Citation for published version:
Stone, JM, Knight, JC & Clowes, J 2008, Visibly "white" light generation in uniform photonic crystal fiber using a microchip laser. in *2008 Conference on Lasers and Electro-Optics & Quantum Electronics and Laser Science Conference.*, CMT5, OSA Publishing, Washington DC, Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science Conference 2008, San Jose, California, USA United States, 4/05/08.

Publication date:
2008

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

Link to publication

Visibly “White” Light Generation in Uniform Photonic Crystal Fiber Using a Microchip Laser

J. M. Stone[1], J. C. Knight[1] and J. Clowes[2]
[1]*Centre for Photonics and Photonic Materials, University of Bath, Bath, BA2 7AY, UK*
[2]*Fianium ltd, 20 Compass Point, Southampton, SO31 4RA, UK*
j.m.stone@bath.ac.uk

Abstract: We describe how to extend the bandwidth of the supercontinuum generated in uniform fibers pumped at 1064nm. The spectra extend to ~400nm, some 50nm deeper into the blue than previously with the same pump source.

OCIS codes: (190.0190) Nonlinear optics, (060.5295) Photonic crystal fibers

1. Intoduction

Broadband supercontinuum generation [1, 2, 3] is one of the most successful applications of photonic crystal fibers (PCF) [4], with compact supercontinuum sources becoming an indispensible piece of equipment in many optical laboratories. More potential applications of supercontinua would be enabled if the spectra were extended further into the infrared or especially into the ultraviolet.

The generation of new optical frequencies in supercontinua is due to several simultaneous or sequential non-linear processes. A principal mechanism for generating the short wavelength “blue” edge was recently identified by Gorbach et al. [5, 6]. A self frequency-shifting soliton propagating in the anomalous-dispersion (infrared) regime effectively traps blue radiation propagating with the same group index on the other arm of the group index curve (which has the shape of a “U” with respect to wavelength) in a potential well and scatters the blue radiation to shorter wavelengths in a cascaded four-wave mixing process. The long- and short-wavelength edges of the supercontinuum are thus intimately related, with the shortest wavelength generated being limited by index matching to the longest co-propagating wavelengths. In order to generate continua with deeper blue frequencies one can modify the group index profile of the fiber in the infrared to rise more steeply with wavelength, and thus to group-index-match to a deeper blue.

2. Experiment

The response of a strand of silica surrounded by air is better in this regard than fibre designs with smaller air holes (Fig. 1a) whereas conventional supercontinuum sources utilize ‘endlessly single mode’ (ESM) fibers with small air holes as shown in Fig 1c. We can therefore expect to generate shorter wavelengths using a high-Δ fiber (with a similar zero-dispersion wavelength and core size) as shown in Fig 1d.

A high-Δ fiber ($d/\Lambda=0.77$, $\Lambda=3.7\mu m$ and a core size of ~4.7μm) was fabricated and compared with a conventional ESM ($d/\Lambda=0.43$, $\Lambda=3.0\mu m$ and again a core size of ~4.7μm) fiber for supercontinuum generation [2]. Ten meter sections of both fibers were pumped with a sub-ns microchip laser at 1064 nm, with the input power varied by means of an ND wheel placed before the fiber input. The extension into the blue and ultraviolet from the high-Δ fiber is visually quite striking giving the output a bright and visually white appearance. The dispersed output spectra of the two fibers can be seen in Fig. 1e, with the high-Δ fiber (bottom) clearly generating deeper blue frequencies under identical pump conditions.

The output spectra of both of the fibers were recorded as a function of power on an optical spectrum analyzer and near infrared spectrometer and the ultraviolet and infrared edges identified. The group index curves of the fibers were modeled [7] and plotted as functions of wavelength. The position of the supercontinuum edges as a function of wavelength were then marked on top of the modeled curves with the corresponding edges joined together, Fig. 1b. The agreement is good (that is, the lines joining the corresponding short and long wavelength edges are almost horizontal on the plot), this gives strong support to the concept of group-index matching between the longest and shortest wavelengths being a limiting factor in blue and ultraviolet supercontinuum generation.

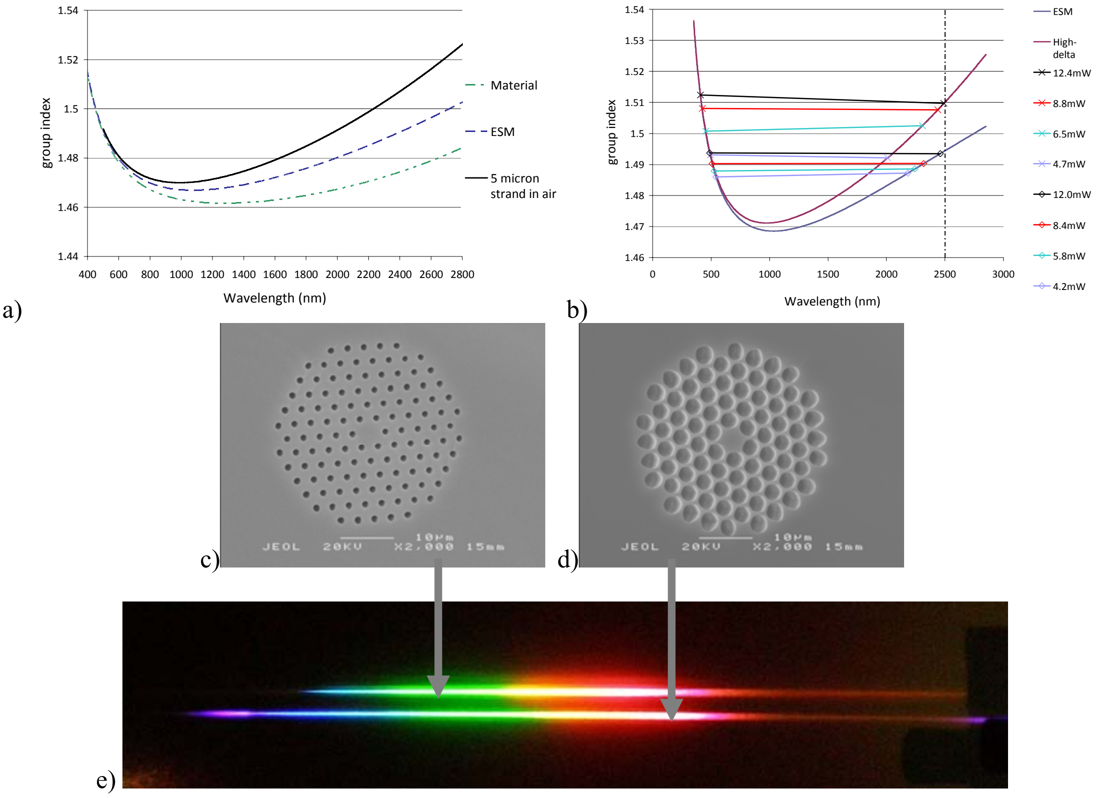

Fig. 1 a) Modeled group index curves as a function of wavelength, for silica (green), an endlessly single mode fiber typically used for supercontinuum generation (blue) and a 5 micron strand of silica in air (black). b) Modeled group index curves for the two fibers, and the experimentally observed long and short wavelength supercontinuum edges as a function of power. c and d) Scanning electron micrographs of the compared fibers, c) is a conventional endlessly single mode fiber and d) a high air filling fraction fiber. e) The dispersed supercontinua generated from the two fibers, as indicated by arrows, under identical pump conditions.

[1] J. K. Ranka *et al.*, "Visible continuum generation in air-silica microstructure optical fibers with anomalous dispersion at 800 nm," Opt. Lett. **25**, 25-27 (2000)

[2] W. Wadsworth, *et al.,* "Supercontinuum and four-wave mixing with Q-switched pulses in endlessly single-mode photonic crystal fibres," Opt. Express **12**, 299-309 (2004)

[3] J. M. Dudley *et al.,* “Supercontinuum generation in photonic crystal fiber,” Rev. Mod. Phys. **78** 1135 (2006)

[4] J. C. Knight, “Photonic crystal fibers,” Nature **424** 847-851 (2003)

[5] A. V. Gorbach et al., "Four-wave mixing of solitons with radiation and quasi-nondispersive wave packets at the short-wavelength edge of a supercontinuum," Opt. Express **14**, 9854-9863 (2006)

[6] A. V. Gorbach and D. V. Skryabin, “Light trapping in gravity-like potentials and expansion of supercontinuum spectra in photonic-crystal fibres,” Nature Photonics **1**, 653 - 657 (2007)

[7] K. Saitoh and M. Koshiba, "Empirical relations for simple design of photonic crystal fibers," Opt. Express **13**, 267-274 (2005)