0.75-6 μm supercontinuum generation using spatiotemporal nonlinear dynamics in graded index multimode fiber

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The periodic self-imaging of a beam in graded index multimode fibers (GIMFs) is at the root of a variety of nonlinear spatiotemporal phenomena, such as Kerr beam self-cleaning [1] and geometrical parametric instabilities (GPI) [2]. These rich dynamics opens new opportunities for tailoring the laser radiation in space, time and frequency. Here, we demonstrate that the interplay between the various manifestations of nonlinearities in GIMFs can be controlled, in order to produce a three-octave-spanning supercontinuum (SC) ranging from 0.75 to 6 μm in a cascade of silica, fluoride and chalcogenide glass fibers. This optimization allows us to leverage 1 μm laser technology, instead of the widespread 2 μm laser technology, to produce mid-infrared (mid-IR) SC. These results pave the way to hyperspectral applications such as spectroscopy, medical imaging or sensing in disjoint spectral domains, without the need for either several laser sources or slow, mechanically tunable sources [3].

We start our study by launching 1064 nm 65 ps laser pulses into a 7 m long piece of GIMF (core/clad diameters 50/125, numerical aperture NA = 0.2). Fig. 1 shows the evolution of the spectrum, measured from 400 nm up to 2400 nm, for varying average powers (from 100 to 420 mW), and for two input beam launching configurations. Quasi fundamental (On-axis) excitation, known to favor geometrical parametric instabilities, led to the generation of narrow lines of radiation at 716 nm and at 2070 nm, with high power density. As shown in Fig. 1a, the spectral profile was somewhat constant upon increasing the launched power. To the contrary, few modes (off-axis) excitation (see Fig. 1b) favored stimulated Raman scattering in the normal dispersion regime (up to about 1300 nm), and soliton formation at high powers. The spectral extent was dramatically increased, when compared to on-axis excitation, thanks to Raman soliton self-frequency shift [4]. This careful analysis suggests that excitation of high-order modes might trigger the formation of high peak power pulses up to the infrared edge of silica transparency, and the subsequent spectral broadening in mid-IR transparent fibers. The input launching conditions were then optimized, in order to ensure that the power spectral density in the mid-IR (see green curve in Fig. 1d) was high enough to extend further the continuum up to 4350 nm in a piece of InF_3 fiber (9.5/125, 0.21, red), and even to 6300 nm in a piece of AsS fiber (9.5/125, 0.3, black). In the last configuration, the output spectrum contained up to 400 nJ of energy over the full bandwidth. Additional application results on molecular spectroscopy will be presented at the conference.

Fig. 1 (a-b) Spectral evolution at the output of the GIMF for various average powers, and two input beam launching configurations. Insets show the spatial distribution of the seed laser beam. (c) Experimental setup for production of mid-IR SC. (d) Spectra measured at the output of the various fibers in the cascade.

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