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Research outputs:

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.

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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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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.

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
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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.

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Ultrafast Mid-IR Nonlinear Optics in Gas-filled Hollow-core Photonic Crystal Fibers

Invention of hollow-core fiber has been proven an ideal medium to study light-gas interaction. Tight confinement of light inside hollowcore fiber allows unremitting and tailored interaction between light and gas over long distances. In this work, we used a special kind of hollowcore fiber − hollow-core anti-resonant (HC-AR) fiber to study the various nonlinear effects filled with Raman free noble gas. One of the main striking features of HC-AR fiber is that ∼99.99% light can be guided inside the central hollow-core region, which significantly enhances damage threshold level. HC-AR fiber can sustain 10s of μJ pulse energies, tolerate multitude-watts of average powers, provide a clean spatial mode profile and give flexible beam handling and delivery. It also offers relatively low-loss, broadband guidance, and low anomalous group-velocity dispersion (GVD). Both the dispersion and nonlinearity can be tuned by simply changing the pressure of the gas while at the same time providing extremely wide transparency ranges. In this thesis, we propose several low-loss broadband guidance HC-AR fibers and investigate soliton-plasma dynamics using HC-AR fiber filled with noble gas in the mid-IR. The combined action of self-focusing self-phase modulation (SPM) and anomalous GVD allows strong soliton self-compression down to sub-single cycle duration inside HC-AR fiber. The peak intensity at the maximum temporal compression can reach over 1014 W/cm2 which is sufficient to ionize the gas and form a plasma. We investigate numerically soliton-plasma interaction in a noblegas-filled silica HC-AR fiber pumped in anomalous dispersion regime 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 also demonstrate coherence of the supercontinuum and find that the spectral coherence drops as the secondary compression stage is initiated.

A new photonic crystal fiber design on the high negative ultra-flattened dispersion for both X and Y polarization modes

Analysis of numerical design and properties of a new silica based photonic crystal fiber (PCF) are proposed in this manuscript. The design performs ultra-flattened negative chromatic dispersion (UNCD) in the optical windows 2nd and 3rd involving O to U bands in the infrared (IF) portion. The guiding properties are observed by employing a circular perfectly matched layer (PML) boundary through the finite-element method (FEM). The proposed design is compatible for the application of residual dispersion compensation (RDC) as it grants negative dispersion (ND) and very low scale dispersion variation (ΔD) of −(253.5±2.5) and −(292±2) ps/nm/km respectively for both X and Y polarization modes within the wavelength boundary of 1.25 to 1.7 μm (450-nm band). Moreover, ±10% alteration in the optimum parameters (OP) is also studied to assess the responsiveness of the dispersion characteristics.
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.

A Novel Low-Loss Diamond-Core Porous Fiber for Polarization Maintaining Terahertz Transmission
We report on the numerical design optimization of a new kind of relatively simple-core porous photonic crystal fiber (PCF) for terahertz (THz) waveguiding. A novel twist is introduced in the regular hexagonal PCF by including a diamond-shaped porous-core inside the hexagonal cladding. The numerical results obtained from an efficient finite-element method, which confirms a high birefringence of the order 10^-2 and low effective material loss of 0.07 cm^-1 at 0.7-THz operating frequency. The proposed PCF is anticipated to be useful in polarization sensitive THz appliances.
We present a new kind of dual-hole unit-based porous-core hexagonal photonic crystal fiber (H-PCF) with low loss and high birefringence in terahertz regime. The proposed fiber offers simultaneously high birefringence and low effective material loss (EML) in the frequency range of 0.5-0.85 THz with single-mode operation. An air-hole pair is used inside the core instead of elliptical shaped air holes to introduce asymmetry for attaining high birefringence; where the birefringence can be enhanced by rotating the dual-hole unit axis of orientation. The proposed H-PCF provides a birefringence of similar to 0.033 and an EML of 0.43 dB/cm at an operating frequency of 0.85 THz.

A Novel Low Loss, Highly Birefringent Photonic Crystal Fiber in THz Regime

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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.

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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.

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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.

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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 antisreresonant 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 silica-based fiber design aimed at 1.06 μm, we show that the loss extinction
The 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.
Novel porous fiber based on dual-asymmetry for low-loss polarization maintaining THz wave guidance

In this Letter, we suggest a novel kind of porous-core photonic crystal fiber (PCF) (to the best of our knowledge) for efficient transportation of polarization maintaining (PM) terahertz (THz) waves. We introduce an asymmetry in both the porous-core and the porous-cladding of the structure to achieve an ultra-high birefringence. Besides, only circular air holes have been used to represent the structure, which makes the fiber remarkably simple. The transmission characteristics have been numerically examined based on an efficient finite element method (FEM). The numerical results confirm a high birefringence of ∼0.045 and a very low effective absorption loss of 0.08 cm⁻¹ for optimal design parameters at 1 THz. We have also thoroughly investigated some important modal properties such as bending loss, power fraction, dispersion, and fabrication possibilities to completely analyze the structure's usability in a multitude of THz appliances. Moreover, physical insights of the proposed fiber have also been discussed. © 2016 Optical Society of America

General information

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Extremely High-Birefringent Asymmetric Slotted-Core Photonic Crystal Fiber in THz Regime

We present a thorough numerical analysis of a highly birefringent slotted porous-core circular photonic crystal fiber (PCF) for terahertz (THz) wave guidance. The slot shaped air-holes break the symmetry of the porous-core which offers a very high birefringence whereas the compact geometry of the circular cladding confines most of the power in the fiber-core. The fiber structure reported in this letter exhibits simultaneously ultrahigh modal birefringence of $7.5 \times 10^{-2}$ and a very low effective absorption loss of 0.07 cm$^{-1}$ for $y$-polarization mode at an operating frequency of 1 THz. It is highly anticipated that the slotted-core waveguide would be of very much convenience in many polarization maintaining THz appliances.

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Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.975 SNIP 1.864
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.224 SNIP 1.678
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.012 SNIP 1.869
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.882 SNIP 2.411
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 3.092 SNIP 2.689
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 3.17 SNIP 2.436
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.97 SNIP 2.1
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 3.43 SNIP 1.656
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.636 SNIP 1.199
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 2.564 SNIP 1.279

Original language: English
Keywords: Birefringence, Polarization, Photonic crystal fiber, Porous-core, Terahertz
DOIs: 10.1109/LPT.2015.2457673
Extremely low-loss single-mode photonic crystal fiber in the terahertz regime
This paper presents an updated design and numerical characterization of a rotated porous-core hexagonal photonic crystal fiber (PCF) for single-mode terahertz (THz) wave guidance. The simulation results are found using an efficient finite element method (FEM) which show a better and ultra-low effective absorption loss of 0.045 cm⁻¹ at 1 THz and a more flattened dispersion of 0.74±0.07 ps/THz/cm in a wider bandwidth (0.54-1.36 THz) than the previously reported results. Besides, the single-mode region has been extended up to 1.74 THz (previously up to 1.3 THz) which is advantageous for wideband THz applications.

Extremely Low Loss THz Guidance Using Kagome Lattice Porous Core Photonic Crystal Fiber
A novel porous core Kagome lattice photonic crystal fiber is proposed for extremely low loss THz waves guiding. It has been reported that 82.5% of bulk effective material loss of Topas can be reduced.

Highly birefringent photonic crystal fiber with ultra-flattened negative dispersion over S + C + L + U bands
We present a new cladding design for photonic crystal fiber (PCF) on a decagonal structure to simultaneously achieve ultra-flattened large negative dispersion and ultrahigh birefrigence. Numerical results confirm that the proposed PCF exhibits ultra-flattened large negative dispersion over the S + C + L + U wavelength bands and average dispersion of...
about −558.96 ps/nm/km with absolute dispersion variation of 9.7 ps/nm/km from 1460 to 1675 nm (215 nm bandwidth). Moreover, ultrahigh birefringence of 0.0299 is also achieved at a 1500 nm wavelength. © 2015 Optical Society of America
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.329 SNIP 1.67
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.219 SNIP 1.604
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.151 SNIP 1.706
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.186 SNIP 1.709
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.054 SNIP 1.852
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.205 SNIP 1.656
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.025 SNIP 1.906
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 1.398 SNIP 1.741
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 1.667 SNIP 1.056
Scopus rating (1999): SJR 1.667 SNIP 1.001
Original language: English
DOIs:
10.1364/AO.54.002786
Source: PublicationPreSubmission
Source-ID: 108731772
Research output: Research - peer-review › Journal article – Annual report year: 2015

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

General information
State: Published
Organisations: Department of Photonics Engineering, Ultrafast Nonlinear Optics group, Fiber Sensors and Supercontinuum Generation
Contributors: Habib, S., Bang, O., Bache, M.
Number of pages: 1
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Title of host publication: 2015 European Conference on Lasers and Electro-Optics
Publisher: Optical Society of America
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Low Loss Double-clad Hollow Core Anti-Resonant Fibers in the Mid-IR

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State: Published
Organisations: Department of Photonics Engineering, Ultrafast Nonlinear Optics group, Fiber Sensors and Supercontinuum Generation
Contributors: Habib, S., Bang, O., Bache, M.
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Title of host publication: European Quantum Electronics Conference 2015
Publisher: Optical Society of America
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.
A kind of porous core photonic crystal fiber (PCF) for terahertz (THz) wave propagation is proposed in this paper. By intentionally rotating the porous core lattice structure, a dispersion of $1.06 \pm 0.12 \text{ ps/THz/cm}$ is observed in a frequency range of 0.5–1.08 THz. Additionally, very low material absorption loss ($0.066 \text{ cm}^{-1}$) and low confinement loss ($4.73 \times 10^4 \text{ cm}^{-1}$) at the operating frequency $f = 1 \text{ THz}$ are obtained. Besides, single-mode properties, power fraction in air core, and frequency response of the proposed PCF are also analyzed. The reported design can be fabricated easily using stack and draw method and be used in potential applications in the THz region.
Low Loss Single-Mode Porous-Core Kagome Photonic Crystal Fiber for THz Wave Guidance

A novel porous-core kagome lattice photonic crystal fiber (PCF) is designed and analyzed in this paper for terahertz (THz) wave guidance. Using finite element method (FEM), properties of the proposed kagome lattice PCF are simulated in details including the effective material loss (EML), confinement loss, single-mode propagation, dispersion profile, and fraction of power in the porous-core with different core porosity. Simulation results indicate that 82.5% of bulk material loss of Topas can be reduced by using core porosity of 70%. The calculated EML is as low as 0.035 cm$^{-1}$ at operating frequency 1 THz. In addition, the proposed PCF also exhibits relatively low confinement loss and a much more flattened dispersion profile with single mode propagation.
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.23 SJR 1.737 SNIP 2.411
Web of Science (2014): Impact factor 2.965
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 4.03 SJR 1.622 SNIP 2.439
Web of Science (2013): Impact factor 2.862
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 3.21 SJR 1.888 SNIP 2.491
Web of Science (2012): Impact factor 2.555
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 3.2 SJR 1.733 SNIP 2.957
Web of Science (2011): Impact factor 2.784
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.737 SNIP 2.401
Web of Science (2010): Impact factor 2.259
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.096 SNIP 2.749
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.198 SNIP 2.443
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.313 SNIP 2.212
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.03 SNIP 2.562
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 2.846 SNIP 2.952
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.332 SNIP 2.688
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.703 SNIP 2.876
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 2.751 SNIP 2.588
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.999 SNIP 2.112
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 2.379 SNIP 1.821
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 2.342 SNIP 1.659

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Projects:

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, Department of Photonics Engineering
Bang, O., Supervisor, Department of Photonics Engineering
Lægsgaard, J., Examiner, Department of Photonics Engineering
Biancalana, F., Examiner
Joly, N., Examiner
Institut stipendie (DTU)
15/04/2014 → 14/06/2017
Award relations: Ultrafast mid-IR nonlinear optics in gas-filled hollow-core photonic crystal fibers
Project: PhD

 Ultrafast mid-IR nonlinear optics in gas-filled hollow-core photonic crystal fibers
Habib, S., Project Participant, Department of Photonics Engineering, Ultrafast Nonlinear Optics group
15/04/2014 → 14/04/2017
Project: Research

Activities:

CREOL, The College of Optics and Photonics
Period: 1 May 2016 → 31 Aug 2016
Selim Habib (Visiting researcher)
Department of Photonics Engineering
Ultrafast Infrared and Terahertz Science

Description
J Scholar visiting research scholar
Activity: Visiting an external institution › Visiting another research institution