Polarization analysis of a supercontinuum generated in a germania-doped photonic crystal fiber

Nicolas Couture[1], Rachel Ostic[1], P. Harshavardhan Reddy[2,3], Shyamal Das[3], Anirban Dhar[3], Mrinmay Pal[3], Mukul Chandra Paul[3], Ajoy Kumar Kar[4], and Jean-Michel Ménard[1]

[1]*Department of Physics, University of Ottawa, Ottawa, ON K1N 6N5, Canada*
[2]*Academy of Scientific and Innovative Research (AcSIR), CSIR-CGCRI Campus, Kolkata-700032, India*
[3]*Fiber Optics and Photonics Division, CSIR-Central Glass and Ceramic Research Institute, Kolkata-700032, India*
[4]*Institute of Photonics and Quantum Sciences, Heriot-Watt University, Riccarton Campus, Edinburgh EH14 4AS, UK*

Abstract: We investigate experimentally the effect of input polarization and pulse energy on the generated supercontinuum. Our detection system reveals the polarization properties of the supercontinuum, a typically unexplored parameter of these sources.

OCIS codes: (320.6629) Supercontinuum generation, (060.5295) Photonic crystal fibers, (300.6190) Spectrometers

1. Introduction

Supercontinuum (SC) generation in optical fibers has been rigorously investigated to enable new applications in the field of optical coherence tomography (OCT), photonic device testing, and optical communication. Silica-based microstructured fibers are now routinely used to produce a broad and flat optical spectrum. The SC, usually between 350 nm and 2400 nm, is limited by the material due to optical damage in the UV and absorption in the mid-infrared. As a result, other types of fibers such as hollow-core photonic crystal fibers (HC-PCFs), using a gas as the optical medium, or specialty fibers relying on fluoride or chalcogenide, have been used to generate SC beyond the spectral limits imposed by silica [1-3]. However, the fabrication of these fibers can be challenging in terms of reproducibility and scalability. Recently, highly germania-doped (GeO_2) silica fibers have attracted interest because of their optical guidance beyond 2400 nm and the fact that they can be easily fabricated with the same equipment and techniques developed for pure silica fibers [4]. Most studies on SC focus on spectral broadening but little is known about polarization (or depolarization) properties of these sources, which can be crucial for three-dimensional imaging in polarization-sensitive OCT [5]. Standard characterization techniques, usually relying on fiber-coupled optical spectrum analyzers (OSAs), do not provide easy access to different polarization components of the light. Consequently, depolarization effects during extreme spectral broadening are still relatively unexplored. Here, we investigate the SC generated inside a highly GeO_2-doped PCF and its polarization properties as a function of the input pulse energy and polarization state. We use a free-space, broadband, and polarization-sensitive spectrometer allowing us to map out the polarization properties of each spectral component.

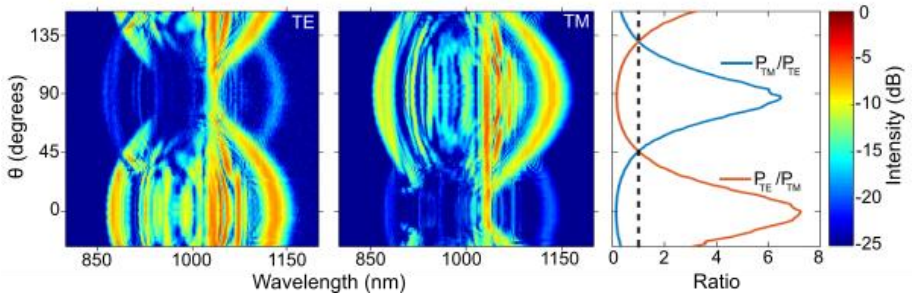

Figure 1. The evolution of the output spectrum of the fiber as the input linear polarization state (θ) is rotated at a fixed input pulse energy of 0.3 nJ. We separate the output spectrum into its transverse electric (TE) and transverse magnetic (TM) polarization components. The ratios of the integrated spectra in TE and TM polarizations are plotted on the right to help us determine the orientation of the principal axes of the fiber.

2. Results and Discussion

The ultrafast source used for SC generation is a Yb:KGW amplifier delivering 180 fs pulses centered at 1030 nm, close to the zero-dispersion wavelength of the PCF. These pulses are injected into the 1.9-meter-long fiber with a coupling efficiency of 40%. The fiber's silica core is doped with 50 mol % of germania and has relatively symmetrical shape with an average diameter of 5 μm. The output end of the PCF is mounted on a manual rotation stage, which is oriented at low power for maximum transmission of the TE polarization through an ultrabroadband wire grid polarizer. This step allows us to assign the principal axes of the fiber to the TE and TM polarization

components in Figs. 1 and 2. The spectra are recorded with a customizable Czerny-Turner configuration monochromator employing three gratings and three detectors – allowing for spectroscopic measurements from 400 nm to 5500 nm. Optical pulse energy launched into the fiber is controlled with a half-wave plate (HWP) located before a polarizing beam splitter. The polarization angle of the input pulse is controlled with another HWP located before the fiber. The polarization dependence of the output spectrum of the fiber with input pulse energy of 0.3 nJ is shown in Fig. 1. The ratio of the integrated spectra (P_{TE} and P_{TM}) is used to determine the orientation of the principal axes of the PCF and the degree of depolarization. We see that the spectral broadening is maximum when light is injected along one of the principal axes, and minimum when the input polarization is oriented at 45° from a principal axis. When injecting light along a principal axis, we measure 15% of the total output power in the orthogonal polarization state, corresponding to a ratio $P_{TE}/P_{TM} \sim 7$. Since the two spectra obtained from orthogonal input polarizations are only slightly different, we can conclude that the fiber is weakly birefringent.

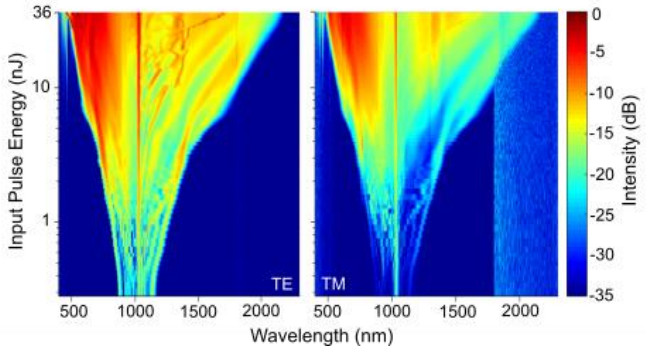

Figure 2. Evolution of the spectrum, separated into its TE (left) and TM (right) components, as we increase the pulse energy launched into the fiber. The pump pulse is centered at λ=1030 nm with a duration τ=180 fs. The input linear polarization was set along one of the principal axes of the fiber (θ=0°).

In Fig. 2, we present the evolution of the output spectrum as a function of input pulse energy. The spectrum is measured for pulse energies between 0.3 and 36 nJ injected in the fiber and θ is set along a principal axis of the fiber (0° in Fig. 1). As we increase the pulse energy, we observe the emergence of Raman self-frequency shifted solitons breaking off from the pump towards the longer wavelengths along with associated dispersive waves extending the SC towards shorter wavelengths [1,4]. At the highest input pulse energies, the broadest spectrum generated spans from 450 nm to 2150 nm (25 dB cut-off). For this spectrum, we observe that the cross-polarized signal (TM in Fig. 2) is stronger in the short wavelength region in comparison to the pump signal, which indicates a depolarization mechanism associated to Rayleigh scattering. In a heavily birefringent fiber, polarization would be well maintained along the input principal axis. In both Figs. 1 and 2, we observe a significant transfer of energy between the orthogonal polarization components aligned along the two principal axes [6]. Comparing the spectra measured in the TE and TM polarization orientations while increasing the input pulse energy reveals that the degree of depolarization increases as the nonlinear effects in the fiber become more prominent.

3. Conclusion

We present a broad SC generated in a highly germania-doped PCF and a free-space detection scheme that reveals the polarization properties across its full spectrum. The capability of separating the spectrum into both TE and TM polarization states facilitates the determination of the optimal input polarization angle for SC generation and the extraction of polarization properties of the PCF. Future work could include the addition of a polarimeter configuration at the output of the spectrometer to reveal the exact polarization state of each spectral component.

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