Optics in 2004

Guest Editors: Bob D. Guenther
David Hardwick, Changsheng Li and R. John Koshel

The December *Optics & Photonics News* (OPN) is a special issue that highlights the most exciting research to emerge in the preceding 12 months in the fast-paced world of optics.

"Optics in 2004" offers readers a unique opportunity to access, in a single source, descriptions of cutting-edge optics research reported in the peer-reviewed press. The areas covered in this year's special issue range from semiconductor optics to nanophotonics and from optical engineering to ultrafast technology. This year's issue comprises 31 summaries that represent the work of 155 authors.

A record number of research groups submitted summaries to "Optics in 2004": there were 104 submissions this year, representing the work of 414 authors. This was a significant increase over the total of 61 submissions to "Optics in 2003."

This year as in previous ones, submissions were judged on the basis of the following requirements:

- the accomplishments described had to have been published in a refereed journal in the year prior to publication in OPN;
- the work had to be illustrated in a clear, concise manner, readily accessible to the at-large optics community.

In addition, the authors were asked to describe the topical area as a whole and to detail the importance of their work in that context.

Although OPN makes every effort to ensure that achievements in all optics subfields are recognized, there are no requirements in the selection process for inclusion of specific topical areas. When a large number of submissions is received for a specific area, it is taken as evidence that the topic has been fertile ground for activity and research. OPN strives to ensure that engineering, science and technology are all represented. The number of papers accepted overall is limited by space.

OPN and OSA would like to thank the hundreds of researchers from around the world who submitted summaries of their peer-reviewed articles to "Optics in 2004."

OSA and the OPN staff would like to take this opportunity to express their heartfelt thanks to the panel of OPN Editorial Advisory Committee members who vetted submissions to "Optics in 2004": Bob D. Guenther (Optics in 2004 Panel Chair), Physics Department, Duke University; David Hardwick, Confluent Photonics Corporation; Changsheng Li, Hong Kong Polytechnic University; R. John Koshel, General Dynamics C4 Systems.

(*Background image*) Each fiber in the spectrometric fabric is a photodetector sensitive to external illumination at a particular wavelength range. Credit: Greg Hren Photography-RLE/Fink Lab, Massachusetts Institute of Technology. [From Nature **431**, 826-9, Oct. 2004.]

Fiber Optics

Low-Index-Contrast Photonic Bandgap Fiber For Transmission of Short Pulsed Light

Jesper Riishede, Jesper Lægsgaard,
Jes Broeng and Anders Bjarklev

In recent years, a new class of optical fiber that operates by the photonic bandgap (PBG) effect has created great excitement in the optical community. One of the most remarkable properties of PBG fibers is their unique ability to confine light to a low-index region, a characteristic that has been used to demonstrate fibers that guide light in a hollow core.[1] Another novel characteristic of PBG fibers is that they have positive waveguide dispersion at long wavelengths at which conventional index-guiding fibers typically have negative waveguide dispersion.[2] This fundamental difference affords a new range of applications based on PBG fibers. Here we suggest that PBG fibers with low-index contrast can be used to obtain fibers with zero dispersion and a large mode area below 800 nm.[3]

The PBG fiber we consider here consists of a triangular lattice of Ge-doped, high-index rods embedded in pure silica. We define a low-index core region by omitting a single rod in the center of the fiber. For our analysis, we used a structure with an index contrast of 1.45/1.47 and a normalized diameter of $d/\Lambda = 0.4$, where Λ is the lattice spacing. Despite the low-index contrast, the fiber was found to support a single, well-confined mode, as shown in the Fig. 1 inset. We used a finite-difference frequency domain method[4] to simulate the optical properties of the PBG fiber.

In our analysis of dispersion properties, we investigated how the zero-dispersion (ZD) wavelength (λ_{ZD}) is affected by the choice of lattice spacing. Since the total dispersion of the fiber can simply be found as a sum of the waveguide and material dispersion,[3] we can use the positive waveguide dispersion of the PBG fiber to compensate for the negative material dispersion in silica below 1.27 μm. Therefore, we are able to shift the zero-dispersion wavelength toward shorter wavelengths.

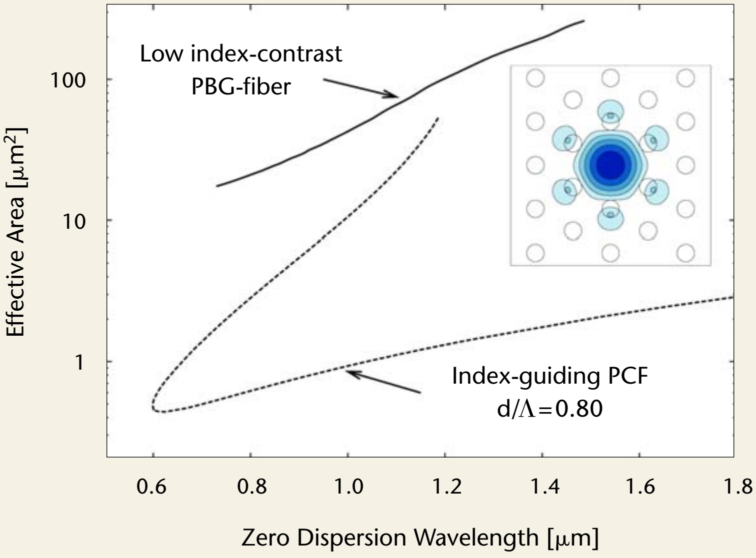

Figure 1. Effective mode area versus the zero-dispersion wavelength. (*Inset*) The fundamental mode of the PBG fiber.

For each value of λ_{ZD}, we also calculated the effective mode area, A_{eff} [Ref. 5]. The result of this calculation is represented by the bold curve in Fig. 1. As seen in Fig. 1, we can shift λ_{ZD} as far down as 730 nm while we maintain a mode area of 17 μm [Ref. 2]. For these calculations, we used only the PBG fiber in the spectral interval, where the fundamental mode is strongly confined to the core region.[3] For index-guiding fiber, the zero-dispersion wavelength can also be shifted well below 800 nm, but this occurs at the expense of a small mode area. The dashed curve in Fig. 1 shows an equivalent analysis for an index-guiding photonic crystal fiber with a hole diameter of $D/\Lambda = 0.8$. By comparison we determined that the mode area of the PBG fiber below 800 nm is approximately one order of magnitude larger than that which can be achieved in an index-guiding fiber with similar dispersion properties.

An optical fiber with a large mode area and zero dispersion is, therefore, a unique combination of optical properties not attainable in index-guiding fibers. A potential application of this low-index-contrast PBG fiber could be distortionless transmission of short pulsed light below 800 nm, e.g., for Ti:sapphire lasers. Because of the large mode area, the fiber is less sensitive to nonlinear effects and therefore allows transmission of considerably larger intensities.

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Generation of a Broadband Continuum With High Spectral Coherence in Tapered Single-Mode Optical Fibers

Fei Lu and Wayne H. Knox

Although supercontinuum (SC) light generated inside photonic crystal fibers (PCF)[1] and tapered fibers has been used as a source for applications such as optical coherence tomography (OCT) and optical frequency metrology, experiments and numerical simulations have shown that the SC generation process is very sensitive to both the quantum noise[2, 3] and technical noise[4] associated with the input pulses. Since ultrabroadband sources with little excess noise are desirable for many applications, it is important to investigate the factors that underlie the noise properties of SC light and to identify the conditions under which low noise and broadband SC light can be generated.

We found that by measuring the mutual spectral coherence of SC light as shown in Fig. 1(a), we could optimize noise performance. Pulses of 100 fs generated by a Ti:sapphire laser are coupled into the tapered fiber to generate continuum trains which are analyzed with a Michelson interferometer with uneven arms of one pulse delay difference. The adjacent continuum pulses overlap and form spectral interferograms, the fringe contrast of which [Fig.1(b)] directly reflects the realistic shot-to-shot stability of the SC generation process: the lower the contrast, the less coherent the SC (fringes washed out by random noises). We observed a dramatic degradation and significant recovery of SC mutual coherence which was strongly dependent on input wavelength [Fig. 1(b)].

By means of CO_2 laser heating, we fabricated a 6-cm long tapered fiber with an outside diameter of 2.7 µm. The zero dispersion wavelength of our tapered fiber was located at ~820 nm. The input wavelength λ_{input} starts from 780 nm (the normal dispersion region), where random noise-seeded modulation instability (MI) is forbidden and SC generation is dominated by deterministic self-phase modulation, which leads to a high coherence SC with a small bandwidth. The coherence decreases when λ_{input} is tuned to the zero-dispersion wavelength. The coherence is degraded more severely when λ_{input} is tuned slightly to the anomalous dispersion side at 860 nm; in this case, however, a broad bandwidth is generated. Surprisingly, the coherence does not degrade further when λ_{input} is tuned deeper into the anomalous dispersion region at 920 nm. Not only is the broad SC bandwidth maintained, a relatively high coherence (mean visibility ~0.7) is also observed over the whole spectrum [blue curve in Fig. 1(b)].

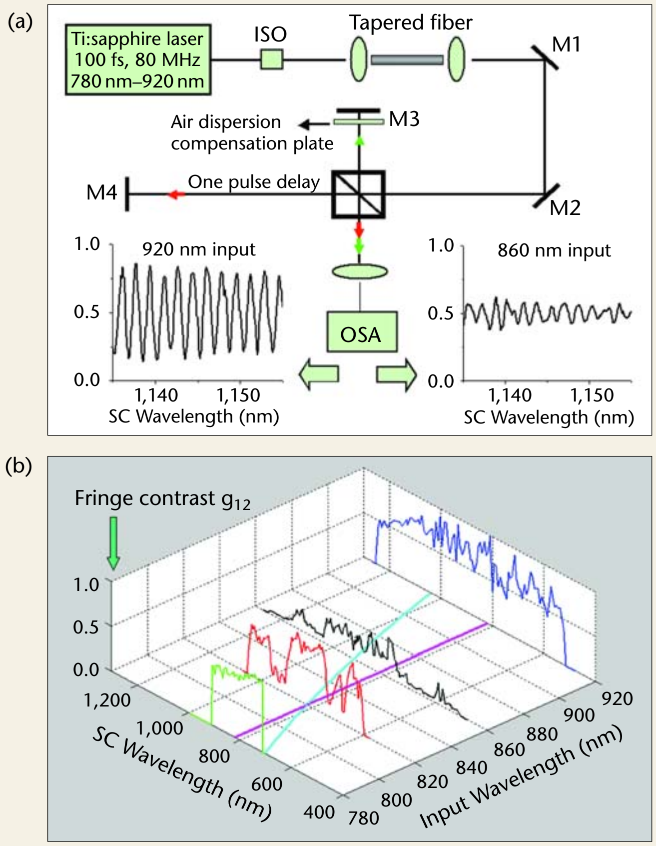

Figure 1. (a) Setup for spectral coherence measurement of SC; (b) SC fringe contrast (over 20 dB bandwidth) vs. input wavelength. All SC (*shown*) were generated with 112 mW power.

This phenomenon can be heuristically understood as follows. The modulation instability (MI) bandwidth decreases considerably with increased anomalous dispersion, and 920 nm input—compared with 860 nm input—corresponds to a lower soliton order. For this reason, the lower order soliton fission process[5] becomes more robust to noise perturbations,[6] resulting in a significant improvement in SC coherence without sacrificing broad bandwidth. We have also verified that light generated in regions of high spectral coherence exhibits a lower level of RF noise**.**

In summary, we have observed strong dependence of SC mutual spectral coherence on λ_{input}. By locating λ_{input} in the relatively deep anomalous dispersion region, a broadband continuum from 500 nm to 1,300 nm with high spectral coherence can be obtained.

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Air-Guided Air-Silica Bragg Fibers With Nanostructured Cladding

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A new class of hollow-core Bragg fibers[1] composed of concentric cylindrical silica rings separated by nanoscale support bridges is presented.[2, 3] These fibers are believed to be especially useful for high-power delivery of light within a broad wavelength range or at multiple wavelength bands. We experimentally observe theoretically predicted hollow-core confinement over an octave frequency range. The bandwidth of bandgap guiding in this type of Bragg fiber far exceeds that of other hollow-core fibers reported in the literature. With the record-low number of three rings of silica cladding layers, these Bragg fibers achieve a propagation loss of the order of 1 dB/m. The concept of hollow-core Bragg fibers, in which the fiber cladding is composed of cylindrical dielectric layers with alternating refractive indices, was first proposed in 1978.[1] Cregan et al. demonstrated another class of hollow-core fibers, namely, photonic crystal fibers, in which the cladding structure is formed by creating a two-dimensional array of airholes in a high-index material, typically silica.[4]

In general, the transmission coefficient through a planar Bragg reflector, which translates to a leakage coefficient of the Bragg fiber, depends exponentially on the number of layers.[5, 6] We consider a specific Bragg fiber with a hollow-core radius of 10 µm. The fiber cladding is formed by three layers with a refractive index of 1.45 and average thickness of 370 nm, separated by 4.10-µm-thick air layers. In practice, support bridges must be introduced to separate the adjacent silica rings. Assuming mass conservation throughout the fiber pulling process, we estimate the support bridge thickness to be in the area of 45 nm, which is in reasonable agreement with the results obtained with scanning electron microscopes.

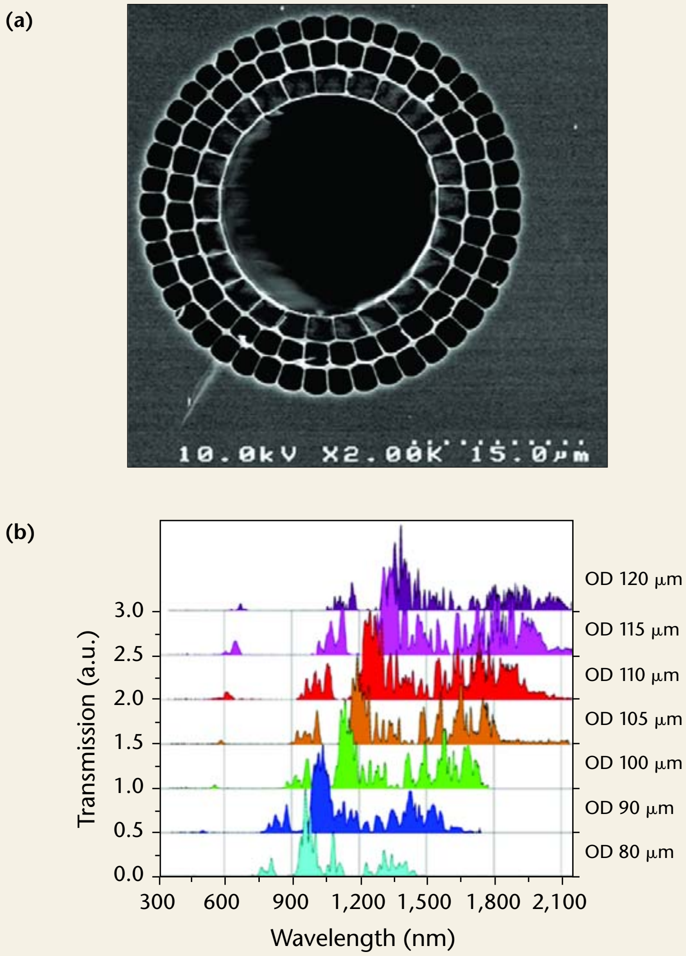

Figure 1. Scanning electron micrograph of a Bragg fiber with an outer diameter of 90 µm and transmission spectra of similar fibers with different scalings.

Because the support bridges are much smaller than the wavelength of interest, we can, to a good approximation, neglect the presence of these support bridges and regard the region between the high-index silica layers as composed entirely of air. An interesting feature that will further inspire the development of this type of fiber is that, with only four silica layers, theoretical considerations predict that the fiber leakage loss can be reduced to less than 0.1dB/km. Also, the Bragg fiber supports low-loss modes (less than 1dB/m) in the 0.82–2.86-µm wavelength range, which is almost two octaves in frequency range, and also in a wavelength interval in which material losses are so high that one could indeed benefit from an air core of the fiber.

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