Sign-Alternating Dispersion Patterning for Supercontinuum Generation

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Supercontinuum generation (SCG), a process that generates a wide and coherent bandwidth of light, has become foundational in emergent optical technologies in a plethora of fields, such as optical coherence tomography (OCT), metrology (e.g., integrated photonic Kerr combs) and precision sensing. As advanced applications of SCG emerge, the requirements on the spectral bandwidth, the coherence, its temporal compressibility, and the quality of the optical spectral content (e.g., a uniformly flat spectral profile) are increasing. Moreover, as these technologies need not be restricted to the lab, the spectral conversion efficiency of SCG must increase from current technology that functions, e.g., in the tens of nJ pulse energy, to sub nJ levels.

Current limitations in SCG are intrinsic to the physics of the process itself. When ultrafast optical pulses are injected into media or waveguides with standard uniform dispersion, coherent spectral broadening through self-phase modulation is terminated via soliton formation in anomalous dispersion (AD) and is terminated via loss of peak intensity and increase in pulse duration in normal dispersion (ND) [1].

We present a new concept for increasing the spectral bandwidth in coherent SCG, wherein we remove these fundamental physical limitations via alternating the sign of higher order dispersion during nonlinear generation. We demonstrate this methodology to push the mentioned limits in SCG by showing how the method enables to overcome spectral stagnation in ND SCG. Consequently, the method promises the advantages of ND SCG, namely, uniformly flat spectral profiles, ultra-high coherence, and easy temporal compression [2] at much lower pump powers than current schemes. Our concept then will support to avoid the trade-offs in current SCG schemes.

We demonstrate the method in a proof of concept experiment by injecting ultrashort laser pulses (75 fs, 1560 nm) into a spliced optical fiber chain, patterned into four ND and three AD dispersion sign-alternating segments of standard telecom step-index fibers (Corning Hi1060flex for ND and SMF28 for AD segments). Fig. 1 shows the large bandwidth enhancement of the dispersion-segmented fiber chain which provides significantly wider spectra than with the same lengths of homogeneous dispersion of either type. The pulse energy (450 pJ) was substantially lower than the value needed to obtain the same spectral width with the ND fiber, demonstrating that the method substantially lowers the powers needed for SCG.

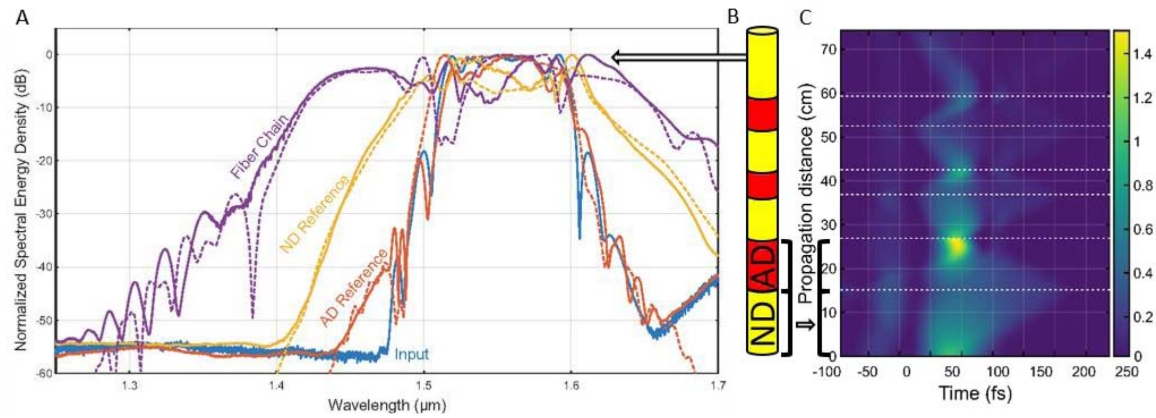

Fig. 1 a) Measured normalized spectral energy density (in dB) obtained from SCG in a dispersion segmented fiber waveguide (chain) and with the same length of the ND fiber and AD fiber are displayed, all with the same input pulse parameters. Comparison with the theoretical model (dotted trace) is also shown. b) A cartoon schematic of the fiber chain is shown, in between the figures, with the correct relative segment lengths. Yellow indicates the ND segments and red the AD segments. Numerically reconstructed normalized intensity color-coded vs time on horizontal axis as measured along the propagation coordinate (vertical axis) in a frame moving with the group velocity. Dotted white line indicates the termination point of the segment. Accelerated temporal defocusing takes place in the ND fiber segments, while the AD segments serve to temporally compress the pulse.

The concept of alternating dispersion, similar to quasi-phase matching, opens a novel degree of freedom in controlling and strengthening coherent nonlinear optical interactions involving broadband light fields, particularly in wave-guided geometries, such as optical fiber, integrated optical waveguides, including Kerr-comb generation in micro-resonators.

References

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