

Supercontinuum Generation in All-Normal Dispersion Optical Fibers using Picosecond Pulses

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Abstract. Supercontinuum generation in all-normal-dispersion fibers has mainly been explored with femtosecond pumping. Here, we demonstrate broadband SC generation in the long picosecond regime by pumping a highly birefringent all-normal-dispersion photonic crystal fiber at 1064 nm. Spectral broadening arises from polarization modulation instability (PMI) combined with stimulated Raman scattering (SRS), producing octave-spanning spectra from 600 nm to 1650 nm.

Supercontinuum (SC) generation in all-normal-dispersion (ANDi) fibers has attracted significant attention due to its ability to deliver broadband, spectrally flat light with high coherence, low noise, and excellent stability [1-2]. These properties are desirable for applications such as optical coherence tomography, ultrafast pulse synthesis, and dual-comb spectroscopy [1-2]. Most studies have focused on femtosecond pumping [3], while the picosecond regime remains largely unexplored despite its practical advantages, including higher pulse energy and better scalability.

Here, we experimentally demonstrate SC generation in a PM-ANDi fiber pumped at 1064 nm with 42-ps pulses. The SC dynamics are strongly polarization dependent, with efficient broadband generation along the slow axis due to the interplay of PMI and SRS. This produces a wide, flat SC from 600 to 1650 nm, bridging femtosecond-driven coherent broadening and picosecond nonlinear dynamics. Experimental results are supported by numerical simulations and analytical phase-matching predictions for PMI sidebands.

The SEM image of the fiber cross-section is shown in the inset of Fig. 1b. The microstructure has an average hole spacing of 1.42 μm and hole diameter of 0.55 μm , except for two slightly larger holes (0.64 μm) across the core (Fig. 1(d)). Fiber properties were simulated using a finite-element method (FEM) mode solver based on the SEM image. Only results along the slow axis are shown, as those along the fast axis are nearly identical. The group-velocity dispersion (GVD) is entirely normal, with a maximum of $-16 \text{ ps}\cdot\text{nm}^{-1}\cdot\text{km}^{-1}$ at 1000 nm, in excellent agreement with measurements (Fig. 1a). Confinement losses remain below 100 dB/km up to 1600 nm (Fig. 1b). The two enlarged holes induce a phase birefringence $\delta n = 2 \times 10^{-4}$ at 1000 nm and a group birefringence δn_g that is negative at 1000 nm and changes sign near 1300 nm, consistent with measurements (Fig. 1c). Figure 1d shows the measured

mode profile with a mode-field diameter of $2.14\ \mu\text{m}$, and the PCF operates in the single-mode regime, as expected from its air-filling fraction of 0.39.

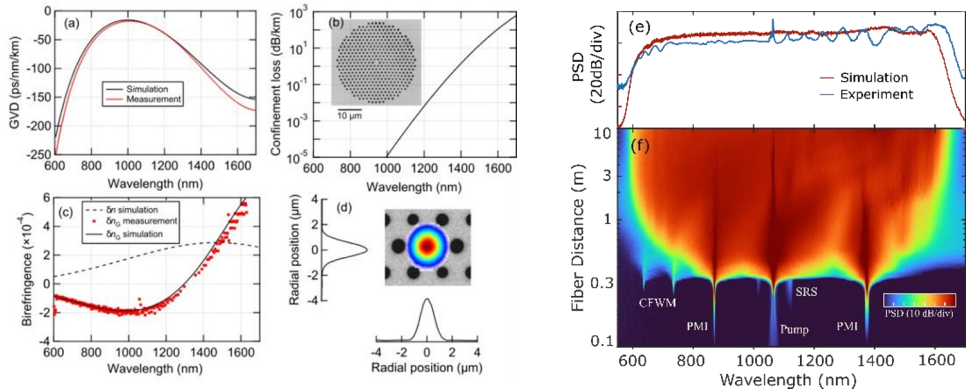


Fig. 1. Properties of the PM-ANDi PCF (left) and comparison between experimental and numerical results. (right). (a) Measured (red) and simulated (black) dispersion along the slow axis. (b) Simulated confinement loss (inset: SEM image of the fiber cross-section). (c) Phase (dashed) and group (solid) birefringence, with experimental measurements (red dots). (d) Core close-up showing the measured mode and corresponding intensity profiles. (e) Experimental (blue) and simulated (red) supercontinuum spectra for pumping at 1064 nm along the slow axis. (f) Simulated spectral evolution along the fiber, highlighting PMI- and SRS-driven broadening ($P = 10\ \text{kW}$, $L = 10\ \text{m}$).

The fiber was pumped with a 1064 nm, 42 ps, 200 kHz picosecond laser (EKSPLA Atlantic 5). The input polarization was controlled using a half-wave plate, and the beam was coupled into the fiber via an aspherical lens with $\sim 60\%$ efficiency. The output spectra were recorded using two optical spectrum analyzers. Fiber lengths ranging from 0.35 m to 10 m were investigated. In the 10 m fiber, SC generation was found to strongly depend on the input polarization state. Pumping along the slow axis produced the broadest spectrum, spanning 600–1650 nm at $-20\ \text{dB}$ (blue trace, Fig. 1e), exceeding typical femtosecond SC bandwidths (650–1350 nm) [3]. Figure 5f presents the simulated spectral evolution along the fiber, highlighting the crucial role of PMI sidebands at 866 nm and 1380 nm. These sidebands arise from vector four-wave mixing (FWM) [4] and satisfy the phase-matching condition governed by both birefringence-induced phase mismatch and dispersion, together with contributions from SRS and cascaded CFWM extending toward the visible.

These results highlight the potential of PM-ANDi fibers and demonstrate that polarization instability can play a constructive role, rather than being merely detrimental as in conventional femtosecond SC generation. Notably, to our knowledge, this is the first observation of PMI in high-birefringence fibers with such a large frequency shift, extending previous reports limited mainly to low-birefringence systems.

References

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