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Ytterbium-doped distributed spectral filtering photonic crystal fibers for use at wavelengths above 1100 nm

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Rare-earth doped high-power fiber lasers and amplifiers have attracted a lot of attention, due to the advantages of the fiber amplification scheme. Compared to conventional optically pumped bulk lasers, heat is dissipated much more effectively in fiber lasers, having a large surface-to-active volume ratio. Thereby, a stable beam with nearly diffraction-limited quality can be achieved. The fibers are often cladding-pumped with a number of low-brightness semiconductor laser diodes, in which way a low-cost pump of several kilowatts can be achieved [1]. However, the frequencies, which can be amplified, are naturally restricted by the gain spectra of the laser-active dopants. Furthermore, special care must be invested to amplify frequencies outside of the peak of the gain spectrum.

There is a special interest in the long wavelength region of the Ytterbium gain spectrum, 1100 nm - 1200 nm, which can reach the yellow-orange light regime through frequency doubling. Yellow-orange light has applications within the medical industry, high-resolution spectroscopy and for laser-guide stars [2]. To achieve amplification at these wavelengths, the larger gain at shorter wavelengths must be suppressed to avoid parasitic lasing due to Amplified Spontaneous Emission (ASE) build-up.
Nonlinear effects, such as stimulated Raman scattering, stimulated Brillouin scattering and four-wave mixing, set the upper limit for achievable powers in fiber amplifiers. To increase the nonlinear threshold, Large-Mode-Area (LMA) fiber designs are desired. However, it can be challenging to maintain Single-Mode (SM) operation with increasing core sizes.

In this work a LMA Distributed Spectral Filtering (DSF) Photonic Crystal Fiber (PCF) for amplification above 1100 nm is presented. The cladding consists of hexagonally placed air holes, seven missing holes define the core. On each side of the core, rows of air holes are replaced with high-index inclusions, a one- and a three-row design has been investigated. Thereby the core mode is confined by both index- and bandgap guiding type mechanisms. Single-mode operation can to a large degree be controlled through index guidance by tuning the air hole diameter. Suppression of unwanted spectral components is realized through bandgap guidance by tailoring the high-index inclusions. A filter of ASE is thereby incorporated in the PCF cladding. Furthermore the inclusions on one side of the core are reduced in diameter with respect to the inclusions on the other side of the core, enabling the DSF effect to be adjusted spectrally from both the red- and blue-edge.
We demonstrate an enhanced suppression of unwanted spectral components in the three-row design compared to the one row design, and SM behaviour is demonstrated for core diameters of ~ 45 μm. Red-shifting of the maximum gain from 1030 nm to above 1100 nm is illustrated by considering the Ytterbium gain curve and a white light transmission measurement of the PCF.

[1] J. Nilsson and D. N. Payne, "High-power fiber lasers", Science 332, p. 921-922 (2011).
[2] C. Boyer, B. Ellerbroek, M. Gedig, E. Hileman, R. Joycec, and M. Liang, "Update on the TMT laser guide star facility design", Proceedings of the SPIE – The International Society for Optical Engineering 7015, 70152N (2008).