Spatio-temporal evolution of ultrashort pulses in graded-index multimode fiber at normal dispersion

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A novel nonlinear phenomenon at normal dispersion regime inside of graded-index multimode fiber (GRIN MMF), geometric parametric instability (GPI), can be observed while propagating beam experiences spatio-temporal evolution. Longhi theoretically predicted this GPI and associated with periodic refocusing inside GRIN MMF [1]. Later his work is verified by Krupa et al. [2] and Lopez-Galmiche et al. [3] and discrete GPI sidebands are reported with more than 120 THz detuning from to pump frequency. These studies focused on quasi-continues pulse evolution in GRIN MMF and the spatio-temporal evolution of femtosecond pulses at normal dispersion regime remains unknown. Here, we present the first experimental observation of GPI sidebands with ultrashort pulses in GRIN MMF. To gain detailed understanding, we perform numerical simulations and theoretical calculations and obtained results are well-aligned with experimental observations.

In experiments, we use an amplified Ti:Sapphire laser as a pump source to generate linearly polarized, single-mode, 200 femtosecond ultrashort pulses at 800 nm with 1 kHz repetition rate. A GRIN MMF with 50 m core diameter is excited with a lens and three-axis translation stage configuration (Fig.1.a). When we excite sufficient amount of high order modes with 354 nJ pump pulse, we obtain first GPI peak pair with 91 THz frequency shift (Fig.1.b Inset). First Stokes and anti-Stokes peaks are observed around 1055 nm and 645 nm with 12 nm and 5 nm spectral bandwidths, respectively. To measure the beam quality of first Stokes peak, we separate it with a long pass filter and obtain a speckle-free, Gaussian-like near-field beam profile. Commonly used theoretical calculation [1,2,3] suggests that ~93 THz frequency detuning is expected for first GPI peak pair when pump pulses are selected at 800 nm. To understand the spatio-temporal evolution of pump pulses, we also perform numerical simulations by coupled-mode analysis method [4]. Even though GRIN MMF supports hundreds of modes at 800 nm, to reduce computation time, we perform a simulation with first three cylindrically symmetric modes and obtain similar results with ~88 THz frequency detuning for first GPI pair (Fig.1.b).

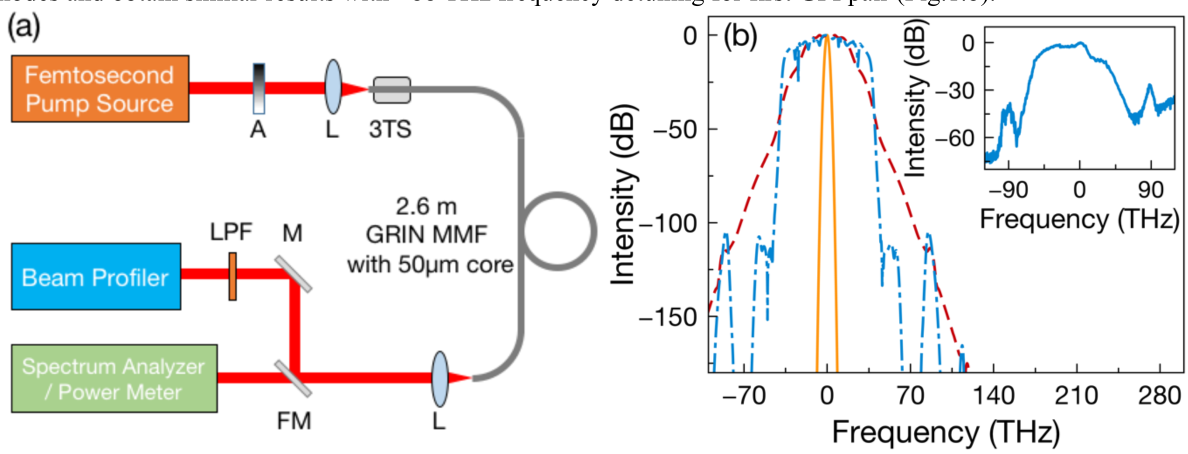

Fig. 1 (a) Schematic of the setup: A, attenuator; L, lens; 3TS, three-axis translation stage; FM, flipped mirror; M, mirror; LPF, long pass filter. (b) Simulation results obtained with 200 fs, 345 nJ pump pulse at 800 nm. Spectrum of launch pulse (solid line), spectrum of after 5 cm propagation (dash line), spectrum of after 2.6 m (dash-dot line). Inset: Experimentally measured spectrum at the end of 2.6 m GRIN MMF obtained with 345 nJ pump pulses.

In conclusion, we study the spatio-temporal evolution of femtosecond pulses in GRIN MMF experimentally and numerically. Our results present the first demonstration of GPI sidebands generation with ultrashort pulses in the literature. Simplified numerical and theoretical models are verified the experimental observations. With unique frequency shift, GPI can be used as new wavelength generation method. Obtained frequency shifts are depending on the wavelength of the pump pulses thus it can be tuned for desired applications.

References

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