 dB coupler with a bandwidth of 0.6 THz centered at 1.4 THz. The broadband coupling is achieved by mechanically downdoping the cores of a dual-core photonic crystal fiber by microstructuring the cores. This is equivalent to chemical downdoping but is easier to realize experimentally.

Collisions and turbulence in optical rogue wave formation

We discuss optical rogue wave generation in terms of collisions and turbulence processes. Simulations of picosecond pulse propagation in optical fibres show rogue soliton generation from either third-order dispersion or Raman scattering independently. Simulations of rogue soliton emergence with dispersive oerturbation in the long-distance limit are also presented.
Design of microstructured waveguide devices for applications in optical sensing: [invited]
Microstructured waveguides provide a versatile platform for controlling interactions between light and their environment. We show how microstructured waveguides may be designed to improve the performance of optical sensors, and discuss their practical implementation.

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Contributors: Town, G., McCosker, R., Yuan, S. W., Bang, O.
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2010 › Research › peer-review

Few-cycle femtosecond optical pulses in the visible and near-Infrared: [invited]

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Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Contributors: Bache, M., Bang, O., Zhou, B., Krolikowski, W., Wise, F.
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Fiber-optical accelerometers based on polymer optical fiber Bragg gratings
Fiber-optical accelerometers based on polymer optical fiber Bragg gratings (FBGs) are reported. We have written 3mm FBGs for 1550nm operation, characterized their temperature and strain response, and tested their performance in a prototype accelerometer.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Brüel and Kjaer Sound and Vibration Measurement A/S, Ibsen Photonics A/S
Contributors: Yuan, S. W., Stefani, A., Bang, O., Andresen, S., Jacobsen, T., Nielsen, F. K., Jacobsen, T., Rose, B., Herholdt-Rasmussen, N.
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Fiber-optical microphones and accelerometers based on polymer optical fiber Bragg gratings: [invited]

Polymer optical fibers (POFs) are ideal for applications as the sensing element in fiber-optical microphones and accelerometers based on fiber Bragg gratings (FBGs) due to their reduced Young’s Modulus of 3.2GPa, compared to 72GPa of Silica. To maximize the sensitivity and the dynamic range of the device the outer diameter and the length of the sensing fiber segment should be as small as possible. To this end we have fabricated 3mm FBGs in single-mode step-index POFs of diameter 115 micron, using 325nm UV writing and a phase-mask technique. 6mm POF sections with FBGs in the center have been glued to standard Silica SMF28 fibers. These POF FBGs have been characterized in terms of temperature and strain to find operating regimes with no hysteresis. Commercial fast wavelength interrogators (KHz) are shown to be able to track the thin POF FBGs and they are finally applied in a prototype accelerometer. The specs are compared to the specs obtained when using Silica FBGs.

Grating writing and growth at 325nm in non-hydrogenated silica fiber

We report on the writing and growth dynamics of Bragg gratings written in standard silica fiber using a 325nm He:Cd laser.

Increasing the blue-shift of a picosecond pumped supercontinuum

The optical fiber based supercontinuum source has recently become a significant scientific and commercial success, with applications ranging from frequency comb production to advanced medical imaging. This one-of-a-kind book explains the theory of fiber supercontinuum broadening, describes the diverse operational regimes and indicates principal areas of applications, making it a very important guide for researchers and graduate students. With contributions from major figures and groups who have pioneered research in this field, the book describes the historical development of the subject, provides a background to the associated nonlinear optical processes, treats the generation mechanisms from continuous wave to femtosecond pulse pump regimes and highlights the diverse applications. A full discussion of numerical methods
and comprehensive computer code are also provided, enabling readers to confidently predict and model supercontinuum generation characteristics under realistic conditions.

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**Microstructured optical fiber refractive index sensor**
We describe a dual-core microstructured optical fiber designed for refractive index sensing of fluids. We show that by using the exponential dependence of intercore coupling on analyte refractive index, both large range and high sensitivity can be achieved in the one device. We also show that selective filling of the microstructure with analyte can increase the device sensitivity by approximately 1 order of magnitude.

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**Modelling of PCF Nonlinearities**

**General information**
Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Plasma Physics and Technology Programme
Contributors: Nikolov, N. I., Sørensen, T., Bang, O., Bjarklev, A. O., Juul Rasmussen, J.
Publication date: 2010
Nonlinear diffraction from a virtual beam

We observe experimentally a novel type of nonlinear diffraction in the process of two-wave mixing on a nonlinear quadratic grating. We demonstrate that when the nonlinear grating is illuminated simultaneously by two noncollinear beams, a second-harmonic diffraction pattern is generated by a virtual beam propagating along the bisector of the two pump beams. The observed diffraction phenomena is a purely nonlinear effect that has no analogue in linear diffraction.

Optical Cherenkov radiation in ultrafast cascaded second-harmonic generation

We show through theory and numerics that when few-cycle femtosecond solitons are generated through cascaded (phase-mismatched) second-harmonic generation, these broadband solitons can emit optical Cherenkov radiation in the form of linear dispersive waves located in the red part of the spectrum. The beating between the dispersive wave and the soliton generates trailing temporal oscillations on the compressed soliton. Insertion of a simple short-wave pass filter after the crystal can restore a clean soliton. On the other hand, bandpass filtering around the dispersive wave peak results in near-transform-limited ultrashort mid-IR pulses with pulse durations much shorter than the input near-IR pulse. The Cherenkov radiation for the crystal considered (β-barium borate) is found for pump wavelengths in the range $\lambda = 0.95–1.45$ μm, and is located in the regime $\lambda = 1.5–3.5$ μm. For shorter pump wavelengths, the phase-matching point is located in the absorption region of the crystal, effectively absorbing the generated dispersive wave. By calculating the phase-matching curves for typically used frequency conversion crystals, we point out that the mid-IR absorption in the crystal in many cases automatically will filter away the dispersive wave. Finally, an investigation of recent experimental results uncovers a four-wave-mixing phenomenon related to Cherenkov radiation that is an additional generation mechanism of long-wavelength radiation that can occur during soliton compression. We discuss the conditions that lead to this alternative
Polymer microstructured fibers for guiding of THz radiation: [invited]

Waveguides of various kinds for guided propagation and manipulation of light at terahertz (THz) frequencies are currently attracting considerable attention. There are several applications and perspectives which drive the development of techniques for waveguiding of broadband as well as narrowband THz radiation, including low-loss transport of THz signals [1] between high-speed devices, integrated components for manipulation of THz light [2], such as power splitters, polarization management, and frequency filters, and confinement of the electric field of a THz signal in a small volume, enabling spectroscopic investigations of minute sample quantities [3]. In this presentation we will describe our current efforts in the development, fabrication and characterization of a class of THz waveguides and components based on microstructured polymer optical fibers (mPOF's) [4] designed for the THz frequency range [5]. Fabrication and characterization of tailored mPOF's Similar to photonic crystal fibers for the near-infrared, we fabricate our mPOF structures in a fiber draw tower. Based on numerical simulations, a fiber cross section is first designed using standard and custom finite-element methods and FDTD methods, and based on the design, a preform is drilled in a low-loss polymer preform. This preform is heated to above the glass transition temperature of the polymer, and the preform is drawn to the desired dimensions in a single manufacturing step. Optical characterization of the fabricated fibers and components is carried out by THz time-domain spectroscopy, where the amplitude and phase of the transmitted signal through the sample is compared to a reference signal. In this manner we can characterize both loss and dispersion of the waveguide. In addition, near-field measurements across the facets of the fiber have allowed a direct visualization of the guided modes in the fiber [5]. We will discuss the optimal material choice for various kinds of polymer-based fibers, including solid-core and air-core photonic crystal fibers, and show examples of characterization of such components. We will also discuss the design of extremely broadband power splitters for the THz range with a uniform 3-dB splitting ratio of several hundred GHz.
Polymer optical fiber bragg grating sensors: measuring acceleration
Fiber-optical accelerometers based on polymer optical fiber Bragg gratings are reported. We have written fiber Bragg gratings for 1550 nm and 850 nm operations, characterized their temperature and strain response, and tested their performance in a prototype accelerometer.

Refractive index sensing in an all-solid twin-core photonic bandgap fiber
We describe a highly sensitive refractive index sensor based on a twin-core coupler in an all-solid photonic bandgap guiding optical fiber. A single hole acts as a microfluidic channel for the analyte, which modifies the coupling between the cores, and avoids the need for selective filling. By operating in the bandgap guiding regime the proposed sensor is capable of measuring refractive indices around that of water, and because the analyte varies the coupling coefficient (i.e., instead of phase matching condition) the device is capable of both high sensitivity and a relatively large dynamic range.
Tensile strain and temperature characterization of FBGs in preannealed Polymer Optical Fibers
Our thermal and tensile strain experiments show that fiber Bragg gratings (FBGs) in preannealed polymer optical fibers (POFs) can offer more stable performance and extend the operating temperature and strain range without hysteresis.

Theory of dispersive wave frequency shift via trapping by a soliton in an axially nonuniform optical fiber
We extend the analytical theory explaining the trapping of normally dispersive waves by a Raman soliton in an axially uniform optical fiber to include axially nonuniform fibers. It is shown how a changing group velocity in such a fiber leads to the same trapping mechanism as for a decelerating Raman soliton in a uniform fiber. In contrast to this latter case, where the trapping always leads to a blueshift of the confined radiation, the additional design flexibility inherent in the nonuniform geometry permits the redshift of dispersive waves trapped by an accelerating soliton, which itself may blueshift as a result of the associated spectral recoil.

Thulium pumped high power supercontinuum in loss-determined optimum lengths of tellurite photonic crystal fiber
We demonstrate the formation of an ultrabroad supercontinuum SC generated in short lengths of highly nonlinear tellurite photonic crystal fibers PCFs specifically designed for high power picosecond pumping at the thulium wavelength 1930 nm. The fibers exhibit high losses caused by material absorption below 500 nm and at long wavelengths 4000 nm by both material and confinement loss. The fibers are endlessly single-mode with a relative hole size of 0.4 and we tune the pitch
from 3 to 7 m to achieve zero-dispersion wavelengths both below and above the pump. We show how the SC has a maximum width at an optimum fiber length after which the bandwidth and power decay due to losses. We thus obtain a maximum bandwidth of 4.6 m for the PCF with the smallest, i.e., 3 m at an optimum length of only 2.8 cm.

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**Bendable, low-loss Topas fibers for the terahertz frequency range**
We report on a new class of polymer photonic crystal fibers for low-loss guidance of THz radiation. The use of the cyclic olefin copolymer Topas, in combination with advanced fabrication technology, results in bendable THz fibers with unprecedented low loss and low material dispersion in the THz regime. We demonstrate experimentally how the dispersion may be engineered by fabricating both high- and low-dispersion fibers with zero-dispersion frequency in the regime 0.5-0.6 THz. Near-field, frequency resolved characterization with high spatial resolution of the amplitude and phase of the modal structure proves that the fiber is single-moded over a wide frequency range, and we see the onset of higher-order modes at high frequencies as well as indication of microporous guiding at low frequencies and high porosity of the fiber. Transmission spectroscopy demonstrates low-loss propagation (<0.1 dB/cm loss at 0.6 THz) over a wide frequency range.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Department of Mechanical Engineering, Terahertz Technologies and Biophotonics
Contributors: Nielsen, K., Rasmussen, H. K., Adam, A. J., Planken, P. C. M., Bang, O., Jepsen, P. U.
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Research output: Contribution to journal › Journal article – Annual report year: 2009 › Research › peer-review

Broadband THz waveguiding and high-precision broadband time-resolved spectroscopy: [invited]
We demonstrate optical fibers designed for the THz frequency range, fabricated in a low-loss polymer. The polymer fibers display a broadband loss of 0.4 dB/cm over the 0.1-1 THz range, with a minimum loss of 0.1 dB/cm in the region near 500 GHz. The fibers, based on endlessly single-mode design, have tailored dispersion and may be bent into sharp bends. Due to the confinement of the THz field in the core of the fibers they are ideal for stable guiding of THz light in confined environments, and may serve as a useful basis for a wealth of fiber-based photonic components in the THz range, particularly in spectroscopic applications where tight confinement of the THz field is required. We further demonstrate a new spectroscopic technique for ultrafast time-resolved THz time-domain spectroscopy which simultaneously acquires both reference and sample data. By using this scheme we show that the influence of fluctuations on the laser parameters during data acquisition can be minimized, and highly reproducible quantitative data can be recorded and extracted in a very efficient manner. This technique may become especially important in the high THz range, where phase noise becomes critical for the accuracy of a measurement.

General information
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Organisations: Department of Photonics Engineering, Terahertz Technologies and Biophotonics, Fiber Sensors & Supercontinuum
Contributors: Cooke, D., Iwaszczuk, K., Nielsen, K., Bang, O., Jepsen, P. U.
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Dispersion-engineered and highly-nonlinear microstructured polymer optical fibres
We demonstrate dispersion-engineering of microstructured polymer optical fibres (mPOFs) made of poly(methyl methacrylate) (PMMA). A significant shift of the total dispersion from the material dispersion is confirmed through measurement of the mPOF dispersion using white-light spectral interferometry. The influence of strong loss peaks on the dispersion (through the Kramers-Kronig relations) is investigated theoretically. It is found that the strong loss peaks of PMMA above 1100 nm can significantly modify the dispersion, while the losses below 1100 nm only modify the dispersion slightly. To increase the nonlinearity of the mPOFs we investigated doping of PMMA with the highly-nonlinear dye Disperse Red 1. Both doping of a PMMA cane and direct doping of a PMMA mPOF was performed.

General information
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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, VB Technical University of Ostrava
Contributors: Frosz, M. H., Nielsen, K., Hlubina, P., Stefani, A., Bang, O.
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2009 › Research › peer-review
Dispersion-tailored, low-loss photonic crystal fibers for the THz range
We have fabricated a new type of photonic crystal fibers based on a cyclic olefin copolymer, transparent in the THz range. We characterize the propagation loss, dispersion, and spatial beam profile in fibers designed for low and high dispersion.

General information
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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Manufacturing Engineering, Department of Mechanical Engineering, Terahertz Technologies and Biophotonics, Delft University of Technology
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Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2009 – Research › peer-review

Dispersive waves in fs cascaded second-harmonic generation
Dispersive waves are observed in simulations of cascaded (phase-mismatched) second-harmonic generation. When generating ultra-short fs compressed near-IR solitons the dispersive waves are strongly red-shifted, depending on the soliton wavelength. Semi-analytical calculations predict the wavelengths.

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Contributors: Bache, M., Bang, O., Krolikowski, W., Wise, F. W.
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Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2009 – Research › peer-review

Enhanced soliton self-frequency shift in a longitudinally varying taper
We propose a method for the enhancement of the soliton self-frequency shift in a tapered PCF with a carefully designed waist diameter profile which optimises the dispersion and nonlinearity at the soliton wavelength.

General information
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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, University of Sydney
Contributors: Judge, A., Bang, O., Eggleton, B., Kuhlmey, B., Mägi, E., Pant, R., de Sterke, C.
Publication date: 2009

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Infiltration liquid crystal in microstructured polymer optical fibers

Here, we firstly demonstrate the photonic bandgap effect with PMMA mPOF by filling the air holes with liquid crystal, and subsequently change the light guidance mechanism from index guiding to bandgap guiding. The triangular structure PMMA mPOF used in the experiment is fabricated. A 60 cm length mPOF is butt-coupled to a conventional single mode fiber (SMF) with the broadband light from a supercontinuum source. It is clear to see the colour of the guided modes is red, since some wavelengths are attenuated by the material loss of PMMA in visible region. A positive dielectric anisotropy liquid crystal E7 is then infiltrated into about 6 cm of the length of mPOF by using capillary forces with the duration of 45 minutes. The transmission spectrum is measured by an optical spectrum analyzer with 1 nm resolution, and normalized to that of the unfilled fiber as shown by the solid line. The difference of spectra clearly reveals that, by filling the liquid crystal, some new bandgaps are formed in the wavelength range of 730 nm -780 nm, which is quite different with the material loss spectrum.

Low-loss and bendable THz fiber with tailored dispersion

A polymer THz fiber made of Topas and having a Photonic Crystal Fiber structure is demonstrated. It has low broadband loss and the dispersion of the fiber can be tailored by adjusting the structural parameters.
Multiorder nonlinear diffraction in frequency doubling processes
We analyze experimentally light scattering from 2 nonlinear gratings and observe two types of second-harmonic frequency-scattering processes. The first process is identified as Raman–Nath type nonlinear diffraction that is explained by applying only transverse phase-matching conditions. The angular position of this type of diffraction is defined by the ratio of the second-harmonic wavelength and the grating period. In contrast, the second type of nonlinear scattering process is explained by the longitudinal phase matching only, being insensitive to the nonlinear grating generation.

Multi-order nonlinear diffraction in second harmonic generation
We analyze the emission patterns in the process of second harmonic (SH) generation in χ(2) nonlinear gratings and identify for the first time, to the best of our knowledge, the evidence of Raman-Nath type nonlinear diffraction in frequency doubling processes.

Noise reduction of high-power supercontinuum sources by back seeding
We investigate noise reduction in seeded supercontinuum generation at powers above the supercontinuum generation threshold and show that seeding of supercontinuum is also beneficial at high pump powers.
Observation of two-dimensional nonlocal gap solitons
We demonstrate, both theoretically and experimentally, the existence of nonlocal gap solitons in two-dimensional periodic photonic structures with defocusing thermal nonlinearity. We employ liquid-infiltrated photonic crystal fibers and show how the system geometry can modify the effective response of a nonlocal medium and the properties of two-dimensional gap solitons. © 2009 Optical Society of America

Optical rogue waves and soliton turbulence in nonlinear fibre optics
We examine optical rogue wave generation in nonlinear fibre propagation in terms of soliton turbulence. We show that higher-order dispersion is sufficient to generate localized rogue soliton structures, and Raman scattering effects are not required.
Optimization of the soliton self-frequency shift in a tapered photonic crystal fiber

Soliton propagation is modeled in a tapered photonic crystal fiber for various taper profiles with the purpose of optimizing the soliton self-frequency shift (SSFS) in such geometries. An optimal degree of tapering is found to exist for tapers with an axially uniform waist. In the case of axially nonuniform waists, an additional enhancement of the SSFS is achieved by varying the taper waist diameter along its length in a carefully designed fashion in order to present an optimal level of group-velocity dispersion to the soliton at each point, thus avoiding the spectral recoil due to the emission of dispersive waves. In doing so, the increased nonlinearity and dispersion engineering afforded by the reduction of the core size are exploited while circumventing the limitation imposed on the soliton redshift by the associated shortening of the red zero-dispersion wavelength.

Periodic refractive index modifications inscribed in polymer optical fibre by focussed IR femtosecond pulses

Focussed femtosecond laser pulses were used to inscribe a periodic array of modifications in the core of a polymer optical fibre. Structural and refractive-index modifications have been observed at different pulse energies using DIC microscopy.
Thermal tunability of photonic bandgaps in liquid crystal infiltrated microstructured polymer optical fibers

We demonstrate the photonic bandgap effect and the thermal tunability of bandgaps in microstructured polymer optical fibers infiltrated with liquid crystal. Two liquid crystals with opposite sign of the temperature gradient of the ordinary refractive index (E7 and MDA-00-1444) are used to demonstrate that both signs of the thermal tunability of the bandgaps are possible. The useful bandgaps are ultimately bounded to the visible range by the transparency window of the polymer.

Ultrasensitive refractive index sensor based on twin-core photonic bandgap fibers

We have theoretically investigated twin-core all-solid photonic bandgap fibers (PBGFs) for evanescent wave sensing of refractive index within one single microfluidic analyte channel centered between the two cores. The sensor can achieve ultrahigh sensitivity by detecting the change in transmission. We find novel features in the sensing characteristics: the sensitivity is higher at the short wavelength edge of a bandgap than at the long wavelength edge, the effective index of the odd supermode (nodd) is more sensitive to ambient refractive index change compared with that of the even supermode (neven).
Ultrasensitive twin-core photonic bandgap fiber refractive index sensor

We propose a microfluidic refractive index sensor based on new polymer twin-core photonic bandgap fiber (PBGF). The sensor can achieve ultrahigh detection limit, i.e. >1.4 $\times 10^{-7}$ RIU refractive index unit (RIU), by measuring the coupling wavelength shift.

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Backseeded high-order parametric gain in supercontinuum generation

In photonic crystal fibers with closely spaced zero dispersion wavelengths it is possible to have two pairs of four-wave mixing (FWM) gain peaks. Here, we demonstrate both numerically and experimentally how the outer four-wave mixing gain peaks can be used to produce a strong amplification peak in a picosecond supercontinuum. The method involves feeding back part of the output light of a SC source and time matching it with the pump light. In this way it is possible to produce a gain of over 20 dB near the FWM gain wavelengths.

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Backseeding of higher order gain processes in picosecond supercontinuum generation

In photonic crystal fibers with closely spaced zero dispersion wavelengths it is possible to have two pairs of four-wave mixing (FWM) gain peaks. Here, we demonstrate both numerically and experimentally how the outer four-wave mixing gain peaks can be used to produce a strong amplification peak in a picosecond supercontinuum. The method involves feeding back part of the output light of a SC source and time matching it with the pump light. In this way it is possible to produce a gain of over 20 dB near the FWM gain wavelengths.

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering
Back seeding of picosecond supercontinuum generation in photonic crystal fibres

Supercontinuum generation (SCG) has been the subject of intense investigation during the last few years and its main mechanisms are now well understood. Focus has shifted towards tailoring the spectrum of the supercontinuum for specific applications. We experimentally investigate SCG with picosecond pumping in photonic crystal fibers with two closely spaced zero dispersion wavelengths. We couple parts of the output spectrum of the supercontinuum source back to the input in order to produce a gain of over 15 dB at some wavelengths. We use a variable time delay to optimize the overlap between the pump and the back seeded pulses and investigate how the delay and spectrum of the back seeded pulse affects the resulting supercontinuum spectrum.

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Broadband light generation at ~1300 nm through spectrally recoiled solitons and dispersive waves

We experimentally study the generation of broadband light at ~1300 nm from an 810 nm Ti:sapphire femtosecond pump laser. We use two photonic crystal fibers with a second infrared zero-dispersion wavelength (λZ2) and compare the efficiency of two schemes: in one fiber λZ2=1400 nm and the light at 1300 nm is composed of spectrally recoiled solitons;
in the other fiber \( \lambda Z_2 = 1200 \) nm and the light at 1300 nm is composed of dispersive waves.

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Teraherts Technologies and Biophotonics, Crystal Fibre A/S
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Source-ID: 211873
Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

**Compression limits in cascaded quadratic soliton compression**
Cascaded quadratic soliton compressors generate under optimal conditions few-cycle pulses. Using theory and numerical simulations in a nonlinear crystal suitable for high-energy pulse compression, we address the limits to the compression quality and efficiency.

**General information**
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Massachusetts Institute of Technology, Cornell University
Contributors: Bache, M., Bang, O., Krolikowski, W., Moses, J., Wise, F. W.
Pages: 1-2
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Controllable nonlocal behaviour by cascaded second-harmonic generation of fs pulses
Second-harmonic generation (SHG) of ultra-short pulses can act as a prototypical nonlocal nonlinear model, since the strength and nature of the temporal nonlocality can be controlled through the phase-mismatch parameter. The presence of a group-velocity mismatch namely implies that when the phase mismatch is small the nonlocal response function becomes oscillatory, while for large phase mismatch it becomes localized. In the transition between the two regimes the strength of the nonlocality diverges, and the system goes from a weakly nonlocal to a strongly nonlocal state. When simulating soliton compression to few-cycle pulses in the cascaded quadratic soliton compressor, the spectral content of the full coupled SHG model is predicted by the nonlocal model even when few-cycle pulses are interacting.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Massachusetts Institute of Technology, Cornell University
Contributors: Bache, M., Bang, O., Krolikowski, W., Moses, J., Wise, F. W.
Pages: 197-199
Publication date: 2008

Degenerate four wave mixing in solid core photonic bandgap fibers
Degenerate four wave mixing in solid core photonic bandgap fibers is studied theoretically. We demonstrate the possibility of generating parametric gain across bandgaps, and propose a specific design suited for degenerate four wave mixing when pumping at 532nm. The possibility of tuning the efficiency of the parametric gain by varying the temperature is also considered. The results are verified by numerical simulations of pulse propagation.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Fiber Optics, Devices and Nonlinear Effects
Contributors: Rasmussen, P. D., Lægsgaard, J., Bang, O.
Pages: 4059-4068
Publication date: 2008
Peer-reviewed: Yes
Geometry and transport in a model of two coupled quadratic nonlinear waveguides
This paper applies geometric methods developed to understand chaos and transport in Hamiltonian systems to the study of power distribution in nonlinear waveguide arrays. The specific case of two linearly coupled $\chi^{(2)}$ waveguides is modeled and analyzed in terms of transport and geometry in the phase space. This gives us a transport problem in the phase space resulting from the coupling of the two Hamiltonian systems for each waveguide. In particular, the effect of the presence of partial and complete barriers in the phase space on the transfer of intensity between the waveguides is studied, given a specific input and range of material properties. We show how these barriers break down as the coupling between the waveguides is increased and what the role of resonances in the phase space has in this. We also show how an increase in the coupling can lead to chaos and global transport and what effect this has on the intensity. ©2008 American Institute of Physics

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Department of Informatics and Mathematical Modeling, Universidad Politécnica de Madrid, Complutense University, Woven Reality ApS
Contributors: Stirling, J. R., Bang, O., Christiansen, P. L., Zakynthianaki, M. S., Johansen, S. K.
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Scopus rating (2008): SJR 1.243 SNIP 1.207
Web of Science (2008): Indexed yes
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URLs:
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Highly sensitive refractometer with a photonic-crystal-fiber long-period grating

General information
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Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Contributors: Rindorf, L. H., Bang, O.
Pages: 563-565
Publication date: 2008
Peer-reviewed: Yes

Publication information
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Ratings:
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 3.501 SNIP 2.449
Increasing the blue-shift of a supercontinuum by modifying the fiber glass composition

Supercontinuum light sources spanning into the ultraviolet-visible wavelength region are highly useful for applications such as fluorescence microscopy. A method of shifting the supercontinuum spectrum into this wavelength region has recently become well understood. The method relies on designing the group-velocity profile of the nonlinear fiber in which the supercontinuum is generated, so that red-shifted solitons are group-velocity matched to dispersive waves in the desired ultraviolet-visible wavelength region. The group-velocity profile of a photonic crystal fiber (PCF) can be engineered through the structure of the PCF, but this mostly modifies the group-velocity in the long-wavelength part of the spectrum. In this work, we first consider how the group-velocity profile can be engineered more directly in the short-wavelength part of the spectrum through alternative choices of the glass material from which the PCF is made. We then make simulations of supercontinuum generation in PCFs made of alternative glass materials. It is found that it is possible to increase the blue-shift of the generated supercontinuum by about 20 nm through a careful choice of glass composition, provided that the alternative glass composition does not have a significantly higher loss than silica in the near-infrared.

Label-free and selective nonlinear fiber-optical biosensing

We demonstrate that the inherent nonlinearity of a microstructured optical fiber (MOF) may be used to achieve label-free selective biosensing, thereby eliminating the need for post-processing of the fiber. This first nonlinear biosensor utilizes a change in the modulational instability (MI) gain spectrum (a shift of the Stokes- or anti-Stokes wavelength) caused by the selective capture of biomolecules by a sensor layer immobilised on the walls of the holes in the fiber. We find that such changes in the MI gain spectrum can be made detectable, and that engineering of the dispersion is important for optimizing the sensitivity. The nonlinear sensor shows a sensitivity of around 10.4nm/nm, defined as the shift in resonance wavelength per nm biolayer, which is a factor of 7.5 higher than the hitherto only demonstrated label-free MOF biosensor.
Limits to compression with cascaded quadratic soliton compressors

We study cascaded quadratic soliton compressors and address the physical mechanisms that limit the compression. A nonlocal model is derived, and the nonlocal response is shown to have an additional oscillatory component in the nonstationary regime when the group-velocity mismatch (GVM) is strong. This inhibits efficient compression. Raman-like perturbations from the cascaded nonlinearity, competing cubic nonlinearities, higher-order dispersion, and soliton energy may also limit compression, and through realistic numerical simulations we point out when each factor becomes important.

We find that it is theoretically possible to reach the single-cycle regime by compressing high-energy fs pulses for wavelengths $\lambda = 1.0\text{–}1.3 \, \mu m$ in a $\beta$-barium-borate crystal, and it requires that the system is in the stationary regime, where the phase mismatch is large enough to overcome the detrimental GVM effects. However, the simulations show that reaching single-cycle duration is ultimately inhibited by competing cubic nonlinearities as well as dispersive waves, that only show up when taking higher-order dispersion into account.
Nonlocal gap soliton in liquid infiltrated photonic crystal fibres

We report on the observation of nonlocal gap solitons in infiltrated photonic crystal fibres. We employ the thermal defocusing nonlinearity of the liquid to study soliton existence and effect of boundaries of the periodic structure.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Contributors: Bennet, F., Rosberg, C., Rasmussen, P. D., Sukhorukov, A., Bang, O., Neshev, D., Krolikowski, W., Kivshar, Y. S.
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Event: Poster session presented at Joint Conference of the Opto-Electronics and Communications Conference and the Australian Conference on Optical Fibre Technology, Sydney, Australia.
Source: orbit
Source-ID: 229446
Research output: Contribution to conference › Poster – Annual report year: 2008 › Research › peer-review

Picosecond supercontinuum generation with back seeding of different spectral parts

We study supercontinuum generation with picosecond pumping and the spectrum obtained when coupling back the part of the output around 1200-1700 nanometres or the part around 700-900 nanometres with a variable time delay.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering
Contributors: Moselund, P. M., Frosz, M. H., Thomsen, C., Bang, O.
Pages: 1-2
Publication date: 2008

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Source: orbit
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2008 › Research › peer-review

Picosecond supercontinuum generation with back seeding of different spectral parts components

We study supercontinuum generation with picosecond pumping and the spectrum obtained when coupling back the part of the output around 1200-1700 nanometres or the part around 700-900 nanometres with a variable time delay.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Koheras A/S
Contributors: Moselund, P. M., Frosz, M. H., Thomsen, C., Bang, O.
Publication date: 2008

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Place of publication: Sydney, Australien
Source: orbit
Source-ID: 220035
Sensitivity of photonic crystal fiber grating sensors: biosensing, refractive index, strain, and temperature sensing
We study the sensitivity of fiber grating sensors in the applications of strain, temperature, internal label-free biosensing, and internal refractive index sensing. New analytical expressions for the sensitivities, valid for photonic crystal fibers are rigorously derived. These are generally valid, and we identify a previously unaccounted term for temperature and strain sensing. It is shown that dispersion plays a central role in determining the sensitivity, and that dispersion may enhance or suppress sensitivity as well as change the sign of the resonant wavelength shifts. We propose a quality factor, Q, for characterizing long period gratings sensors.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Contributors: Rindorf, L. H., Bang, O.
Pages: 310-324
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Journal: Journal of the Optical Society of America - B - Optical Physics
Volume: 25
Issue number: 3
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Scopus rating (2008): SJR 1.735 SNIP 1.343
Web of Science (2008): Indexed yes
Original language: English
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Source: orbit
Source-ID: 213656

Research output: Contribution to journal › Journal article – Annual report year: 2008 › Research › peer-review

Spatiotemporal control of light by Bloch-mode dispersion in multi-core fibers
We study theoretically the dispersion properties of Bloch modes and nonlinearly-induced defect states in two-dimensional waveguide arrays. We define the conditions for achieving anomalous group-velocity dispersion and discuss possibilities for generation of spatiotemporal solitons.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Fiber Optics, Devices and Nonlinear Effects
Contributors: Rasmussen, P. D., Sukhorukov, A., Neshev, D., Krolikowski, W., Bang, O., Lægsgaard, J., Kivshar, Y.
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Scopus rating (2008): SJR 3.559 SNIP 2.473
Web of Science (2008): Indexed yes
Original language: English
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Source-ID: 222025
Spatiotemporal light localization in infiltrated waveguide arrays

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum, Fiber Optics, Devices and Nonlinear Effects
Contributors: Rasmussen, P. D., Neshev, D., Sukhorukov, A., Krolikowski, W., Bang, O., Lægsgaard, J., Kivshar, Y. S.
Publication date: 2008
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Event: Poster session presented at 19th International Conference on Optical Fibre Sensors, Perth, Australia.
Source: orbit
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Research output: Contribution to conference › Poster – Annual report year: 2008 › Research › peer-review

We study light propagation in hexagonal waveguide arrays and show that simultaneous spatiotemporal localisation is possible by combination of engineered anomalous dispersion through selective excitation of Bloch-modes and spatial confinement in a nonlinear defect mode.

Accurate nonlocal theory for cascaded quadratic soliton compression

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics, Massachusetts Institute of Technology, Cornell University
Contributors: Bache, M., Bang, O., Moses, J., Wise, F., Krolikowski, W.
Publication date: 2007

We study soliton compression in bulk quadratic nonlinear materials at 800 nm, where group-velocity mismatch dominates. We develop a nonlocal theory showing that efficient compression depends strongly on characteristic nonlocal time scales related to pulse dispersion.
**Bragg gratings in Topas**

We report for the first time fibre Bragg grating inscription in microstructured optical fibre fabricated from Topas® cyclic olefin copolymer. The temperature sensitivity of the grating was studied revealing a positive Bragg wavelength shift of approximately 0.8 nmK⁻¹, the largest sensitivity yet observed for a fibre Bragg grating.

**Cascaded quadratic soliton compression at 800 nm**

We study soliton compression in quadratic nonlinear materials at 800 nm, where group-velocity mismatch dominates. We develop a nonlocal theory showing that efficient compression depends strongly on characteristic nonlocal time scales related to pulse dispersion.

**Designing quadratic nonlinear photonic crystal fibers for soliton compression to few-cycle pulses**

Second-harmonic generation (SHG) in the limit of large phase mismatch, given by \( \Delta \beta = \beta_2 - 2\beta_1 \) effectively induces a Kerr-like nonlinear phase shift on the fundamental wave (FW). The phase mismatch determines the sign and magnitude of the effective Kerr nonlinearity, making large negative phase shifts accessible. This self-defocusing nonlinearity can be used to compress a pulse when combined with normal dispersion, and problems normally encountered due to self-focusing in cubic media are avoided. Thus, having no power limit, in bulk media a self-defocusing soliton compressor can create high-energy near single-cycle fs pulses (Liu et al., 2006). However, the group-velocity mismatch (GVM) between the FW and second harmonic (SH), given by the inverse group velocity difference \( d_{12} = 1/V_{g,1} - 1/V_{g,2} \), limits the pulse quality and compression ratio. Especially very short input pulses (}
Enhanced stability of nonlocal solitons in saturable focusing media

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, French Alternative Energies and Atomic Energy Commission, University of Wisconsin-Madison, Australian National University
Contributors: Skupin, S., Saffman, M., Krolikowski, W., Bang, O.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Research output: Contribution to conference > Conference abstract for conference – Annual report year: 2007 > Research > peer-review

Finite-difference modeling of Bragg fibers with ultrathin cladding layers via adaptive coordinate transformation
As an alternative to the finite-element analysis or subgridding, coordinate transformation is used to “stretch” the fine-structured cladding of a Bragg fiber, and then the fullvector, equidistant-grid finite-difference computations of the modal structure are performed.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Polytechnique Montreal
Contributors: Shyroki, D., Lægsgaard, J., Bang, O., Skorobogatiy, M.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Research output: Contribution to conference > Poster – Annual report year: 2007 > Research > peer-review

General covariance in computational electrodynamics
We advocate the generally covariant formulation of Maxwell equations as underpinning some recent advances in computational electrodynamics—in the dimensionality reduction for separable structures; in mesh truncation for finite-difference computations; and in adaptive coordinate mapping as opposed to subgridding.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics, Nanophotonics
Contributors: Shyroki, D., Lægsgaard, J., Bang, O., Lavrinenko, A.
Number of pages: 82
Pages: OR-06.03
Publication date: 2007

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Title of host publication: Proceedings OWTNM - Modelling of waveguides and devices
Infiltrated microstructured fibers as tunable and nonlinear optical devices
We study the light guiding properties of microstructured optical fibers infiltrated with nonlinear liquids and demonstrate their applicability for spatial beam control in novel type tunable and nonlinear optical devices.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Centre for Ultrahigh-bandwidth Devices for Optical Systems
Contributors: Rosberg, C. R., Bennet, F., Neshev, D. N., Sukhorukov, A. A., Krolikowski, W., Kivshar, Y. S., Bang, O., Bjarklev, A. O.
Publication date: 2007
Peer-reviewed: Yes
Event: Poster session presented at Workshop of the Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS), Murramarang Resort, South Durras, NSW, Australia.

Kraftig som en laser, hvidere end solen: Superkontinuumsgenerering - den ultimative hvidlyskilde

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Contributors: Frosz, M. H., Bang, O.
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Edition: 1
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URLs:
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Source-ID: 202177

Localized biosensing with Topas microstructured polymer optical fiber

General information
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Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Department of Management Engineering, Radiation Physics, Radiation Research Division, Risø National Laboratory for Sustainable Energy
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Publication information
Journal: Optics & Photonics News
Volume: 18
Issue number: 12
ISSN (Print): 1047-6938
Localized biosensing with Topas microstructured Polymer Optical Fiber

We present what is believed to be the first microstructured polymer optical fiber (mPOF) fabricated from Topas cyclic olefin copolymer, which has attractive material and biochemical properties. This polymer allows for a novel type of fiber-optic biosensor, where localized sensor layers may be activated on the inner side of the air holes in a predetermined section of the mPOF. The concept is demonstrated using a fluorescence-based method for selective detection of fluorophore-labeled antibodies. © 2007 Optical Society of America

Localized biosensing with Topas microstructured polymer optical fiber: Erratum

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Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Department of Management Engineering, Risø National Laboratory for Sustainable Energy, Bioneer A/S
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Scopus rating (2007): SJR 3.503 SNIP 2.09
Web of Science (2007): Indexed yes
Original language: English
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Methods of supercontinuum generation for effective down-conversion in photonic crystal fibers

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics, Risø National Laboratory for Sustainable Energy, Optics and Plasma Research Department, Optical Diagnostics and Information Processing, Terahertz Technologies and Biophotonics
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Peer-reviewed: Yes
Event: Abstract from Photonics West 2007, San Jose, CA, United States.

Modulational instability in the nonlocal chi(2)-model
We investigate in detail the linear regime of the modulational instability (MI) properties of the plane waves of the nonlocal model for chi(2)- media formulated in Nikolov et al. [N.I. Nikolov, D. Neshev, O. Bang, W.Z. Krolikowski, Quadratic solitons as nonlocal solitons, Phys. Rev. E 68 (2003) 036614; I.V. Shadrivov, A.A. Zharov, Dynamics of optical spatial solitons near the interface between two quadratically nonlinear media, J. Opt. Soc. Amer. B 19 (2002) 596-602]. It is shown that the MI is of the oscillatory type and of finite bandwidth. Moreover, it is possible to identify regions in the parameter space for which a fundamental gain band exists, and regions for which higher order gain bands and modulational stability exist. We also show that the MI analysis for the nonlocal model is applicable in the finite walk-off case. Finally, we show that the plane waves of the nonlocal chi((2))-model are recovered as the asymptotic limit of one of the branches of the plane waves (i.e. the adiabatic branch or the acoustic branch) of the full chi((2))-model by means of a singular perturbational approach. It is also proven that the stability results for the adiabatic branch continuously approach those of the nonlocal chi((2))-model, by using the singular perturbational approach. The other branch of the plane waves (i.e. the nonadiabatic branch or the optical branch) is always modulationally unstable. We compare the MI results for the adiabatic branch with the predictions obtained from the full chi((2))-model in the non-walk-off limit. It is concluded that for most physical relevant parameter regimes it suffices to use the nonlocal model in order to determine the MI properties. (c) 2007 Elsevier B.V. All rights reserved.

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Publication status: Published
Organisations: Risø National Laboratory for Sustainable Energy, Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Plasma Physics and Technology, Optics and Plasma Research Department
Contributors: Wyller, J. A., Krolikowski, W., Bang, O., Petersen, D., Juul Rasmussen, J.
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Original language: English
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Source: orbit
Source-ID: 216501
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Multi-antibody biosensing with Topas microstructured polymer optical fiber
We present a Topas based microstructured polymer optical fiber multi-antibody biosensor. This polymer allows localized activation of sensor layers on the inner side of the air holes. This concept is used to create two different sensor sections in
the same fiber. Simultaneous detection of two kinds of fluorophore-labeled antibodies by a fluorescence-based method is demonstrated.

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Department of Management Engineering, Rise National Laboratory for Sustainable Energy, Bioneer A/S
Publication date: 2007
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Event: Poster session presented at 16th International Conference on Plastic Optical Fibers, Turin, Italy.
Source: orbit
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Research output: Contribution to conference › Poster – Annual report year: 2007 › Research › peer-review

Nonlocal explanation of stationary and nonstationary regimes in cascaded pulse compression
We study pulse compression in quadratic materials and show that group-velocity mismatch creates two nonlocal oscillatory and localized regimes that describe nonstationary and stationary pulse compression. The theory is used to accurately predict the transition.

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Cornell University
Contributors: Bang, O., Bache, M., Moses, J., Wise, F.
Pages: TuC5
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Publisher: OSA
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Nonlocal explanation of stationary and nonstationary regimes in cascaded soliton pulse compression

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Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering
Contributors: Bache, M., Bang, O., Moses, J., Wise, F.
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Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Photonic crystal fiber gratings: prospects for label-free biosensors

**General information**
**Recent developments of Bragg gratings in PMMA and TOPAS polymer optical fibers**

We report on the temperature response of FBGs recorded in pure PMMA and TOPAS holey fibers. The gratings are fabricated in the near IR using a cw He-Cd laser operating at 325nm. The room temperature grating response is non-linear and characterised by quadratic behaviour for temperatures from room temperature to the glass transition temperature, and this permanent change is affected by the thermal history of the gratings. We also report the first FBG inscription in microstructured polymer optical fibres fabricated from Topas. This material is fully polymerised and has a very low moisture absorption, leading to very good fibre drawing properties. Furthermore, although Topas is chemically inert and biomolecules do not readily bind to its surface, treatment with Antraquinon and subsequent UV activation allows sensing molecules to be deposited in well defined spatial locations. When combined with grating technology this provides considerable potential for label-free biosensing.

**Rigorous modeling of cladding modes in photonic crystal fibers**

We study the cladding modes of a photonic crystal fiber (PCF) with a finite size cladding using a finite element method. The cladding consists of seven rings of air holes with bulk silica outside.

**Soliton compression to few-cycle pulses by cascaded quadratic nonlinearities**

Theoretical and numerical investigation of pulse-compression in a nonlinear crystal is presented. SHG soliton number is introduced and show that compression only takes place when it is larger than the "usual" Kerr soliton number. Pulse compression with cascaded quadratic nonlinearities requires that the ratio of the SHG and Kerr soliton numbers N>1.
Soliton compression to few-cycle pulses using quadratic nonlinear photonic crystal fibers: A design study

We show theoretically that high-quality soliton compression from ~500 fs to ~10 fs is possible in poled silica photonic crystal fibers using cascaded (2):(2) nonlinearities. A moderate group-velocity mismatch optimizes the compression.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Cornell University
Contributors: Bache, M., Moses, J., Lægsgaard, J., Bang, O., Wise, F.
Pages: CThQ4
Publication date: 2007

Soliton compression to ultra-short pulses using cascaded quadratic nonlinearities in silica photonic crystal fibers

We investigate the possibility of using poled silica photonic crystal fibers for self-defocusing soliton compression with cascaded quadratic nonlinearities. Such a configuration has promise due to the desirable possibility of reducing the group-velocity mismatch. However, this unfortunately leads to increased phase mismatch, and the dispersion is often anomalous. All this reduces the design parameter space where soliton compression is possible, and poses strong requirements on the poling efficiency. We propose to use quasi-phase matching in order to reach realistic requirements on the quadratic nonlinearity, and show that compression of nJ pulses to few-cycle duration is possible in such a fiber. A small amount of group-velocity mismatch optimizes the compression.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Cornell University
Contributors: Bache, M., Lægsgaard, J., Bang, O., Moses, J., Wise, F. W.
Pages: 1-24
Publication date: 2007
Spiralling solitons and multipole localized modes in nonlocal nonlinear media
We analyze the propagation of rotating multi-soliton localized structures in optical media with spatially nonlocal nonlinearity. We demonstrate that nonlocality stabilizes the azimuthal breakup of rotating dipole as well as multipole localized soliton modes. We compare the results for two different models of nonlocal nonlinearity and suggest that the stabilization mechanism is a generic property of a spatial nonlocal nonlinear response independent of its particular functional form.

Supercontinuum generation in photonic crystal fibers using quasi-CW pumping
Liquid-infiltrated photonic crystal fibers (PCFs) offer a new way of studying light propagation in periodic and discrete systems. A wide range of available fiber structures combined with the ease of infiltration opens up a range of novel experimental opportunities for optical detection and bio-sensing as well as active devices for all-optical switching at low (mW) laser powers. Commercially available PCFs infiltrated with liquids also provide a versatile and compact tool for exploration of the fundamentals of nonlinear beam propagation in periodic photonic structures. To explore the full scientific and technological potential of liquid-infiltrated PCFs it is important to understand the temporal dynamics of nonlinear beam propagation in such structures. In this work we consider thermally induced spatial nonlinear effects in infiltrated photonic crystal fibers. We experimentally study the temporal dynamics of nonlinear beam reshaping occurring on a short time scale before the establishment of a steady state regime. In experiment, a 532nm laser beam can be injected into a single hole of an infiltrated PCF cladding structure, and the temporal dynamics of the nonlinear response is measured by monitoring the evolution of the fiber output beam in the few micro or milliseconds after the beam is turned on. The
characterization of the temporal behavior of the thermal nonlinear response provides important information about the nonlocality associated with heat diffusion inside the fiber, thus enabling studies of long-range interactions in nonlinear discrete media.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Bennet, F., Rosberg, C. R., Neshev, D. N., Rasmussen, P. D., Bang, O., Krolikowski, W., Bjarklev, A. O., Kivshar, Y. S.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Source-ID: 208715
Research output: Contribution to conference › Poster – Annual report year: 2007 › Research › peer-review

The role of the second zero-dispersion wavelength in generation of supercontinua and bright-bright soliton-pairs across the zero-dispersion wavelength: erratum
An erratum is presented explaining that the observation in the original paper (Optics Express, volume 13, issue 16, page 6181-6192, 2005), of a bright-bright soliton with one color in the anomalous dispersion region and the other color in the normal dispersion region was mistaken; both parts of the soliton-pair were located in regions with anomalous dispersion.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Frosz, M. H., Falk, P. A., Bang, O.
Pages: 5262-5263
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 15
Issue number: 8
ISSN (Print): 1094-4087
Ratings:
Scopus rating (2007): SJR 3.299 SNIP 2.08
Web of Science (2007): Indexed yes
Original language: English
Source: orbit
Source-ID: 197584
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Tunable all-optical devices based on liquid-filled photonic crystal fibers
Nonlinear periodic photonic structures offer unique opportunities for manipulating the flow of light by exploiting the interplay between nonlinearity and the discreteness of periodic systems. To fully explore the rich physics and technological potential of periodic and nonlinear optical media, it is desirable to identify accessible experimental platforms that combine the advantages of high-quality fabricated structures with the attractiveness of tunable and strongly nonlinear materials for light control. In this work we suggest to use liquid-filled photonic crystal fibers (PCFs) for the study of discrete and nonlinear light propagation in extended two-dimensional periodic systems. We experimentally demonstrate strongly tunable beam diffraction in a triangular waveguide array created by infiltration of a high index liquid into the cladding holes of a standard PCF, and employ the thermal nonlinearity of the liquid to achieve beam self-defocusing at higher light intensity. Based on the observed effects we devise a compact all-optical power limiter device with tunable characteristics. The use of commercially available PCFs in combination with liquid infiltration avoids the need for specialized high-precision fabrication procedures, and provides high tunability and nonlinearity at moderate laser powers while taking advantage of a compact experimental setup. The increasingly broad range of PCF structures available could stimulate further efforts in applying them in discrete nonlinear optics and all-optical devices. The long propagation lengths accessible in fiber-based discrete systems could even allow for experimental studies of combined spatial and temporal nonlinear effects and thus pave the road for future demonstrations of spatiotemporal control of light.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Rosberg, C. R., Bennet, F., Neshev, D. N., Rasmussen, P. D., Bang, O., Krolikowski, W., Bjarklev, A. O., Kivshar, Y. S.
Tunable Beam Diffraction in Infiltrated Microstructured Fibers
We experimentally study beam propagation in two-dimensional photonic lattices in microstructured optical fibers infiltrated with high index liquids. We demonstrate strongly tunable beam diffraction by dynamically varying the coupling between individual lattice sites.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Centre for Ultrahigh-bandwidth Devices for Optical Systems
Contributors: Rosberg, C. R., Bennet, F. H., Neshev, D. N., Sukhorukov, A. A., Krolikowski, W., Kivshar, Y. S., Rasmussen, P. D., Bang, O., Bjarklev, A. O.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Source-ID: 208714
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2007 › Research › peer-review

Tunable Diffraction and Self-Defocusing in Liquid-Filled Photonic Crystal Fibers
We suggest and demonstrate a novel platform for the study of tunable nonlinear light propagation in two-dimensional discrete systems, based on photonic crystal fibers filled with high index nonlinear liquids. Using the infiltrated cladding region of a photonic crystal fiber as a nonlinear waveguide array, we experimentally demonstrate highly tunable beam diffraction and thermal self-defocusing, and realize a compact all-optical power limiter based on a tunable nonlinear response.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Fibers & Nonlinear Optics, Centre for Ultrahigh-bandwidth Devices for Optical Systems
Contributors: Rosberg, C. R., Bennet, F. H., Neshev, D. N., Rasmussen, P. D., Bang, O., Krolikowski, W., Bjarklev, A. O., Kivshar, Y. S.
Pages: 12145-12150
Publication date: 2007
Peer-reviewed: Yes
Event: Abstract from Frontiers in Optics 2007/Laser Science XXIII conferences, San Jose, California, USA.
Source: orbit
Source-ID: 208717
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2007 › Research › peer-review

Tunable Nonlinear Beam Defocusing in Infiltrated Photonic Crystal Fibers
We demonstrate a novel experimental platform for discrete nonlinear optics based on infiltrated photonic crystal fibers. We observe tunable discrete diffraction and nonlinear self-defocusing, and apply the effects to realize a compact all-optical power limiter.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Centre for Ultrahigh-bandwidth Devices for Optical Systems
Contributors: Rosberg, C. R., Bennet, F. H., Neshev, D. N., Rasmussen, P. D., Bang, O., Krolikowski, W., Bjarklev, A. O., Kivshar, Y. S.
Publication date: 2007
Peer-reviewed: Yes
Source: orbit
Source-ID: 208678
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review
**A microstructured Polymer Optical Fiber Biosensor**

We demonstrate selective detection of fluorophore labeled antibodies from minute samples probed by a sensor layer of the complementary biomolecules immobilized inside the air holes of microstructured Polymer Optical Fibers.

**Biosensing using microstructured polymer optical fibers**

**Chromatic dispersion of liquid crystal infiltrated capillary tubes and photonic crystal fibers**

We consider chromatic dispersion of capillary tubes and photonic crystal fibers infiltrated with liquid crystals. A perturbative scheme for inclusion of material dispersion of both liquid crystal and the surrounding waveguide material is derived. The method is used to calculate the chromatic dispersion at different temperatures.
Group-velocity matched nonlinear photonic crystal fibers
A quadratic nonlinear index-guiding silica PCF is optimized for efficient second-harmonic generation through dispersion calculations. Zero group-velocity mismatch is possible for any pump wavelength above 780 nm. Very high conversion efficiencies and bandwidths are found.

Localized biosensing with Topas microstructured polymer optical fiber

Microstructured Optical Fibers, fundamental properties and biosensor applications
Microstructured polymer optical fiber biosensors for detection of DNA and antibodies

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Publication date: 2006
Peer-reviewed: Yes
Event: Abstract from 18th International Conference on Optical Fibre Sensors, Cancun, Mexico.
Source: orbit
Source-ID: 194032
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2006 › Research › peer-review

Modulational instability in generalized nonlinear optical media

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Krolikowski, W., McCarthy, G., Saffman, M., Bang, O., Wyller, J., Rasmussen, J.
Publication date: 2006
Host publication information
Title of host publication: Trends in Lasers and Electro-Optics Research
Publisher: Nova publishers
ISBN (Print): 1-59454-498-0
Source: orbit
Source-ID: 193718
Research output: Chapter in Book/Report/Conference proceeding › Book chapter – Annual report year: 2006 › Research › peer-review

MPOF Biosensors

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Contributors: Bang, O.
Publication date: 2006
Peer-reviewed: Yes
Event: Abstract from International workshop on POFs and International workshop on MPOFs: WorkPOF 2006, Rio de Janeiro, Brazil.
Source: orbit
Source-ID: 193745
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2006 › Research › peer-review
Nanoengineering of photonic crystal fibers for supercontinuum spectral shaping

Supercontinuum generation using picosecond pulses pumped into cobweb photonic crystal fibers is investigated. Dispersion profiles are calculated for several fiber designs and used to analytically investigate the influence of the fiber structural parameters (core size and wall thickness) on the location of the Stokes and anti-Stokes bands and gain bandwidth. An analysis shows that the Raman effect is responsible for reducing the four-wave mixing gain and a slight reduction in the corresponding frequency shift from the pump, when the frequency shift is much larger than the Raman shift. Using numerical simulations we find that four-wave mixing is the dominant physical mechanism for the pumping scheme considered, and that there is a trade-off between the spectral width and the spectral flatness of the supercontinuum. The balance of this trade-off is determined by nanometer-scale design of the fiber structural parameters. It is also shown that the relatively high loss of the nonlinear fiber does not significantly affect the supercontinuum generation.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Frosz, M. H., Sørensen, T., Bang, O.
Pages: 1692-1699
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Journal of the Optical Society of America - B
Volume: 23
Issue number: 8
ISSN (Print): 0740-3224
Ratings:
Scopus rating (2006): SJR 1.705 SNIP 1.408
Web of Science (2006): Indexed yes
Original language: English
Source: orbit
Source-ID: 190947
Research output: Contribution to journal > Journal article – Annual report year: 2006 > Research > peer-review

Nonlocal description of X waves in quadratic nonlinear materials

We study localized light bullets and X-waves in quadratic media and show how the notion of nonlocality can provide an alternative simple physical picture of both types of multi-dimensional nonlinear waves. For X-waves we show that a local cascading limit in terms of a nonlinear Schrodinger equation does not exist - one needs to use the nonlocal description, because the nonlocal response function does not converge towards a delta-function. Also, we use the nonlocal theory to show for the first time that the coupling to second harmonic is able to generate an X-shape in the fundamental field despite having anomalous dispersion, in contrast to the predictions of the cascading limit.

General information
Publication status: Published
Organisations: Department of Mathematics, Dynamical systems, Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Australian National University, University of Ferrara
Contributors: Larsen, P. U. V., Sørensen, M. P., Bang, O., Krolikowski, W. Z., Trillo, S.
Pages: 036614
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Physical Review E
Volume: 73
Issue number: 3
ISSN (Print): 2470-0045
Ratings:
Scopus rating (2006): SJR 1.828 SNIP 1.336
Web of Science (2006): Indexed yes
Original language: English
Keywords: X-waves, Nonlocal description, Nonlinear optics, Quadratic nonlinear materials
Electronic versions:
Larsen.pdf
DOIs:
10.1103/PhysRevE.73.036614
Observation of attraction between dark solitons
We demonstrate a dramatic change in the interaction forces between dark solitons in nonlocal nonlinear media. We present what we believe is the first experimental evidence of attraction of dark solitons. Our results indicate that attraction should be observable in other nonlocal systems, such as Bose-Einstein condensates with repulsive long-range interparticle interaction.

Photonic crystal fiber long-period gratings for biochemical sensing
We present experimental results showing that long-period gratings in photonic crystal fibers can be used as sensitive biochemical sensors. A layer of biomolecules was immobilized on the sides of the holes of the photonic crystal fiber and by observing the shift in the resonant wavelength of a long-period grating it was possible to measure the thickness of the layer. The long-period gratings were inscribed in a large-mode area silica photonic crystal fiber with a CO2 laser. The thicknesses of a monolayer of poly-L-lysine and double-stranded DNA was measured using the device. We find that the grating has a sensitivity of approximately 1.4nm/1nm in terms of the shift in resonance wavelength in nm per nm thickness of biomolecule layer.
Second-harmonic generation with zero group-velocity mismatch in nonlinear photonic crystal fibers

We consider an index-guiding silica photonic crystal fiber with a triangular hole-pattern and a periodically poled quadratic nonlinearity. By tuning the pitch and the relative size of the holes, second-harmonic generation with zero group-velocity mismatch is found to be feasible for any fundamental wavelength above 780 nm. The phase-velocity mismatch has a lower limit with coherence lengths in the micron range. The nonlinear strength is optimized when the fundamental has maximum confinement in the core. The conversion bandwidth allows for fs-pulse conversion and 4-180%/Wmiddotcm2 relative efficiencies were found.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Bache, M., Lægsgaard, J., Bang, O., Bjarklev, A. O.
Pages: 49-54
Publication date: 2006

Host publication information
Title of host publication: Proceedings ICTON 2006
Volume: 2
Publisher: IEEE
Electronic versions:
Bache.pdf
DOIs:
10.1109/ICTON.2006.248320

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Source: orbit
Source-ID: 191798
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2006 → Research → peer-review

Second-harmonic Generation with Zero Group-Velocity Mismatch in Nonlinear Photonic Crystal Fibers

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Contributors: Bache, M., Lægsgaard, J., Bang, O., Bjarklev, A. O.
Pages: 49-54
Publication date: 2006

Host publication information
Title of host publication: ICTON Catalogue
Soliton collision and Raman gain regimes in continuous-wave pumped supercontinuum generation

We numerically investigate supercontinuum generation using continuous-wave pumping. It is found that energy transfer during collision of solitons plays an important role. The relative influence of Raman gain on spectral broadening is shown to depend on the width of the calculation time window. Our results indicate that increasing the spectral linewidth of the pump can decrease the supercontinuum spectral width. Using a fiber with smaller dispersion at the pump wavelength reduces the required fiber length by decreasing the temporal width of the solitons formed from modulation instability. This also reduces the sensitivity to the pump spectral linewidth.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Frosz, M. H., Bang, O., Bjarklev, A. O.
Pages: 9391-9407
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Volume: 14
Issue number: 20
ISSN (Print): 1094-4087
Ratings:
Scopus rating (2006): SJR 3.387 SNIP 2.349
Web of Science (2006): Indexed yes
Original language: English
Electronic versions:
3.pdf
DOI:
10.1364/OE.14.009391
URLs:
http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-14-20-9391
Source: orbit
Source-ID: 192529
Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report
year: 2006 › Research › peer-review

Stability of two-dimensional spatial solitons in nonlocal nonlinear media

We discuss the existence and stability of two-dimensional solitons in media with spatially nonlocal nonlinear response. We show that such systems, which include thermal nonlinearity and dipolar Bose-Einstein condensates, may support a variety of stationary localized structures, including rotating dipole solitons. We also demonstrate that the stability of these structures critically depends on the spatial profile of the nonlocal response function.

General information
Publication status: Published
Organisations: Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Australian National University
Contributors: Skupin, S., Bang, O., Edmundson, D., Krolikowski, W.
Number of pages: 8
Pages: 066603
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Physical Review E
Volume: 73
Issue number: 6
ISSN (Print): 2470-0045
Ratings:
Scopus rating (2006): SJR 1.828 SNIP 1.336
Stability of two-dimensional spatial solitons in nonlocal nonlinear media

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Skupin, S., Bang, O., Edmundson, D., Krolikowski, W.
Publication date: 2006
Peer-reviewed: Yes
Event: Abstract from SIAM Conference on Nonlinear Waves and Coherent Structures, Seattle, United States.
Source: orbit
Source-ID: 194034
Research output: Contribution to conference » Conference abstract for conference – Annual report year: 2006 » Research » peer-review

Stable rotating dipole solitons in nonlocal media

We present the first example of stable rotating two-soliton bound states in nonlinear optical media with nonlocal response. We show that, in contrast to media with local response, nonlocality opens possibilities to generate stable azimuthons.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Lopez-Aguayo, S., Skupin, S., Desyatnikov, A. S., Bang, O., Krolikowski, W., Kivshar, Y. S.
Pages: QThJ3
Publication date: 2006

Host publication information
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Place of publication: Long Beach, California
Publisher: CLEO Conference Org.
ISBN (Print): 1-55752-813-6
Source: orbit
Source-ID: 189559
Research output: Chapter in Book/Report/Conference proceeding » Article in proceedings – Annual report year: 2006 » Research » peer-review

Stable rotating dipole solitons in nonlocal optical media

We reveal that nonlocality can provide a simple physical mechanism for stabilization of multihump optical solitons and present what we believe to be the first example of stable rotating dipole solitons and soliton spiraling, which we are known to be unstable in all types of realistic nonlinear media with a local response.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Lopez-Aguayo, S., Desyatnikov, A. S., Kivshar, Y. S., Skupin, S., Krolikowski, W., Bang, O.
Pages: 1100-1102
Publication date: 2006
Peer-reviewed: Yes
Supercontinuum generation in fibers infiltrated with liquid crystals

Supercontinuum generation in a capillary tube infiltrated with a nematic liquid crystal is investigated theoretically in the near infrared region. A liquid crystal with a high electronic nonlinearity is chosen, which makes it possible to generate 100 nm wide supercontinua using IO ps pulses with peak power 1.5 kW in a 10 cm long waveguide. The possibility of tuning the spectrum of the generated Supercontinuum by changing the dispersion of the waveguide is also considered. It is found that the broadening of the spectrum in both the normal and anomalous regime is mainly due to self phase modulation, and therefore the dispersion of the waveguide is only of minor importance. The tuning of the dispersion is achieved by varying the temperature of the liquid crystal inside the capillary.

The influence of input pump polarization on supercontinuum generation in photonic crystal fibers

The influence of input pump polarization on supercontinuum generation in photonic crystal fibers is studied both theoretically and experimentally. The results show that the polarization of the input pump pulse has a significant impact on the generation of supercontinuum.

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Contributors: Rasmussen, P. D., Bang, O., Lægsgaard, J., Rottwitt, K.
Pages: Mo.D2.3
Publication date: 2006

Host publication information
Title of host publication: International Conference on Transparent Optical Networks, 2006
Volume: 2
Publisher: IEEE
Electronic versions:
Rasmussen.pdf
DOIs: 10.1109/ICTON.2006.248321

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Source: orbit
Source-ID: 189925
Research output: Chapter in Book/Report/Conference proceeding → Conference abstract in proceedings – Annual report year: 2006 → Research → peer-review
Towards biochips using microstructured optical fiber sensors

In this paper we present the first incorporation of a microstructured optical fiber (MOF) into biochip applications. A 16-mm-long piece of MOF is incorporated into an optic-fluidic coupler chip, which is fabricated in PMMA polymer using a CO2 laser. The developed chip configuration allows the continuous control of liquid flow through the MOF and simultaneous optical characterization. While integrated in the chip, the MOF is functionalized towards the capture of a specific single-stranded DNA string by immobilizing a sensing layer on the microstructured internal surfaces of the fiber. The sensing layer contains the DNA string complementary to the target DNA sequence and thus operates through the highly selective DNA hybridization process. Optical detection of the captured DNA was carried out using the evanescent-wave-sensing principle. Owing to the small size of the chip, the presented technique allows for analysis of sample volumes down to 300 nL and the fabrication of miniaturized portable devices.

Tuning quadratic nonlinear photonic crystal fibers for zero group-velocity mismatch

A nonlinear index-guiding silica PCF is optimized for efficient second-harmonic generation through dispersion calculations. Zero group-velocity mismatch is possible for any pump wavelength above 780 nm. Very high conversion efficiencies and bandwidths are found.
Tuning quadratic nonlinear photonic crystal fibers for zero group-velocity mismatch

We consider an index-guiding silica photonic crystal fiber with a triangular hole pattern and a periodically poled quadratic nonlinearity. By tuning the pitch and the relative hole size, second-harmonic generation with zero group-velocity mismatch is found for any fundamental wavelength above 780 nm. The nonlinear strength is optimized when the fundamental has maximum confinement in the core. The conversion bandwidth allows for femtosecond-pulse conversion, and 4%-180% W\(^{-1}\) cm\(^{-2}\) relative efficiencies were found.

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**Escape angles for out-of-phase nematicons**

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Rasmussen, P. D., Bang, O., Krolikowski, W.
Publication date: 2005
Peer-reviewed: Yes
Event: Poster session presented at Nonlinear Guided Waves and Their Applications, Dresden, Germany.
Source: orbit
Source-ID: 188144
Research output: Contribution to conference › Poster – Annual report year: 2005 › Research › peer-review

**High-resolution, real-time imaging using a fiber-based optical coherence tomography system**

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Risø National Laboratory
Contributors: Falk, P. A., Frosz, M. H., Thrane, L., Bang, O., Andersen, P. E., Bjarklev, A. O.
Publication date: 2005
Peer-reviewed: Yes
Event: Poster session presented at DTU Medical Visionday, DTU, Kgs. Lyngby, Denmark.
Source: orbit
Source-ID: 183096
Research output: Contribution to conference › Poster – Annual report year: 2005 › Research › peer-review

**Modulation Instability in nonlocal chi2-model**

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Wyller, J., Krolikowski, W. Z., Bang, O., Petersen, D., Rasmussen, J.
Publication date: 2005
Peer-reviewed: Yes
Event: Poster session presented at Australian Institute of Physics 16th Biennial Congress 2005, Canberra, Australia.
Source: orbit
Source-ID: 183177
Research output: Contribution to conference › Poster – Annual report year: 2005 › Research › peer-review

**Nano-engineering of photonic crystal fibers for supercontinuum generation**

**General information**
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Frosz, M. H., Sørensen, T., Bang, O.
Publication date: 2005

**Host publication information**
Title of host publication: Proceedings
Editor: Bang, O.
Source: orbit
Source-ID: 183108
Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2005 › Research › peer-review
Nonlinear wave dynamics in nonlocal media

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fibers & Nonlinear Optics
Contributors: Rasmussen, J., Bang, O., Krolikowski, W., Wyller, J.
Publication date: 2005
Peer-reviewed: No
Source: orbit
Source-ID: 188143
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2005 › Research

Observation of attraction forces between dark solitons

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Neshev, D., Dreishuh, A., Krolikowski, W., Bang, O.
Publication date: 2005

Host publication information
Title of host publication: Proceedings NLGW 2005
Source: orbit
Source-ID: 188142
Research output: Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2005 › Research › peer-review

Observation of attraction of dark solitons

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Petersen, D., Neshev, D., Krolikowski, W. Z., Dreischuh, A., Bang, O.
Number of pages: 1
Publication date: 2005

Host publication information
Title of host publication: Proceedings CLEO 2005
Source: orbit
Source-ID: 183166
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research › peer-review

Ring vortex solitons in nonlocal nonlinear media

We study the formation and propagation of two-dimensional vortex solitons, i.e. solitons with a phase singularity, in optical materials with a nonlocal focusing nonlinearity. We show that nonlocality stabilizes the dynamics of an otherwise unstable vortex beam. This occurs for either single or higher charge fundamental vortexes as well as higher order (multiple ring) vortex solitons. Our results pave the way for experimental observation of stable vortex rings in other nonlocal nonlinear systems including Bose-Einstein condensates with pronounced long-range interparticle interaction.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Briedis, D., Petersen, D., Edmundson, D., Krolikowski, W., Bang, O.
Pages: 435-443
Publication date: 2005
Peer-reviewed: Yes

Publication information
Journal: Optics Express
Selective detection of antibodies in microstructured polymer optical fibers

We demonstrate selective detection of fluorophore labeled antibodies from minute samples probed by a sensor layer of complementary biomolecules immobilized inside the air holes of microstructured Polymer Optical Fiber (mPOF). The fiber core is defined by a ring of 6 air holes and a simple procedure was applied to selectively capture either α-streptavidin or α-CRP antibodies inside these air holes. A sensitive and easy-to-use fluorescence method was used for the optical detection. Our results show that mPOF based biosensors can provide reliable and selective antibody detection in ultra small sample volumes.
Soliton interactions in nematic liquid crystals (NLC)

Supercontinuum generation in a photonic crystal fiber tapered to normal dispersion for all wavelengths

Supercontinuum generation in a photonic crystal fiber with two zero-dispersion wavelengths tapered to normal dispersion at all wavelengths
Peer-reviewed: Yes

**Publication information**

**Journal:** Optics Express  
**Volume:** 13  
**Issue number:** 19  
**ISSN (Print):** 1094-4087

**Ratings:**
- Scopus rating (2005): SJR 3.412 SNIP 2.459
- Web of Science (2005): Indexed yes
- Original language: English
- Source: orbit
- Source-ID: 183072

**Research output:** Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

**Supercontinuum generation in photonic crystal fibers: The role of the second zero dispersion wavelength**

We study supercontinuum generation in photonic crystal fibers with various distances between the two zero dispersion wavelengths. Controllable generation of a red-shifted, nearly Gaussian shaped spectrum with a 3-dB bandwidth of 200 nm is found.

**General information**

**Publication status:** Published  
**Organisations:** Fibers & Nonlinear Optics, Department of Photonics Engineering, Risø National Laboratory  
**Contributors:** Frosz, M. H., Bang, O., Bjarklev, A. O., Andersen, P. E., Broeng, J.  
**Pages:** 1255-1257  
**Publication date:** 2005

**Host publication information**

**Title of host publication:** Conference on Lasers and Electro-Optics, 2005. (CLEO).  
**Volume:** 2  
**Publisher:** IEEE  
**ISBN (Print):** 1-55752-795-4

Electronic versions:
- Frosz.pdf  

**DOIs:**
- 10.1109/CLEO.2005.202090

**Bibliographical note**

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**Source:** orbit  
**Source-ID:** 183098

**Research output:** Chapter in Book/Report/Conference proceeding › Conference abstract in proceedings – Annual report year: 2005 › Research

**Supercontinuum generation in untapered and tapered photonic crystal fibers with two zero dispersion wavelengths**

**General information**

**Publication status:** Published  
**Organisations:** Fibers & Nonlinear Optics, Department of Photonics Engineering  
**Contributors:** Frosz, M. H., Falk, P. A., Pedersen, L., Bang, O., Bjarklev, A. O.  
**Pages:** 190-197  
**Publication date:** 2005  
**Peer-reviewed:** Yes

**Publication information**

**Journal:** Photonic Crystal Materials and Devices III  
**Volume:** 5733  
**Original language:** English

**Source:** orbit  
**Source-ID:** 183110

**Research output:** Contribution to journal › Conference article – Annual report year: 2005 › Research › peer-review
Supercontinuum generation in untapered and tapered photonic crystal fibers with two zero dispersion wavelengths

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Frosz, M. H., Falk, P. A., Pedersen, L., Bang, O., Bjarklev, A. O.
Publication date: 2005
Peer-reviewed: Yes
Event: Abstract from Photonics West 2005, San Jose, CA, United States.
Source: orbit
Source-ID: 183099
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2005 › Research › peer-review

Theory of nonlocal soliton interaction in nematic liquid crystals
We investigate interactions between spatial nonlocal bright solitons in nematic liquid crystals using an analytical “effective particle” approach as well as direct numerical simulations. The model predicts attraction of out-of-phase solitons and the existence of their stable bound state. This nontrivial property is solely due to the nonlocal nature of the nonlinear response of the liquid crystals. We further predict and verify numerically the critical outwards angle and degree of nonlocality which determine the transition between attraction and repulsion of out-of-phase solitons.

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering, Australian National University
Contributors: Rasmussen, P. D., Bang, O., Krolikowski, W.
Pages: 066611
Publication date: 2005
Peer-reviewed: Yes

Publication information
Journal: Physical Review E
Volume: 72
Issue number: 6
ISSN (Print): 2470-0045
Ratings:
Scopus rating (2005): SJR 1.77 SNIP 1.32
Web of Science (2005): Indexed yes
Original language: English
Electronic versions:
Per.pdf
DOIs: 10.1103/PhysRevE.72.066611

Bibliographical note
Copyright 2005 American Physical Society
Source: orbit
Source-ID: 184499
Research output: Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

The role of tapering and second zero dispersion wavelength for supercontinuum generation in photonic crystal fibers

General information
Publication status: Published
Organisations: Fibers & Nonlinear Optics, Department of Photonics Engineering
Contributors: Falk, P. A., Frosz, M. H., Bang, O.
Publication date: 2005
Peer-reviewed: No
Event: Poster session presented at Annual meeting of the Danish Optical Society 2005, Roskilde, Denmark.
Source: orbit
Source-ID: 183159
The role of the second zero-dispersion wavelength in generation of supercontinua and bright-bright soliton-pairs across the zero-dispersion wavelength

Supercontinuum generation with femtosecond pulses in photonic crystal fibers with two zero-dispersion wavelengths (ZDWs) is investigated numerically. The role of the higher ZDW is examined for 5 fiber designs with a nearly constant lower ZDW. It is found that the resulting spectrum is mainly determined by self-phase modulation in the first few mm of fiber, followed by soliton self-frequency shift and amplification of dispersive waves. It is demonstrated how femtosecond soliton pulses can be generated with any desired center wavelength in the 1020-1200 nm range by adjusting the fiber length. Further, the generation of a bright-bright soliton-pair from an initial single red-shifted soliton is found. The soliton-pair has one color in the anomalous dispersion region and the other color in the normal dispersion region, which has not previously been described for bright-bright soliton-pairs.

Attraction of nonlocal dark optical solitons

We study the formation and interaction of spatial dark optical solitons in materials with a nonlocal nonlinear response. We show that unlike in local materials, where dark solitons typically repel, the nonlocal nonlinearity leads to a long-range attraction and formation of stable bound states of dark solitons. (C) 2004 Optical Society of America
A nonlocal description of two-color parametric solitons

**General information**
Publication status: Published
Organisations: Department of Photonics Engineering
Contributors: Nikolov, N., Neshev, D., Bang, O., Krolikowski, W., Wyller, J.
Publication date: 2004
Peer-reviewed: Yes
Event: Poster session presented at Nonlinear Guided Waves and Their Applications, Toronto, Canada.
Source: orbit
Source-ID: 155773
Research output: Contribution to conference › Poster – Annual report year: 2004 › Research › peer-review

Bubble generation in a twisted and bent DNA-like model
The DNA molecule is modeled by a parabola embedded chain with long-range interactions between twisted base pair dipoles. A mechanism for bubble generation is presented and investigated in two different configurations. Using random normally distributed initial conditions to simulate thermal fluctuations, a relationship between bubble generation, twist and curvature is established. An analytical approach supports the numerical results.

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Fiber Sensors & Supercontinuum, Department of Photonics Engineering, University of Seville
Contributors: Larsen, P. U. V., Christiansen, P. L., Bang, O., Archilla, J. R., Gaididei, Y. B.
Pages: 036609
Publication date: 2004
Peer-reviewed: Yes

**Publication information**
Journal: Physical Review E
Volume: 70
Issue number: 3
ISSN (Print): 2470-0045
Ratings:
Scopus rating (2004): SJR 1.751 SNIP 1.272
Web of Science (2004): Indexed yes
Original language: English
Keywords: LONG-RANGE, MOVING BREAKHRS, DISCRETE BREAKHRS, TODA LATTICE MODEL, NONLINEAR MODEL, ENERGY LOCALIZATION, KLEIN-GORDON MODEL, DENATURATION, DYNAMICS, CHAIN
Electronic versions:
Leth.pdf
DOIs:
10.1103/PhysRevE.70.036609
URLs:

**Bibliographical note**
Source: orbit
Source-ID: 154555
Research output: Contribution to journal › Journal article – Annual report year: 2004 › Research › peer-review

Cob-web microstructured fibers optimized for supercontinuum generation with picosecond pulses

**General information**
Publication status: Published
Organisations: Glass Components and Materials, Department of Photonics Engineering
Contributors: Sørensen, N. T., Nikolov, N., Bang, O., Bjarklev, A. O., Hougaard, K. G., Hansen, K. P., Rasmussen, J.
Publication date: 2004
Peer-reviewed: Yes
Source: orbit
Complete modulational-instability gain spectrum of nonlinear quasi-phase-matching gratings
We consider plane waves propagating in quadratic nonlinear slab waveguides with nonlinear quasi-phasesmatching gratings. We predict analytically and verify numerically the complete gain spectrum for transverse modulational instability, including hitherto undescribed higher-order gain bands.

Dispersion engineered cob-web photonic crystal fibers for efficient supercontinuum generation
Highly nonlinear cob-web photonic crystal fibers are engineered to have dispersion profiles for efficient direct degenerate four-wave mixing and optimized supercontinuum generation with low-power picosecond pulses. This process is robust to fiber irregularities.

Dispersion engineered nano-structured cob-web photonic crystal fibres for efficient supercontinuum generation
Highly nonlinear cob-web photonic crystal fibres are engineered to have dispersion profiles for efficient direct degenerate four-wave mixing and optimized supercontinuum generation with low-power picosecond pulses. This process is robust to fiber irregularities.
Energy funneling in a bent chain of Morse oscillators with long-range coupling

A bent chain of coupled Morse oscillators with long-range dispersive interaction is considered. Moving localized excitations may be trapped in the bending region. Thus chain geometry acts like an impurity. An energy funneling effect is observed in the case of random initial conditions.

Modulation instability in a nonlocal\( x(2) \) - model

We present an overview of recent advances in the understanding of optical beams in nonlinear media with a spatially nonlocal nonlinear response. We discuss the impact of nonlocality on the modulational instability of plane waves, the collapse of finite-size beams, and the formation and interaction of spatial solitons.
Nonlinear wave propagation in nonlocal media

We investigate the propagation of partially coherent beams in spatially nonlocal nonlinear media with a logarithmic type of nonlinearity. We derive analytical formulas for the evolution of the beam parameters and conditions for the formation of nonlocal incoherent solitons.

Nonlocal incoherent solitons

Nonlocal incoherent solitons

We investigate the propagation of partially coherent beams in spatially nonlocal nonlinear media with a logarithmic type of nonlinearity. We derive analytical formulas for the evolution of the beam parameters and conditions for the formation of nonlocal incoherent solitons.
Nonlocal incoherent solitons in materials with a logarithmic nonlinearity

General information
Publication status: Published
Organisations: Glass Components and Materials, Department of Photonics Engineering
Contributors: Bang, O., Wyller, J., Krolikowski, W.
Publication date: 2004
Peer-reviewed: No
Source: orbit
Source-ID: 155591
Research output: Contribution to conference › Paper – Annual report year: 2004 › Research

Nonlocal solitons

General information
Publication status: Published
Organisations: Glass Components and Materials, Department of Photonics Engineering
Contributors: Bang, O.
Publication date: 2004
Peer-reviewed: No
Source: orbit
Source-ID: 155590
Research output: Contribution to conference › Paper – Annual report year: 2004 › Research

Optical beams and spatial solitons in nonlocal nonlinear media

General information
Publication status: Published
Organisations: Department of Photonics Engineering
Contributors: Krolikowski, W., Nikolov, N., Bang, O., Neshev, D., Wyller, J., Rasmussen, J., Edmundson, D.
Publication date: 2004
Peer-reviewed: Yes
Source: orbit
Source-ID: 155757
Research output: Contribution to conference › Paper – Annual report year: 2004 › Research › peer-review
Phase- and group velocity matching in triangular photonic crystal fibres

General information
Publication status: Published
Organisations: Glass Components and Materials, Department of Photonics Engineering
Contributors: Nielsen, H., Lægsgaard, J., Bang, O., Bjarklev, A. O.
Pages: 5-7
Publication date: 2004
Peer-reviewed: No

Publication information
Journal: DOPS NYT
Volume: 19
Issue number: 4
Original language: English
Source: orbit
Source-ID: 155477
Research output: Contribution to journal – Journal article – Annual report year: 2004 – Research

Photonic crystal fiber based antibody detection

General information
Publication status: Published
Organisations: Department of Photonics Engineering
Publication date: 2004
Peer-reviewed: Yes
Event: Paper presented at IEEE international conference on sensors, Orlando, Florida, USA.
Source: orbit
Source-ID: 155702

An original approach for detecting labeled antibodies based on strong penetration photonic crystal fibers is introduced. The target antibody is immobilized inside the air-holes of a photonic crystal fiber and the detection is realized by the means of evanescent-wave fluorescence spectroscopy and the use of a transversal illumination setup.

Photonic crystal fiber based antibody detection

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Pages: 1222-1225
Publication date: 2004

Host publication information
Volume: 3
Publisher: IEEE
ISBN (Print): 0-7803-8692-2
Keywords: Biosensor, Photonic crystal fiber, Cy3, Antibody detection, Fluorescence
Electronic versions:
Duval.pdf
DOI: 10.1109/ICSENS.2004.1426399

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Source: orbit
Photonic crystal fiber design for broadband directional coupling
A novel design for a broadband directional coupler based on a photonic crystal fiber is investigated numerically. It is shown that suitable index-depressing doping of the core regions in an index-guiding twin-core photonic crystal fiber can stabilize the coupling coefficient between the cores over an extremely broad (octave-spanning) frequency range.

Photonic crystal structures in sensing technology

Second-harmonic generation in microstructured fibres: simultaneous phase- and group-velocity matching

Simultaneous phase- and group-velocity matching in photonic crystal fibres
Designing the dispersion for optimum supercontinuum bandwidth using picosecond pulses

Generation of a 800nm wide within 20dB super-continuum with picosecond pulses is possible by proper design of the dispersion to enhance the efficiency of the direct degenerate four-wave-mixing. The robustness to random fluctuations along the fiber is also improved.

Improving efficiency of supercontinuum generation in photonic crystal fibers

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Scopus rating (2003): SJR 1.747 SNIP 1.423
Web of Science (2003): Indexed yes
Original language: English
URLs:

Research output: Contribution to journal › Journal article – Annual report year: 2003 › Research › peer-review
Improving efficiency of supercontinuum generation in photonic crystal fibres by direct degenerate four-wave mixing

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Photonics Engineering
Contributors: Nikolov, N. I., Sørensen, N. T., Bang, O., Bjarklev, A. O.
Pages: November 17
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: Virtual Journal of Nanoscale Science & Technology
Volume: 8
Issue number: 20
ISSN (Print): 1553-9644
Original language: English
Source: orbit
Source-ID: 61588
Research output: Contribution to journal → Journal article – Annual report year: 2003 → Research → peer-review

Large amplitude spatial fluctuations in the boundary region of the Bose-Einstein condensate in the Gross-Pitaevskii regime

The Gross-Pitaevskii regime of a Bose-Einstein condensate is investigated using a fully non-linear approach. The confining potential first adopted is that of a linear ramp. An infinite class of new analytical solutions of this linear ramp potential approximation to the Gross-Pitaevskii equation is found which are characterised by pronounced large-amplitude oscillations close to the boundary of the condensate. The limiting case within this class is a nodeless ground state which is known from recent investigations as an extension of the Thomas-Fermi approximation. We have found the energies of the oscillatory states to lie above the ground state energy but recent experimental work, especially on spatially confined superconductors, indicates that such states may be easily occupied and made manifest at finite temperatures. We have also investigated their stability using a Poincare section analysis as well as a linear perturbation approach. Both these techniques demonstrate stability against small perturbations. Finally, we have discussed the relevance of these quasi-one-dimensional solutions in the context of the fully three-dimensional condensates. This has been argued on the basis of numerical work and asymptotic approximations. (C) 2003 Elsevier Science B.V. All rights reserved.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Tuszynski, J. A., Middleton, J., Portet, S., Dixon, J. M., Bang, O., Christiansen, P. L., Salerno, M.
Pages: 455-476
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: Physica A: Statistical Mechanics and its Applications
Volume: 325
Issue number: 3-4
ISSN (Print): 0378-4371
Ratings:
Scopus rating (2003): SJR 0.669 SNIP 0.716
Web of Science (2003): Indexed yes
Original language: English
DOIs:
10.1016/S0378-4371(03)00287-5
URLs:
Source: orbit
Source-ID: 58475
Research output: Contribution to journal → Journal article – Annual report year: 2003 → Research → peer-review

Nonlinear waves in nonlocal media

General information
Publication status: Published
Nonlocal solitons

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Department of Informatics and Mathematical Modeling, Department of Physics
Contributors: Krolikowski, W., Bang, O., Nikolov, N. I., Neshev, D., Rasmussen, J., Christiansen, P. L., Wyller, J.
Publication date: 2003
Peer-reviewed: Yes
Event: Poster session presented at ACOLS, Melbourne, Victoria, Australia.
Source: orbit
Source-ID: 61539
Research output: Contribution to conference – Poster – Annual report year: 2003 – Research – peer-review

Optical Beams in Nonlocal Nonlinear Media

We discuss propagation of optical beams in nonlocal Kerr-like media with the nonlocality of general form. We study the effect of nonlocality on modulational instability of the plane wave fronts, collapse of finite beams and formation of spatial solitons.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Risø National Laboratory for Sustainable Energy
Contributors: Królikowski, W., Bang, O., Wyller, J., Juul Rasmussen, J.
Pages: 133-147
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: Acta Physica Polonica A
Volume: 103
Issue number: 2-3
ISSN (Print): 0587-4246
Ratings:
Scopus rating (2003): SJR 0.248 SNIP 0.313
Web of Science (2003): Indexed yes
Original language: English
URLs:
Source: orbit
Source-ID: 58448
Research output: Contribution to journal – Conference article – Annual report year: 2003 – Research – peer-review

Quadratic solitons as nonlocal solitons

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Department of Informatics and Mathematical Modeling
Contributors: Krolikowski, W., Bang, O., Neshev, D., Nikolov, N. I.
Publication date: 2003
Peer-reviewed: Yes
Source: orbit
Source-ID: 61534
Quadratic solitons as nonlocal solitons

We show that quadratic solitons are equivalent to solitons of a nonlocal Kerr medium. This provides new physical insight into the properties of quadratic solitons, often believed to be equivalent to solitons of an effective saturable Kerr medium. The nonlocal analogy also allows for analytical solutions and the prediction of bound states of quadratic solitons.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Fiber Sensors & Supercontinuum, Department of Photonics Engineering, Australian National University
Contributors: Nikolov, N. I., Neshev, D., Bang, O., Królikowski, W.
Pages: 366141-366145
Publication date: 2003
Peer-reviewed: Yes

Publication information
Volume: 68
Issue number: 3
Article number: 036614
ISSN (Print): 1063-651X
Ratings:
Scopus rating (2003): SJR 1.359 SNIP 1.206
Web of Science (2003): Indexed yes
Original language: English
Keywords: SPATIAL SOLITARY WAVES, CRYSTALS, PHYSICS, NONLINEAR MEDIA
Electronic versions:
Nikolai.pdf
DOIs:
10.1103/PhysRevE.68.036614

Bibliographical note
Source: orbit
Source-ID: 58458
Research output: Contribution to journal › Journal article – Annual report year: 2003 › Research › peer-review

Quadratic solitons described as nonlocal solitons

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Photonics Engineering
Contributors: Nikolov, N. I., Neshev, D., Bang, O., Krolikowski, W.
Publication date: 2003
Peer-reviewed: Yes
Event: Poster session presented at 16th International Conference on Laser Spectroscopy, Palm Cove, Australia.
Source: orbit
Source-ID: 61554
Research output: Contribution to conference › Poster – Annual report year: 2003 › Research › peer-review

Collapse arrest and soliton stabilization in nonlocal nonlinear media

We investigate the properties of localized waves in cubic nonlinear materials with a symmetric nonlocal nonlinear response of arbitrary shape and degree of nonlocality, described by a general nonlocal nonlinear Schrodinger type equation. We prove rigorously by bounding the Hamiltonian that nonlocality of the nonlinearity prevents collapse in, e.g., Bose-Einstein condensates and optical Kerr media in all physical dimensions. The nonlocal nonlinear response must be symmetric and have a positive definite Fourier spectrum, but can otherwise be of completely arbitrary shape and degree of nonlocality. We use variational techniques to find the soliton solutions and illustrate the stabilizing effect of nonlocality.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Plasma Physics and Technology Programme, Risø National Laboratory for Sustainable Energy, Australian National University, Agricultural University of Norway
Contributors: Bang, O., Krolikowski, W., Wyller, J., Juul Rasmussen, J.
Complete description of all modulational instability gain bands generated by nonlinear QPM gratings

Engineering of spatial solitons in two-period QPM structures
Escape angles in bulk chi((2)) soliton interactions

We develop a theory for nonplanar interaction between two identical type I spatial solitons propagating at opposite, but arbitrary transverse angles in quadratic nonlinear (or so-called chi((2))) bulk media. We predict quantitatively the outwards escape angle, below which the solitons turn around and collide, and above which they continue to move away from each other. For in-plane interaction, the theory allows prediction of the outcome of a collision through the inwards escape angle, i.e., whether the solitons fuse or cross. We find an analytical expression determining the inwards escape angle using Gaussian approximations for the solitons. The theory is verified numerically.

Generic features of modulational instability in nonlocal Kerr media

The modulational instability (MI) of plane waves in nonlocal Kerr media is studied for a general response function. Several generic properties are proven mathematically, with emphasis on how new gain bands are formed through a bifurcation process when the degree of nonlocality, sigma, passes certain bifurcation values and how the bandwidth and maximum of each individual gain band depends on sigma. The generic properties of the MI gain spectrum, including the bifurcation phenomena, are then demonstrated for the exponential and rectangular response functions. For a focusing nonlinearity the nonlocality tends to suppress MI, but can never remove it completely, irrespectively of the shape of the response function. For a defocusing nonlinearity the stability properties depend sensitively on the profile of the response function. For response functions with a positive-definite spectrum, such as Gaussians and exponentials, plane waves are always stable, whereas response functions with spectra that are not positive definite (such as the rectangular) will lead to MI if sigma exceeds a certain threshold. For the square response function, in both the focusing and defocusing case, we show analytically and numerically how new gain bands that form at higher wave numbers when sigma increases will eventually dominate the existing gain bands at lower wave numbers and abruptly change the length scale of the periodic pattern that may be observed in experiments.
Improving efficiency of supercontinuum generation in photonic crystal fibers by direct degenerate four-wave-mixing

The efficiency of supercontinuum generation in photonic crystal fibers is significantly improved by designing the dispersion to allow widely separated spectral lines generated by degenerate four-wave-mixing directly from the pump to broaden and merge.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Photonics Engineering
Contributors: Nikolov, N. I., Bang, O., Bjarklev, A. O.
Pages: 1-2
Publication date: 2002

Host publication information
Title of host publication: 28th European Conference on Optical Communication : ECOC 2002 Technical Digest
Volume: 3
Publisher: IEEE
ISBN (Print): 87-90974-63-8
Electronic versions:
Nikolov.pdf

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Source: orbit
Source-ID: 58207
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2002 › Research › peer-review
Modulational-instability gain bands in quasi-phase-matched materials

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O., Neilson, D. (ed.)
Pages: 280-282
Publication date: 2002

Host publication information
Title of host publication: Proceedings of the Australian Institute of Physics 15th Biennial Congress, Australian Institute of Physics
Source: orbit
Source-ID: 58236
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2002 – Research

Plane waves in periodic, quadratically nonlinear slab waveguides: stability and exact Fourier structure

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Pages: 812-821
Publication date: 2002
Peer-reviewed: Yes

Publication information
Journal: Optical Society of America. Journal B: Optical Physics
Volume: 19
Issue number: 4
ISSN (Print): 0740-3224
Ratings:
Scopus rating (2002): SJR 1.771 SNIP 1.401
Web of Science (2002): Indexed yes
Original language: English
URLs:
Source: orbit
Source-ID: 58069

Soliton engineering with two-period QPM gratings

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Johansen, S. K., Carrasco, S., Torner, L., Bang, O.
Publication date: 2002

Host publication information
Title of host publication: Nonlinear Guided Waves and Their Applications : OSA Technical Digest
Publisher: Optical Society of America
URLs:
Source: orbit
Source-ID: 58240
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2002 – Research

Soliton interaction in weakly nonlocal nonlinear media

General information
Accurate switching intensities and length scales in quasi-phase-matched materials
We consider unseeded typeI second-harmonic generation in quasi-phase-matched quadratic nonlinear materials and derive an accurate analytical expression for the evolution of the average intensity. The intensity- dependent nonlinear phase mismatch that is due to the cubic nonlinearity induced by quasi phase matching is found. The equivalent formula for the intensity of maximum conversion, the crossing of which changes the one-period nonlinear phase shift of the fundamental abruptly by $\pi$, corrects earlier estimates [Opt.Lett. 23, 506 (1998)] by a factor of 5.3. We find the crystal lengths that are necessary to obtain an optimal flat phase versus intensity response on either side of this separatrix intensity.
Asymmetric induced cubic nonlinearities in homogeneous and quasi-phase-matched quadratic materials: signature and importance

In continuous-wave operation asymmetric induced nonlinearities induce an intensity-dependent phase mismatch that implies a nonzero so-called separatrix intensity, the crossing of which changes the one-period phase shift of the fundamental by $\pi$, with obvious use in switching applications. We derived a formula for this QPM-induced separatrix intensity that corrects earlier estimates by a factor of 5.3, and we found the optimum crystal lengths for a flat phase-versus-intensity response on each side of the separatrix.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Bang, O., Corney, J. F.
Pages: 42
Publication date: 2001
Peer-reviewed: Yes

Determination of escape angles in quadratic bulk experiments with two identical solitons

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Johansen, S. K., Bang, O., Sørensen, M. P.
Pages: 149-151
Publication date: 2001

Modulational instability in nonlocal Kerr media

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Bang, O., Krolikowski, W., Rasmussen, J. J., Wyller, J.
Pages: 161-163
Publication date: 2001
Modulational instability in nonlocal nonlinear Kerr media

We study modulational instability (MI) of plane waves in nonlocal nonlinear Kerr media. For a focusing nonlinearity we show that, although the nonlocality tends to suppress MI, it can never remove it completely, irrespective of the particular profile of the nonlocal response function. For a defocusing nonlinearity the stability properties depend sensitively on the response function profile: for a smooth profile (e.g., a Gaussian) plane waves are always stable, but MI may occur for a rectangular response. We also find that the reduced model for a weak nonlocality predicts MI in defocusing media for arbitrary response profiles, as long as the intensity exceeds a certain critical value. However, it appears that this regime of MI is beyond the validity of the reduced model, if it is to represent the weakly nonlocal limit of a general nonlocal nonlinearity, as in optics and the theory of Bose-Einstein condensates.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Plasma Physics and Technology Programme, Risø National Laboratory for Sustainable Energy, Australian National University, Agricultural University of Norway
Contributors: Krolikowski, W., Bang, O., Juul Rasmussen, J., Wyller, J.
Pages: 016612
Publication date: 2001
Peer-reviewed: Yes

Publication information
Volume: 64
Issue number: 1
ISSN (Print): 1063-651X
Ratings:
Scopus rating (2001): SJR 1.057 SNIP 1.393
Web of Science (2001): Indexed yes
Original language: English
Keywords: LATTICES, SCHRODINGER-EQUATION; SOLITONS, DYNAMICS, BOSE-EINSTEIN CONDENSATION
Electronic versions:
Ole.pdf
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10.1103/PhysRevE.64.016612
URLs:
http://link.aps.org/doi/10.1103/PhysRevE.64.016612

Bibliographical note
Copyright (2001) American Physical Society
Source: orbit
Source-ID: 57774
Research output: Contribution to journal › Journal article – Annual report year: 2001 › Research › peer-review

Modulational Instability in periodic quadratic nonlinear materials

We investigate the modulational instability of plane waves in quadratic nonlinear materials with linear and nonlinear quasi-phase-matching gratings. Exact Floquet calculations, confirmed by numerical simulations, show that the periodicity can drastically alter the gain spectrum but never completely removes the instability. The low-frequency part of the gain spectrum is accurately predicted by an averaged theory and disappears for certain gratings. The high-frequency part is related to the inherent gain of the homogeneous non-phase-matched material and is a consistent spectral feature.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Pages: 133901
Publication date: 2001
Peer-reviewed: Yes
Modulationally stable propagation in periodic quadratically nonlinear slab waveguides

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Pages: 179-181
Publication date: 2001

Host publication information
Title of host publication: Nonlinear Guided Waves and Their Applications, OSA Technical Digest
Publisher: Optical Society of America
URLs:
Source: orbit
Source-ID: 57898
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings → Annual report year: 2001 → Research

Nonlinearity and disorder: Classification and stability of nonlinear impurity modes
We study the effects produced by competition of two physical mechanisms of energy localization in inhomogeneous nonlinear systems. As an example, we analyze spatially localized modes supported by a nonlinear impurity in the generalized nonlinear Schrödinger equation and describe three types of nonlinear impurity modes, one- and two-hump symmetric localized modes and asymmetric localized modes, for both focusing and defocusing nonlinearity and two different (attractive or repulsive) types of impurity. We obtain an analytical stability criterion for the nonlinear localized modes and consider the case of a power-law nonlinearity in detail. We discuss several scenarios of the instability-induced dynamics of the nonlinear impurity modes, including the mode decay or switching to a new stable state, and collapse at the impurity site.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Plasma Physics and Technology Programme, Risø National Laboratory for Sustainable Energy, Australian National University
Contributors: Sukhorukov, A. A., Kivshar, Y. S., Bang, O., Juul Rasmussen, J., Christiansen, P. L.
Pages: 036601.1 - 036601.18
Publication date: 2001
Peer-reviewed: Yes

Publication information
Volume. 63
Nonlinearity and disorder: Theory and applications
Proceedings of the NATO Advanced Research Workshop (ARW) entitled Nonlinearity and Disorder: Theory and Applications, held in Tashkent, Uzbekistan, October 2-6, 2001. Phenomena of coherent structures in nonlinear systems and disorder are considered opposite in nature. For example one of the most fascinating nonlinear wave phenomenon - the soliton - is a highly coherent object, but in disordered linear media we know of the existence of the famous Anderson localization, which means the appearance of localized wave structures in disordered linear media. Investigations of wave phenomena in disordered nonlinear media show the rich varieties of phenomena interpolating between these two limiting cases. Related problems are the existence of partially coherent nonlinear wave packets in nonlinear media. These aspects have attracted a lot of attention in recent years due to investigations of the photorefractive solitons. Another very fast growing area induced by the technological development is statistical phenomena in nonlinear pulse propagation in optical fibers. Intrinsic randomness of existing optical communication systems has an important impact on the performance of planned soliton communication systems, in particular dispersion-managed solitons, and require the development of optical soliton theory for these cases.

Parametric localized modes in quadratic nonlinear photonic structures
We analyze two-color spatially localized nonlinear modes formed by parametrically coupled fundamental and second-harmonic fields excited at quadratic (or chi^2) nonlinear interfaces embedded in a linear layered structure-a quadratic nonlinear photonic crystal. For a periodic lattice of nonlinear interfaces, we derive an effective discrete model for the amplitudes of the fundamental and second-harmonic waves at the interfaces (the so-called discrete chi^2 equations) and find, numerically and analytically, the spatially localized solutions-discrete gap solitons. For a single nonlinear interface in a linear superlattice, we study the properties of two-color localized modes, and describe both similarities to and differences from quadratic solitons in homogeneous media.
Rigorous proof of soliton stability and absence of collapse in Kerr media and Bose-Einstein condensates with a general nonlocal nonlinearity

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Bang, O., Krolikowski, W., Wyller, J., Rasmussen, J. J.
Pages: 130-132
Publication date: 2001

**Host publication information**
Title of host publication: Nonlinear Guided Waves and Their Applications: OSA Technical Digest
Publisher: Optical Society of America
Source: orbit
Source-ID: 57895
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2001 – Research

Solitons in nonlocal nonlinear media: Exact solutions
We investigate the propagation of one-dimensional bright and dark spatial solitons in a nonlocal Kerr-like media, in which the nonlocality is of general form. We find an exact analytical solution to the nonlinear propagation equation in the case of weak nonlocality. We study the properties of these solitons and show their stability.

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Australian National University
Contributors: Krolikowski, W., Bang, O.
Pages: 016610
Publication date: 2001
Peer-reviewed: Yes

**Publication information**
Solitons in quadratic nonlinear photonic crystals
We study solitons in one-dimensional quadratic nonlinear photonic crystals with modulation of both the linear and nonlinear susceptibilities. We derive averaged equations that include induced cubic nonlinearities, which can be defocusing, and we numerically find previously unknown soliton families. Because of these induced cubic terms, solitons still exist even when the effective quadratic nonlinearity vanishes and conventional theory predicts that there can be no soliton. We demonstrate that both bright and dark forms of these solitons can propagate stably.

Collapse suppression and soliton stabilization through nonlocality in bulk Kerr media
We show that self-focusing cannot occur in bulk Kerr media with a nonlocal nonlinear response. We find the stationary solutions and show that nonlocality makes them stable. The results are verified numerically.
Effective nonlinearities and multi-wavelength second-harmonic generation in modulated quasi-phase-matching gratings

Quasi-phase-matching gratings induce Kerr effects in quadratic nonlinear materials. We show analytically and confirm numerically how modulating the grating changes the effective quadratic and cubic nonlinearities and allows for multi-wavelength second-harmonic generation.
Effects of linear gratings in quasi-phased-matched quadratic materials with induced Kerr effects

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Pages: 9-10
Publication date: 2000
Peer-reviewed: No

Engineering of effective quadratic and cubic nonlinearities in two-period QPM gratings
Summary form only given. Quasi-phase-matching (QPM) by electric-field poling in ferro-electric materials, such as LiNbO3, is promising due to the possibilities of engineering the photolithographic mask, and thus the QPM grating, without also generating a linear grating. A proper design of the longitudinal grating structure allows for distortion free temporal pulse compression, soliton shaping, broad-band phase matching, multiwavelength second-harmonic generation (SHG), and an enhanced cascaded phase shift. Transverse patterning can be used for beam-tailoring, broad-band SHG and soliton steering.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Bang, O., Clausen, C. A. B., Torner, L.
Pages: 147-148
Publication date: 2000
Fusion arrest and collapse phenomena due to Kerr-nonlinearity in quadratic media
Emphasizing collapse phenomena it is investigated to what extend the always present cubic nonlinearity affects the properties of soliton interaction in quadratic bulk media. An effective particle approach is applied and verified by numerical simulations.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Fiber Sensors & Supercontinuum, Department of Photonics Engineering
Contributors: Johansen, S. K., Bang, O., Sørensen, M. P.
Pages: 99-101
Publication date: 2000

Host publication information
Place of publication: Kaua'i-Lihue, HI
Publisher: Optical Society of America
Electronic versions:
bang.pdf
DOIs:
10.1109/NLO.2000.883589

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Source: orbit
Source-ID: 176493
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2000 › Research › peer-review

Influence of Four-Wave Mixing and Walk-Off on the Self-Focusing of Coupled Waves
Four-wave mixing and walk-off between two optical beams are investigated for focusing Kerr media. It is shown that four-wave mixing reinforces the self-focusing of mutually trapped waves by lowering their power threshold for collapse, only when their phase mismatch is small. On the contrary, walk-off inhibits the collapse by detrapping the beams, whose partial centroids experience nonlinear oscillations.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, CEA, Australian National University
Contributors: Bergé, L., Bang, O., Krolikowski, W.
Pages: 3302-3305
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Physical Review Letters
Volume: 84
Issue number: 15
ISSN (Print): 0031-9007
Ratings:
Scopus rating (2000): SJR 5.901 SNIP 3.165
Web of Science (2000): Indexed yes
Original language: English
Keywords: MEDIA, PULSE-PROPAGATION, STABILITY, BIREFRINGENT OPTICAL FIBERS, EQUATIONS, VECTOR SOLITONS, AMPLITUDES, SPATIAL SOLITONS
Electronic versions:
Bang.pdf
DOIs:
10.1103/PhysRevLett.84.3302
URLs:
Modulational stability and dark solitons in periodic quadratic nonlinear media
We show that stable dark solitons exist in quadratic nonlinear media with periodic linear and nonlinear susceptibilities. We investigate the modulational stability of plane waves in such systems, a necessary condition for stable dark solitons.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Pages: 362-364
Publication date: 2000

Host publication information
Place of publication: Kaua`i-Lihue, HI
Electronic versions:
ole.pdf
DOIs:
10.1109/NLO.2000.883676

Bibliographical note
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Source: orbit
Source-ID: 176468

Multi-component optical solitary waves
We discuss several novel types of multi-component (temporal and spatial) envelope solitary waves that appear in fiber and waveguide nonlinear optics. In particular, we describe multi-channel solitary waves in bit-parallel-wavelength fiber transmission systems for high-performance computer networks, multi-color parametric spatial solitary waves due to cascaded nonlinearities of quadratic materials, and quasiperiodic envelope solitons due to quasi-phase-matching in Fibonacci optical superlattices. (C) 2000 Elsevier Science B.V. All rights reserved.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Kivshar, Y. S., Sukhorukov, A. A., Ostrovskaya, E. A., Alexander, T. J., Bang, O., Saltiel, S. M., Clausen, C. B., Christiansen, P. L.
Pages: 152-173
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Physica A: Statistical Mechanics and its Applications
Volume: 288
Issue number: 1-4
ISSN (Print): 0378-4371
Ratings:
Scopus rating (2000): SJR 0.934 SNIP 0.784
Original language: English
DOIs:
10.1016/S0378-4371(00)00420-9
Multi-wavelength and multi-colour temporal and spatial optical solitons

We present an overview of several novel types of multi-component envelope solitary waves that appear in fiber and waveguide nonlinear optics. In particular, we describe multi-channel solitary waves in bit-parallel-wavelength fiber transmission systems for high performance computer networks, multi-color parametric spatial solitary waves due to cascaded nonlinearities of quadratic materials, and quasiperiodic envelope solitons in Fibonacci optical superlattices.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Kivshar, Y. S., Sukhorukov, A. A., Ostrovskaya, E. A., Bang, O., Clausen, C. A. B.
Pages: 9-19
Publication date: 2000

Host publication information
Title of host publication: Optical Pulse and Beam Propagation II, Proceedings of SPIE, vol.3927
Source: orbit
Source-ID: 176496

Optical spatial solitons in nonlocal nonlinear medium

General information
Publication status: Published
Organisations: Department of Photonics Engineering, Department of Informatics and Mathematical Modeling
Contributors: Krolikowski, W., Luther-Davies, B., Bang, O.
Pages: 209-211
Publication date: 2000

Host publication information
Title of host publication: Nonlinear Optics: Materials, Fundamentals and Applications, OSA Technical Digest
Publisher: Optical Society of America
Source: orbit
Source-ID: 200189

Robustness of quadratic solitons with periodic gain

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Torner, L., Torres, J. P., Bang, O.
Pages: 479-485
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Optics Communications
Volume: 185
ISSN (Print): 0030-4018
Ratings:
Scopus rating (2000): SJR 1.102 SNIP 0.894
Web of Science (2000): Indexed yes
Original language: English
Source: orbit
Source-ID: 176433
Soliton collisions in quadratic bulk media with a \( \text{nonvanishing Kerr non-linearity} \)

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Johansen, S. K., Bang, O.
Pages: 12-13
Publication date: 2000
Peer-reviewed: No

**Publication information**
Journal: DOPS Nyt - Danish Optical Society News, Special issue on Northern Optics
Volume: 15
Original language: English
URLs:
Source: orbit
Source-ID: 199903
Research output: Contribution to journal › Journal article – Annual report year: 2000 › Research

**Soliton interaction in quadratic and cubic bulk media**
Summary form only given. The understanding of how and to what extend the cubic nonlinearity affects beam propagation and spatial soliton formation in quadratic media is of vital importance in fundamental and applied nonlinear physics. We consider beam propagation under type-I SHG conditions in lossless bulk second order nonlinear optical materials with a nonvanishing third order nonlinearity. It is known that in pure second order systems a single soliton can never collapse whereas in systems with both nonlinearities and that stable single soliton propagation can only in some circumstances be achieved.

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Johansen, S. K., Bang, O.
Number of pages: 96
Publication date: 2000

**Host publication information**
Title of host publication: Quantum Electronics and Laser Science Conference
Publisher: Optical Society of America
ISBN (Print): 1-55752-608-7
Electronic versions:
Johansen.pdf

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Source: orbit
Source-ID: 176494
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2000 › Research › peer-review

**Spatial solitons in nonlinear photonic crystals**
We study solitons in one-dimensional quadratic nonlinear photonic crystals with periodic linear and nonlinear susceptibilities. We show that such crystals support stable bright and dark solitons, even when the effective quadratic nonlinearity is zero.

**General information**
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Corney, J. F., Bang, O.
Number of pages: 2
Pages: 122-124
Publication date: 2000
Unified model for partially coherent solitons in logarithmically nonlinear media

General information
Publication status: Published
Organisations: Australian National University
Contributors: Krolikowski, W., Edmundson, D., Bang, O.
Pages: 3122-3126
Publication date: 2000
Peer-reviewed: Yes

Publication information
Volume: 61
Issue number: 3
ISSN (Print): 1063-651X
Ratings:
Scopus rating (2000): SJR 1.888 SNIP 1.259
Web of Science (2000): Indexed yes
Original language: English
DOIs:
10.1103/PhysRevE.61.3122
Source: orbit
Source-ID: 264108
Research output: Contribution to journal → Journal article – Annual report year: 2000 → Research → peer-review

Collapse of Incoherent Light Beams in Inertial Bulk Kerr Media

We use the coherent density function theory to show that partially coherent beams are unstable and may collapse in inertial bulk Kerr media. The threshold power for collapse, and its dependence on the degree of coherence, is found analytically and checked-numerically. The internal dynamics of the walk-off modes is illustrated for collapsing and diffracting partially coherent beams.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Australian National University
Contributors: Bang, O., Edmundson, D., Królikowski, W.
Pages: 5479-5482
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: Physical Review Letters
Volume: 83
Issue number: 26
ISSN (Print): 0031-9007
Ratings:
Scopus rating (1999): SJR 6.273 SNIP 2.974
Fusion, collapse, and stationary bound states of incoherently coupled waves in bulk cubic media

We study the interaction between two localized waves that propagate in a bulk (two transverse dimensions) Kerr medium, while being incoherently coupled through cross-phase modulation. The different types of stationary solitary wave solutions are found and their stability is discussed. The results of numerical simulations suggest that the solitary waves are unstable. We derive sufficient conditions for when the wave function is bound to collapse or spread out, and we develop a theory to describe the regions of different dynamical behavior. For localized waves with the same center we confirm these sufficient conditions numerically and show that only when the equations and the initial conditions are symmetric are they also close to bring necessary conditions. Using Gaussian initial conditions we predict and confirm numerically the power dependent characteristic initial separations that divide the phase space into collapsing and diffracting solutions, and further divide each of these regions into subregions of coupled (fusion) and uncoupled dynamics. Finally we illustrate how, close to the threshold of collapse, the waves can cross several times before eventually collapsing or diffracting.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Physics, Risø National Laboratory for Sustainable Energy
Contributors: Bang, O., Bergé, L., Juul Rasmussen, J.
Pages: 4600-4613
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: Physical Review E
Volume: 59
Issue number: 4
ISSN (Print): 1063-651X
Ratings:
Scopus rating (1999): SJR 1.919 SNIP 1.238
Quasiperiodic Envelope Solitons
We analyze nonlinear wave propagation and cascaded self-focusing due to second-harmonic generation in Fibonacci optical superlattices and introduce a novel concept of nonlinear physics, the quasiperiodic soliton, which describes spatially localized self-trapping of a quasiperiodic wave. We point out a link between the quasiperiodic soliton and partially incoherent spatial solitary waves recently generated experimentally.

Two-Color Nonlinear Localized Modes in Photonic Crystals
Two-color nonlinear localized photonic modes

Stationary solutions and self-trapping in discrete quadratic nonlinear systems
Spatial Solitons and Induced Kerr Effects in Quasi-Phase-Matched Quadratic Media

We show that the evolution of the average intensity of cw beams in a quasi-phase-matched quadratic (or chi((2))) medium is strongly influenced by induced Kerr effects, such as self- and cross-phase modulation. We prove the existence of rapidly oscillating solitary waves (a spatial analog of the guided-center soliton) supported by the quadratic and induced cubic nonlinearities.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Australian National University
Contributors: Clausen, C. A. B., Bang, O., Kivshar, Y.
Pages: 4749-4752
Publication date: 1997
Peer-reviewed: Yes

Publication information
Journal: Physical Review Letters
Volume: 78
Issue number: 25
ISSN (Print): 0031-9007
Original language: English
Keywords: GUIDING-CENTER SOLITON, LIGHT, WAVE-GUIDE, 2ND-HARMONIC GENERATION, 2ND-ORDER, NONLINEARITIES
Electronic versions:
Bang.pdf
DOIs: 10.1103/PhysRevLett.78.4749
URLs: http://link.aps.org/doi/10.1103/PhysRevLett.78.4749

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Source: orbit
Source-ID: 168705

Temperature effects in a nonlinear model of monolayer Scheibe aggregates

A nonlinear dynamical model of molecular monolayers arranged in Scheibe aggregates is derived from a proper Hamiltonian. Thermal fluctuations of the phonons are included. The resulting equation for the excitons is the two dimensional nonlinear Schrödinger equation with noise. Two limits of the complicated spectrum of the noise are considered: time independent, spatially white noise, simply corresponding to disorder in the arrangement of the molecules, and pure white noise. Parameter values are found by comparison with experiments by Mobius and Kuhn [Isr. J. Chem. 18, 375 (1979)] and order of magnitude estimates given where experiments are not available. The temperature dependent coherence time is found from numerical simulations. Experiments show that the excitons stay coherent during their lifetime. This is in correspondence with the model at temperatures lower than 3 K. To increase this limiting temperature it is found that the dipole-dipole coupling and the exciton-phonon coupling must be decreased significantly.

General information
Publication status: Published
Organisations: Department of Informatics and Mathematical Modeling, Technical University of Denmark, Bogolyubov Institute for Theoretical Physics
Contributors: Bang, O., Christiansen, P. L., If, F., Rasmussen, K., Gaididei, Y. B.
Pages: 4627-4636
Publication date: 1994
Peer-reviewed: Yes

Publication information
Volume: 49
Issue number: 5
ISSN (Print): 1063-651X
Original language: English
Keywords: ASSEMBLIES, ENERGY-TRANSFER, EXCITONS, DECAY
Electronic versions:
Projects:

**High-Speed Time-stretch Optical coherence tomography**
Jensen, M., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Israelsen, N. M., Supervisor
Samfinansierede - Virksomhed
01/09/2017 → 31/08/2020
Award relations: High-Speed Time-stretch Optical coherence tomography
Project: PhD

**Polymer Optical Fiber Bragg Gratings for high sensitivity distributed biochemical sensors**
Inglev, R., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Janting, J., Supervisor
Nielsen, K., Supervisor
Samfinanseret - Andet
01/09/2017 → 31/08/2020
Award relations: Polymer Optical Fiber Bragg Gratings for high sensitivity distributed biochemical sensors
Project: PhD

**Gas-filled Hollow-Core Photonic Crystal Fibers for sensing applications and ultrafast non-linear optics**
Adamu, A. I., PhD Student, Department of Photonics Engineering
Markos, C., Main Supervisor
Bang, O., Supervisor
Forskningsrådsfinansiering
01/08/2017 → 31/07/2020
Award relations: Gas-filled Hollow-Core Photonic Crystal Fibers for sensing applications and ultrafast non-linear optics
Project: PhD

**Multi-tone supercontinuum sources for food control applications with IR spectroscopy**
Kwarkye, K., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Marie Curie (EU-stipendium)
01/06/2017 → 31/05/2020
Award relations: Multi-tone supercontinuum sources for food control applications with IR spectroscopy
Project: PhD

**Supercontinuum generation with rugged femtosecond fibre lasers**
Rao Delanthabettu Shivarama, S., PhD Student, Department of Photonics Engineering
Bache, M., Main Supervisor, Risø National Laboratory for Sustainable Energy
Moselund, P. M., Supervisor, Department of Photonics Engineering
Zhou, B., Supervisor, Department of Photonics Engineering
Bang, O., Main Supervisor, Department of Photonics Engineering
Anden EU-finansiering
15/02/2017 → 14/02/2020
Award relations: Supercontinuum generation with rugged femtosecond fibre lasers
Project: PhD
High-power visible-near-IR Supercontinuum sources for spectroscopic photoacoustic microscopy
Dasa, M. K., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Jain, D., Supervisor
Markos, C., Supervisor
Marie Curie (EU-stipendium)
01/02/2017 → 31/01/2020
Award relations: High-power visible-near-IR Supercontinuum sources for spectroscopic photoacoustic microscopy
Project: PhD

Rekonfigurérbare optiske bølgelederstrukturer genereret ved solitonvekselvirkning
Larsen, P. U. V., PhD Student, Department of Mathematics
Sørensen, M. P., Main Supervisor
Bang, O., Supervisor
Christiansen, P. L., Supervisor
Hjorth, P. G., Examiner
Rasmussen, J. J., Examiner
01/09/2002 → 15/05/2006
Award relations: Rekonfigurérbare optiske bølgelederstrukturer genereret ved solitonvekselvirkning
Project: PhD

Modellering og udvikling af fotoniske krystal bølgeledere
Bergbäck Knudsen, E., PhD Student, Department of Photonics Engineering
Bjarklev, A. O., Main Supervisor
Broeng, J., Supervisor
Bang, O., Examiner
Andersen, P. E., Examiner
Andrés, M. V., Examiner
DTU-lønnet stipendie
01/02/2000 → 31/07/2003
Award relations: Modellering og udvikling af fotoniske krystal bølgeledere
Project: PhD

Low noise femtosecond supercontinuum sources
Bravo Gonzalo, I., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Sørensen, M. P., Supervisor
Lægsgaard, J., Examiner
Grundforskningsfonden
01/09/2015 → 07/11/2018
Award relations: Low noise femtosecond supercontinuum sources
Project: PhD

Low-noise supercontinuum lasers for Optical Coherence Tomography systems
Engelsholm, R. D., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Thomsen, C. L., Supervisor
Lægsgaard, J., Examiner
Buczynski, R., Examiner
Horak, P., Examiner
Markos, C., Supervisor
Technical University of Denmark
01/05/2015 → 23/01/2019
Award relations: Low-noise supercontinuum lasers for Optical Coherence Tomography systems
Project: PhD
Design and fabrication of UV waveguiding polymer tube
Pedersen, J. K. M., PhD Student, Department of Photonics Engineering
Nielsen, K., Main Supervisor
Bang, O., Supervisor
Lindvold, L. R., Examiner
Kalli, K., Examiner
Webb, D. J., Examiner
Samfinansieret - Andet
01/09/2014 → 11/01/2018
Award relations: Design and fabrication of UV waveguiding polymer tube
Project: PhD

Ultrafast mid-IR nonlinear optics in gas-filled hollow-core photonic crystal fibers
Habib, S., PhD Student, Department of Photonics Engineering
Bache, M., Main Supervisor
Bang, O., Supervisor
Lægsgaard, J., Examiner
Joly, N., Examiner
Biancalana, F., Examiner
Technical University of Denmark
15/04/2014 → 14/06/2017
Award relations: Ultrafast mid-IR nonlinear optics in gas-filled hollow-core photonic crystal fibers
Project: PhD

Speciality and Microstructured Polymer Optical FBG Sensors
Woyessa, G., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Markos, C., Supervisor
Nielsen, K., Supervisor
Lindvold, L. R., Examiner
Schuster, K., Examiner
Kalli, K., Examiner
Marie Curie (EU-stipendium)
01/03/2014 → 23/08/2017
Award relations: Speciality and Microstructured Polymer Optical FBG Sensors
Project: PhD

POF based Glucose Sensor Incorporating Grating Wavelength Filters
Hassan, H. U., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Aasmul, S., Supervisor
Nielsen, K., Supervisor
Jepsen, P. U., Examiner
Sugden, K., Examiner
Eksternt EU-finansieret
15/01/2014 → 08/03/2017
Award relations: POF based Glucose Sensor Incorporating Grating Wavelength Filters
Project: PhD

Optical Fiber based Biosensors
Rindorf, L. H., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Jensen, J. B., Supervisor
Lindvold, L. R., Supervisor
Pedersen, L. H., Supervisor
Lægsgaard, J., Examiner
Larsen, U. D., Examiner
Lading, L., Supervisor
Webb, D. J., Examiner
InnovationsPhD
01/11/2004 → 29/01/2008
Award relations: Optical Fiber based Biosensors
**Polymer fiber-optical microphones**
Stefani, A., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Yuan, S. W., Supervisor
Rottwitt, K., Examiner
Schuster, K., Examiner
Keiding, S. R., Examiner
Offentlig finansiering
01/01/2009 → 22/03/2012
Award relations: Polymer fiber-optical microphones
Project: PhD

**Photonic crystal rod amplifiers: Understanding a new class of active optical waveguides**
Hansen, K. R., PhD Student, Department of Photonics Engineering
Lægsgaard, J., Main Supervisor
Broeng, J., Supervisor
Bang, O., Examiner
Bischoff, S., Examiner
Dajani, I. A., Examiner
Forskningsrådsfinansiering
01/01/2010 → 04/04/2013
Award relations: Photonic crystal rod amplifiers: Understanding a new class of active optical waveguides
Project: PhD

**Coherent energy transport, thermal effects, and radiative decay in ordered molecular monolayers by nonlinear dynamical models**
Bang, O., PhD Student
Gammel ordning u/skema-SU
01/08/1991 → 01/01/1995
Award relations: Coherent energy transport, thermal effects, and radiative decay in ordered molecular monolayers by nonlinear dynamical models
Project: PhD

**Spatial solitons, vortices, and patterns in non-linear optical media**
Bache, M., PhD Student, Department of Informatics and Mathematical Modeling
Christiansen, P. L., Main Supervisor
Bang, O., Supervisor
Rasmussen, J. J., Supervisor
Tromborg, B., Examiner
Firth, W. J., Examiner
Saffman, M., Supervisor
Pedersen, T. G., Examiner
DTU, Samfinansiering
01/04/1999 → 08/11/2002
Award relations: Spatial solitons, vortices, and patterns in non-linear optical media
Project: PhD

**Nonlinear Photonic Crystals**
Nikolov, N. I., PhD Student, Department of Informatics and Mathematical Modeling
Christiansen, P. L., Main Supervisor
Bang, O., Supervisor
Bjarklev, A. O., Supervisor
Rasmussen, J. J., Supervisor
Rottwitt, K., Examiner
Berge, L., Examiner
Monro, T., Examiner
DTU, Samfinansiering
01/02/2001 → 18/08/2004
Award relations: Nonlinear Photonic Crystals
Project: PhD
Nonlinear dynamics of optical polymers
Johansen, S. K., PhD Student, Department of Informatics and Mathematical Modeling
Bang, O., Main Supervisor
Serensen, M. P., Supervisor
Tønner, L., Supervisor
Bjarklev, A. O., Examiner
Baldi, P., Examiner
Rasmussen, J. J., Examiner
DTU, Samfinansiering
01/06/1999 → 15/11/2002
Award relations: Nonlinear dynamics of optical polymers
Project: PhD

Fibre Laser based broadband THz imaging systems
Eichhorn, F., PhD Student, Department of Photonics Engineering
Jepsen, P. U., Main Supervisor
Pedersen, J. E., Supervisor
Bang, O., Examiner
Keil, U. D. F., Examiner
Koch, M., Examiner
1/3 DTU-stip, 2/3 FUR/andet
01/08/2006 → 03/03/2010
Award relations: Fibre Laser based broadband THz imaging systems
Project: PhD

Biomedical Applications of Photonic Crystal Fibres
Frosz, M. H., PhD Student, Department of Photonics Engineering
Bjarklev, A. O., Main Supervisor
Andersen, P. E., Supervisor
Bang, O., Supervisor
Broeng, J., Supervisor
Rottwitt, K., Examiner
Dudley, J. M., Examiner
Keiding, S. R., Examiner
DTU-lønnet stipendie
01/09/2003 → 05/02/2007
Award relations: Biomedical Applications of Photonic Crystal Fibres
Project: PhD

Liquid Crystal Filled Microstructured Polymer Optival Fibres
Rasmussen, P. D., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Lægsgaard, J., Supervisor
Rottwitt, K., Examiner
Broeng, J., Examiner
Skryabin, D. V., Examiner
DTU-lønnet stipendie
01/08/2005 → 25/09/2008
Award relations: Liquid Crystal Filled Microstructured Polymer Optival Fibres
Project: PhD

Advanced devices for ultra-high capacity optical communication systems
Öhman, F., PhD Student, Department of Photonics Engineering
Mørk, J., Main Supervisor
Bischoff, S., Supervisor
Tromborg, B., Supervisor
Bang, O., Examiner
Shtaif, M., Examiner
Grisen, G., Examiner
DTU-lønnet stipendie
01/09/2001 → 18/03/2005
Award relations: Advanced devices for ultra-high capacity optical communication systems
Project: PhD

**Infrared Supercontinuum Generation in Soft Glass Fibers**
Agger, C., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Lægsgaard, J., Examiner
Vlachos, K. G., Examiner
Wyller, J. A., Examiner
Technical University of Denmark
15/10/2009 → 18/12/2012
Award relations: Infrared Supercontinuum Generation in Soft Glass Fibers
Project: PhD

**THz-BREW: Terahertz Broadband Relaxtion dynamics of Electons in Water**
Wang, T., PhD Student, Department of Photonics Engineering
Jepsen, P. U., Main Supervisor
Cooke, D., Supervisor
Bang, O., Examiner
Zeitler, J. A., Examiner
Planken, P. C. M., Examiner
Eksternt finansieret virksomhed
15/06/2012 → 09/11/2015
Award relations: THz-BREW: Terahertz Broadband Relaxtion dynamics of Electons in Water
Project: PhD

**Long-pulse Super-continuum Light Sources**
Moselund, P. M., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Dudley, J. M., Examiner
Rottwitt, K., Examiner
Thomsen, C. L., Supervisor
Keiding, S. R., Examiner
1/3 DTU-stip, 2/3 FUR/andet
01/04/2006 → 23/09/2009
Award relations: Long-pulse Super-continuum Light Sources
Project: PhD

**Hollow-core fibers for high power laser applications**
Michieletto, M., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Lyngsøe, J. K., Supervisor
Lægsgaard, J., Supervisor
Bache, M., Examiner
Correra, R. A., Examiner
Belardi, W., Examiner
Eksternt EU-finansieret
01/01/2013 → 30/09/2016
Award relations: Hollow-core fibers for high power laser applications
Project: PhD

**Laser frequency standards based on gas-filled hollow-core fibres**
Triches, M., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Hald, J., Supervisor
Lægsgaard, J., Supervisor
Bache, M., Examiner
Artt, J., Examiner
Corwin, K., Examiner
Eksternt EU-finansieret
01/02/2013 → 02/11/2016
Award relations: Laser frequency standards based on gas-filled hollow-core fibres
Project: PhD
2-10μm mid-infrared supercontinuum light sources
Petersen, C. R., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Møller, U. V., Supervisor
Bache, M., Examiner
Buczynski, R., Examiner
Dudley, J. M., Examiner
Offentlig finansiering
01/08/2013 → 02/11/2016
Award relations: 2-10μm mid-infrared supercontinuum light sources
Project: PhD

Topas microstructured polymer optical fibers for biosensing and terahertz waveguides
Nielsen, K., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Jepsen, P. U., Supervisor
Rasmussen, H. K., Supervisor
Laegsgaard, J., Examiner
Koch, M., Examiner
Keiding, S. R., Examiner
Technical University of Denmark
01/02/2008 → 20/04/2011
Award relations: Topas microstructured polymer optical fibers for biosensing and terahertz waveguides
Project: PhD

Modelling of Mid-ir supercontinuum Generation in Chalcogendie Fibers
Kubat, I., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Møller, U. V., Supervisor
Laegsgaard, J., Examiner
Keiding, S. R., Examiner
Taylor, J. R., Examiner
Institut, samfinansiering
01/11/2012 → 27/01/2016
Award relations: Modelling of Mid-ir supercontinuum Generation in Chalcogendie Fibers
Project: PhD

Femtosecond few-cycle mid-infrared laser pulses
Liu, X., PhD Student, Department of Photonics Engineering
Bache, M., Main Supervisor
Zhou, B., Supervisor
Bang, O., Examiner
Minardi, S., Examiner
Jedrkiewicz, O., Examiner
Technical University of Denmark
15/10/2012 → 15/06/2016
Award relations: Femtosecond few-cycle mid-infrared laser pulses
Project: PhD

Modal instabilities in large mode area fiber amplifiers and lasers
Johansen, M. M., PhD Student, Department of Photonics Engineering
Laegsgaard, J., Main Supervisor
Alkeskjold, T. T., Supervisor
Bang, O., Examiner
Dong, L., Examiner
Misas, C. J., Examiner
Technical University of Denmark
01/01/2012 → 14/06/2017
Award relations: Modal instabilities in large mode area fiber amplifiers and lasers
Project: PhD
Photonic crystal THz fibres and functional fibres devices
Bao, H., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Jepsen, P. U., Supervisor
Broeng, J., Examiner
Town, G., Examiner
Koch, M., Examiner
Technical University of Denmark
15/11/2011 → 27/02/2015
Award relations: Photonic crystal THz fibres and functional fibres devices
Project: PhD

Photonic Cristal Fiber based Sensors for Label-Free Detection of Biomolecules
Emiliyanov, G. A., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Jensen, J. B., Supervisor
Pedersen, L. H., Supervisor
Jepsen, P. U., Examiner
Kristensen, M. L., Examiner
Ludvigsen, H., Examiner
1/3 DTU-stip, 2/3 FUR/andet
15/01/2005 → 29/05/2008
Award relations: Photonic Cristal Fiber based Sensors for Label-Free Detection of Biomolecules
Project: PhD

Fiber Bragg grating (FBG) strain sensors in all-solid microstructured polymer optical fibers
Bundalo, I., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Nielsen, K., Supervisor
Lægsgaard, J., Examiner
Kalli, K., Examiner
Webb, D. J., Examiner
Technical University of Denmark
01/03/2013 → 07/12/2016
Award relations: Fiber Bragg grating (FBG) strain sensors in all-solid microstructured polymer optical fibers
Project: PhD

Continuous Wave Supercontinuum Light Sources based on Tapered Photonic Crystal Fibres
Larsen, C., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Hansen, K. P., Supervisor
Mattsson, K. E., Supervisor
Bache, M., Examiner
Ul Alam, S., Examiner
Ludvigsen, H., Examiner
Technical University of Denmark
01/08/2010 → 19/03/2014
Award relations: Continuous Wave Supercontinuum Light Sources based on Tapered Photonic Crystal Fibres
Project: PhD

Deep-blue Supercontinuum Light Sources based on Tapered Photonic Crystal Fibres
Sørensen, S. T., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Lægsgaard, J., Examiner
Travers, J. C., Examiner
Genty, G., Examiner
Thomsen, C. L., Supervisor
Technical University of Denmark
01/05/2010 → 21/06/2013
Award relations: Deep-blue Supercontinuum Light Sources based on Tapered Photonic Crystal Fibres
Project: PhD
Nonlinear properties of soft glass waveguides
Steffensen, H., PhD Student, Department of Photonics Engineering
Rottwitt, K., Main Supervisor
Bang, O., Supervisor
Jepsen, P. U., Supervisor
Lægsgaard, J., Examiner
Dudley, J. M., Examiner
Planken, P. C. M., Examiner
Technical University of Denmark
01/09/2009 → 21/06/2013
Award relations: Nonlinear properties of soft glass waveguides
Project: PhD

Technology for POFBG fabrication and interrogation
Ganziy, D., PhD Student, Department of Photonics Engineering
Bang, O., Main Supervisor
Rose, B., Supervisor
Jepsen, P. U., Examiner
Caucheteur, C., Examiner
Albert, J., Examiner
Eksternt EU-finansieret
01/03/2014 → 14/06/2017
Award relations: Technology for POFBG fabrication and interrogation
Project: PhD

Light and Food
Møller, U. V., Project Manager, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Bang, O., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Petersen, C. R., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Project ID: 70748
External Project ID: 132-212-3
Innovationsfonden
01/05/2013 → 30/04/2017
Collaborators: FOSS A/S, NKT Group, Aarhus University, University of Copenhagen
Award relations: Light and Food
Project: Research

MINERVA: Mid- to NEaR infrared spectroscopy for improVed medical diAgnostics (MINERVA)
EU FP7 project
Bang, O., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Møller, U. V., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Kubat, I., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
FP7 Contract ID: 317803
Project ID: 70500
01/11/2012 → 31/10/2016
Collaborators: BBT-Materials Processing Ltd., NKT Group, University of Nottingham, Gloucestershire Hospitals NHS Trust, Vivid Components Ltd., Gooch and Housego Ltd., LiSA Laser Products GmbH, University of Exeter, IRnova AB, University of Münster, Polytechnic University of Valencia, Xenics nv
Project: Research

Femto-VINIR: Few-cycle femtosecond optical pulses in the visible and near-infrared
Ultra-short femtosecond laser pulses challenge the limits in optics. It is said that they are as hard to measure as they are to generate, and that they are hard to generate is beyond any doubt. This project aims to change that: starting from cheap fiber lasers and only a single active component it is the goal to generate ultra-short high-energy laser pulses in the visible and near-infrared (VINIR) areas.

With ultra-short femtosecond laser pulses it is possible to film, e.g., chemical reactions and molecular vibrations real time: exactly as a person standing in a stroboscope light, it is possible to get a unique insight into how the processes evolve step-by-step. The pulses can also be used for nanosurgery, where non-invasive surgery of living cells is possible, and micromachining of materials with nanometer resolution.
No lasers can directly generate ultra-short femtosecond laser pulses with duration of just a few optical cycles (5-20 fs). Today one has therefore to use very complicated setups and expensive equipment, especially in the VINIR areas, which are so important in medicine and biophysics. The goal of the project is to use optical solitons to compress longer laser pulses – generated by cheap, stable, effective and compact pulsed high-energy fiber lasers – in an ordinary nonlinear crystal. The combination of a cheap laser source and simple equipment will lead to a much more wide-spread and commercial use of ultra-short pulses: femtosecond laser pulses will become common to everybody.

Bache, M., Project Manager, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Bang, O., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Krolkowski, W., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Jepsen, P. U., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Cooke, D., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Wise, F. W., Project Participant

01/04/2009 → 31/03/2012
Award relations: Few-cycle femtosecond optical pulses in the visible and near-infrared
Project: Research

Optical transducer systems: : Optical microphones, accelerometers and pressure transducers based on FBG (Fiber Bragg Grating) technology and optical detectors
Jacobson, T., Contact Person, Ibsen Photonics A/S
Rose, B., Project Participant, Ibsen Photonics A/S
Sørensen, O. B., Project Participant, DPA Microphones A/S
Nielsen, F. K., Project Participant, Brüel and Kjær Sound and Vibration Measurement A/S
Hübner, J., Project Participant, Department of Micro- and Nanotechnology
Bang, O., Project Participant, Department of Photonics Engineering

Project ID: 70446
01/09/2008 → 31/08/2011
Award relations: Optical transducer systems: : Optical microphones, accelerometers and pressure transducers based on FBG (Fiber Bragg Grating) technology and optical detectors
Project: Research

Infrared high-power lasers and broadband light sources based on novel soft glass fiber technology
Thomsen, C. L., Contact Person, Koheras A/S
Broeng, J., Project Participant
Bang, O., Project Participant, Department of Photonics Engineering, Fiber Sensors & Supercontinuum
Keiding, S. R., Project Participant, Aarhus University

Project ID: 70485, DTU DOC 09/00463
01/09/2009 → 31/08/2012
Collaborators: Crystal Fibre A/S, Aarhus University, Koheras A/S
Award relations: Infrared high-power lasers and broadband light sources based on novel soft glass fiber technology
Project: Research

ITRUS: Intelligent Tapers and Seeding for taming the optical Rogue wave and develop stable deep-blue Supercontinuum light sources
Bang, O., Contact Person, Department of Photonics Engineering
Frosz, M. H., Project Participant, Department of Photonics Engineering
Meller, U. V., Project Participant, Department of Photonics Engineering
Dudley, J. M., Project Participant, Département d’Optique P.M. Duffieux, Institut FEMTO-ST, CNRS UMR 6174,
Thomsen, C. L., Project Participant, NKT Group

Project ID: 70606
Forskningsrådene - Andre: DKK5,760,000.00
01/05/2010 → 30/04/2013
Collaborators: Universite de Franche-Comte, NKT Group, Département d’Optique P.M. Duffieux, Institut FEMTO-ST, CNRS UMR 6174,
Award relations: Intelligent Tapers and Seeding for taming the optical Rogue wave and develop stable deep-blue Supercontinuum light sources
Project: Research
**Polymer-fibre based biosensor based on nonlinear optical effects**
Frosz, M. H., Project Manager, Department of Photonics Engineering, Center for Information and Communication Technologies
Bang, O., Project Participant, Department of Photonics Engineering, Center for Information and Communication Technologies
Dudley, J., Project Participant, Universite de Franche-Comte
Pedersen, L., Project Participant, Bioneer A/S
Forskningsrådene - STVF: DKK2,085,000.00
01/03/2008 → 01/03/2011
Collaborators: Universite de Franche-Comte, Bioneer A/S
Award relations: Polymer-fibre based biosensor based on nonlinear optical effects
Project: Research

**Træktårn til mikrostrukturerede optiske polymerfibre**
Bang, O., Contact Person, Department of Photonics Engineering, Fibers & Nonlinear Optics
Project ID: 70273
Forskningsrådene - STVF: DKK1,500,000.00
01/10/2004 → 30/09/2005
Award relations: Træktårn til mikrostrukturerede optiske polymerfibre
Project: Research

**Jorck og Hustrus Fond Pris**
Bang, O., Project Manager, Department of Photonics Engineering, Fibers & Nonlinear Optics
Project ID: 70269
Forsk. Private danske - Fonde: DKK150,000.00
01/07/2004 → 31/10/2010
Award relations: Jorck og Hustrus Fond Pris
Project: Research

**All-Optical Signal Processing in Quadratic Nonlinear Materials**
Danish Technical Scientific Research Council
Projektno. 1280
Bang, O., Project Manager, Department of Informatics and Mathematical Modeling
Corney, J. F., Project Participant, Department of Informatics and Mathematical Modeling
Ukendt: DKK648,000.00
01/09/1999 → 31/03/2002
Award relations: All-Optical Signal Processing in Quadratic Nonlinear Materials
Project: Research

**Activities:**

**Polarization noise study in all-normal dispersion fiber supercontinuum generation**
Period: 29 Jan 2018
Ivan Bravo Gonzalo (Speaker)
Rasmus Dybbro Engelsholm (Other)
Andreas Falkenstrøm Mieritz (Other)
Mads Peter Sørensen (Other)
Ole Bang (Other)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Department of Applied Mathematics and Computer Science
Dynamical Systems
Center for Intelligent Drug Delivery and Sensing Using Microcontainers and Nanomechanics
Ultra-low noise supercontinuum source for ultra-high resolution optical coherence tomography at 1300 nm
Period: 28 Jan 2018
Ivan Bravo Gonzalo (Speaker)
Michael Maria (Other)
Rasmus Dybbro Engelsholm (Other)
Thomas Feuchter (Other)
Lasse Leick (Other)
Peter Morten Moselund (Other)
Adrian Podoleanu (Other)
Ole Bang (Other)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Optical Coherence Tomography, General aspects and use in Laryngology
Period: 8 Dec 2017
Niels Møller Israelsen (Lecturer)
Deepak Jain (Other)
Ole Bang (Other)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Degree of recognition: International

Phase estimation for global defocus correction in optical coherence tomography
Period: 8 Sep 2017
Mikkel Jensen (Speaker)
Niels Møller Israelsen (Guest lecturer)
Ole Bang (Guest lecturer)
Adrian Podoleanu (Guest lecturer)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Degree of recognition: International
Documents:
Phase estimation for global defocus correction in optical coherence tomography

Related event
29/01/2018 → …
Activity: Talks and presentations › Conference presentations

Related event
SPIE Photonics West 2018: SPIE BIOS: Design and Quality for Biomedical Technologies XI
27/01/2018 → …
Activity: Talks and presentations › Conference presentations

Related event
WORLD VOICE CONSORTIUM CONGRESS 2017: VII World Voice Consortium Congress is a multidisciplinary voice meeting held in Copenhagen, DK, targeting voice professionals: artists, clinicians, coaches, teachers and scientists.
08/12/2017 → 10/12/2017
Copenhagen, Denmark
Activity: Talks and presentations › Conference presentations

Related event
Versatile hand-held master-slave optical coherence tomography instrument for non-destructive testing

**Period:** 8 Sep 2017

**Manual Marques (Other)**

**Adrian Bradu (Lecturer)**

**Sylvain Rivet (Other)**

**Ramona Cernat (Other)**

**Niels Møller Israelsen (Other)**

**Ole Bang (Other)**

**Adrian Podoleanu (Other)**

**Department of Photonics Engineering**

**Fiber Sensors & Supercontinuum**

**Degree of recognition:** International

**Related event**

2nd Canterbury Conference on Optical Coherence Tomography: Emphasis on broadband sources

06/09/2017 → 08/09/2017

Canterbury, United Kingdom

Activity: Talks and presentations › Conference presentations

Resolution dependence on phase extraction by the Hilbert transform in phase calibrated and dispersion compensated ultrahigh resolution spectrometer based OCT

**Period:** 7 Sep 2017

**Niels Møller Israelsen (Lecturer)**

**Michael Maria (Other)**

**Thomas Feuchter (Other)**

**Adrian Bradu (Other)**

**Adrian Podoleanu (Other)**

**Ole Bang (Other)**

**Department of Photonics Engineering**

**Fiber Sensors & Supercontinuum**

**Degree of recognition:** International

**Related event**

2nd Canterbury Conference on Optical Coherence Tomography: Emphasis on broadband sources

06/09/2017 → 08/09/2017

Canterbury, United Kingdom

Activity: Talks and presentations › Conference presentations

Noise study of all-normal dispersion supercontinuum sources for potential application in optical coherence tomography

**Period:** 6 Sep 2017 → 9 Sep 2017

**Ivan Bravo Gonzalo (Speaker)**

**Rasmus Dybbro Engelsholm (Other)**

**Ole Bang (Other)**

**Department of Photonics Engineering**

**Fiber Sensors & Supercontinuum**

**Degree of recognition:** International

**Related event**
Master/slave: a better tool for Gabor filtering optical coherence tomography imaging instruments
Period: 29 Jun 2017
Ramona Cernat (Other)
Adrian Bradu (Lecturer)
Niels Möller Israelsen (Other)
Ole Bang (Other)
Sylvain Rivet (Other)
David-Garway Heath (Other)
Ranjan Rajendram (Other)
Adrian Podoleanu (Other)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Degree of recognition: International

Related event
European Conference on Biomedical Optics 2017
25/06/2017 → 29/06/2017
Munich, Germany
Activity: Talks and presentations › Conference presentations

Non-destructive testing of layer-to-layer fusion of a 3D print using ultrahigh resolution optical coherence tomography
Period: 26 Jun 2017
Niels Möller Israelsen (Lecturer)
Michael Maria (Other)
Thomas Feuchter (Other)
Adrian Podoleanu (Other)
Ole Bang (Other)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Degree of recognition: International

Related event
SPIE Optical Metrology, Internationales Congress Center Munich, Germany, 25 - 29 June 2017
25/06/2016 → 29/06/2016
München, Germany
Activity: Talks and presentations › Conference presentations

Hvorledes kan man udvikle en optiksensor i Danmark
Period: 28 Oct 2010
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Related event
Hvorledes kan man udvikle en optiksensor i Danmark
28/10/2010 → 28/10/2010
Risø, Roskilde, Denmark
Activity: Other
Optik i Arbejdstøj
Period: 28 Oct 2010
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Description
Place: Risø, Roskilde

Related external organisation
Unknown Organization
Activity: Talks and presentations › Conference presentations

2nd Workshop on Specialty Optical Fibers and Their Applications
Period: 13 Oct 2010
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Description
Place: Oaxaca, Mexico
Degree of recognition: International

Related event
2nd Workshop on Specialty Optical Fibers and Their Applications
13/10/2010 → 15/10/2010
Oaxaca, Mexico
Activity: Talks and presentations › Conference presentations

2nd Workshop on Specialty Optical Fibers and Their Applications
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum
Degree of recognition: International

Related event
2nd Workshop on Specialty Optical Fibers and Their Applications
13/10/2010 → 15/10/2010
Oaxaca, Mexico
Activity: Talks and presentations › Conference presentations

OSA Optics & Photonics Congress: Nonlinear Photonics
Period: 21 Jun 2010 → 24 Jun 2010
Ole Bang (Organizer)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Related event
OSA Optics & Photonics Congress: Nonlinear Photonics
21/06/2010 → 24/06/2010
Karlsruhe, Germany
COST Action 299, Optical Fibers for New Challenges Facing the Information Society
Period: 15 Mar 2010 → 17 Mar 2010
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Related event

ICT COST Action 299
15/03/2010 → 17/03/2010
Activity: Talks and presentations › Conference presentations

Optical Fibers for New Challenges Facing the Information Society
Period: 5 Mar 2010 → 17 Mar 2010
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Description
Place: Cluj-Napoca, Romania

Related external organisation
Unknown Organization
Activity: Talks and presentations › Conference presentations

Biosensing with microstructured polymer optical fibers
Period: 2 Apr 2009 → 3 Apr 2009
Ole Bang (Speaker)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Related event

COST 299 Meeting
02/04/2009 → 03/04/2009
Lanarca, Cyprus
Activity: Talks and presentations › Conference presentations

Enhanced soliton self-frequency shift by intelligent tapering
Period: 10 Feb 2009 → 13 Feb 2009
Ole Bang (Participant)
Department of Photonics Engineering
Fiber Sensors & Supercontinuum

Description
A novel approach to enhance the redshift of optical solitons is proposed in which the profile of a tapered PCF is designed such that the soliton experiences an optimal level of dispersion at each point along the tapered region.

Documents:
2009_CUDOSWorkshop_AlexJudge.pdf

Related event

Enhanced soliton self-frequency shift by intelligent tapering: Presented at CUDOS Workshop 2009
10/02/2009 → 13/02/2009
Australia
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.