Transitioning from micro to nano-photonics with Photonic Crystal Fibers

Maksim Skorobogatiy

Department of Engineering Physics, Ecole Polytechnique de Montréal (University of Montréal), Canada
web: http://www.photonics.phys.polymtl.ca/

In the past 10 years Photonic Crystal Fibers (PCFs) made a rapid transition from the novelty research item into the commercially available product. Unlike standard optical fibers, PCFs feature very complex transverse geometries that contain a large number of micro- and nano-sized voids or layers. It is the complexity of the fiber crossection that allows to design the fiber very unusual optical properties. Proposed applications of the PCFs are numerous and among others include: photonic bandgap fibers for transmission of high power mid-IR light [1], bio-compatible and bio-degradable microstructured fibers for medical applications [2,3], high numerical aperture microstructured fibers for efficient light collection [4], high bit rate data communication [5], photonic bandgap fibers for esthetic illumination and photonic textiles [6,7,8], subwavelength microstructured fibers for low-loss transmission of the mid-IR and THz light [9], as well as metallized and photonic bandgap fibers for resonant sensing applications [10,11].

I will first argue that the PCF technology is positioned inherently at the crossover between the micro- and nano-photonics. This is due to the fact that guidance in most PCF types relies on the coherent light scattering by the strongly subwavelength ($\lambda/5$-$\lambda/10$) features present in the fiber crossection. The "nano" size of such features is a direct consequence of the high refractive index contract of the material combinations utilized during fiber fabrication. To support my argument, I will consider the case of solid-core photonic bandgap Bragg fibers featuring in their crossection a periodic sequence of high and low refractive-index nano-layers. Application of such fibers in high bit rate data communication [5], and newly-discovered photonic bandgap textiles [6,7,8] will be detailed.

Secondly, I will show how introduction of the nano-sized air holes into the fiber crossection can greatly enhance modal field in the air region. This effect can be used to design highly porous subwavelength fibers [9] that guide light mostly in the air region. Such fibers enable low-loss transmission in the spectral regions where materials with low absorption losses are not available (THz spectral region, for example). As individual features in the crossection of such fibers are as small as $\lambda/10$-$\lambda/100$, guidance in the porous subwavelength fibers does not rely on the coherent light scattering, but it is rather a function of the "averaged" response of the porous meta-material. Application of such fibers for low-loss THz transmission and all-fiber THz components [9] will be detailed.

Thirdly, functionalization of the PCF microstructure with nano-materials such as quantum dots, carbon nano-tubes or metallic nano-layers truly merges the traditional nano-technology with the field of photonic crystal fibers. In this final part of my talk I will review fusion of PCFs with plasmonics in order to design compact, while ultrasensitive optical sensors of changes in the analyte refractive index. Particularly, I will detail metallized PCFs where fundamental core guided mode is phase matched with a plasmon wave propagating at the fiber/analyte interface. Ultra-high sensitivity and operation almost anywhere in the E&M spectrum from the visible to THz is enabled by this technology.

[1] S.G. Johnson, M. Ibanescu, M. Skorobogatiy, O. Weiseberg, T.D. Engeness, M. Soljacic, S.A. Jacobs, J.D. Joannopoulos, and Y. Fink, "Low-Loss Asymptotically Single-Mode Propagation in Large Core OmniGuide Fibers," Optics Express, vol. 9, p. 748 (2001).
[2] A. Dupuis, N. Guo, Y. Gao, N. Godbout, S. Lacroix, C. Dubois, and M. Skorobogatiy "The prospective for the biodegradable microstructured optical fibers," Optics Letters, vol. 32, pp. 109-111 (2007).

[3] A. Dupuis, N. Guo, Y. Gao, O. Skorobogata, B. Gauvreau, C. Dubois, M. Skorobogatiy, "Fabrication strategies and potential applications of the "green" microstructured optical fibers" Journal of Biomedical Optics, vol. 13, 054003 (2008).
[4] B. Gauvreau, F. Desevedavy, N. Guo, D. Khadri, A. Hassani and M. Skorobogatiy, "High numerical aperture polymer microstructured fiber with three super-wavelength bridges," Journal of Optics A: Pure and Applied Optics, vol. 11, 085102 (2009).
[5] M. Skorobogatiy and N. Guo, "Bandwidth enhancement by differential mode attenuation in multimode photonic crystal Bragg fibers," Optics Letters, vol. 32, p. 900 (2007).
[6] B. Gauvreau, N. Guo, K. Schicker, K. Stoeffler, F. Boismenu, A. Ajji, R. Wingfield, C. Dubois, M. Skorobogatiy, "Color-changing and color-tunable photonic bandgap fiber textiles," Opt. Express, Vol. 16, pp. 15677-15693 (2008).
[7] "News and Views - Colour-tunable textiles," Nature Photonics, vol. 2, p. 650 (2008).
[8] "Back Scatter - Photonic Fabric," Physics Today, October, p. 180 (2008).
[9] A. Dupuis, J.-F. Allard, D. Morris, K. Stoeffler, C. Dubois, and M. Skorobogatiy, "Fabrication and THz loss measurements of porous subwavelength fibers using a directional coupler method," Opt. Express, vol. 17, pp. 8012–8028 (2009).
[10] B. Gauvreau, A. Hassani, M. Fassi Fehri, A. Kabashin, and M. A. Skorobogatiy, "Photonic bandgap fiber-based Surface Plasmon Resonance sensors," Opt. Express, vol. 15, 11413-11426 (2007).
[11] "Research Highlights - Plasmonics: sensors tune in," Nature Photonics, October, (2006).