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Supercontinuum Generation with Self-Healing Airy Pulses

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Abstract: We report experiments and simulations of supercontinuum generation with Airy pulses in a microstructured fiber. The dominant peak of the pulse is continuously rebuilt after soliton formation events resulting in the generation of distinct spectral features.

OCIS codes: (190.5940) Self-action effects; (320.7110) Ultrafast nonlinear optics; (320.6629) Supercontinuum generation

If ultrashort optical pulses propagating in a transparent medium have sufficient peak power, they experience dramatic spectral broadening. This complex phenomenon results from the interplay between linear dispersion and nonlinear Kerr and Raman effects. It is known as supercontinuum generation [1].

Optical fibers, particularly microstructured fibers, are especially well suited for studies of supercontinuum generation because the light field is tightly confined in the small fiber core, thus high peak intensity can be maintained over a substantial propagation length. In addition, dispersion of a microstructured fiber can be manipulated with by the design of the waveguide. Supercontinuum generation in microstructured fibers had been actively studied over the last decade [2]. Generally, if the spectrum of the input optical pulse resides in the anomalous dispersion regime of the fiber, the input pulse evolves into a soliton, and the excess energy is emitted in the form of the so-called dispersive wave. Both soliton and dispersive wave have associated distinct features in the spectrum of the generated supercontinuum.

The vast majority of research on supercontinuum generation in fibers utilized bell-shaped input pulses such as Gaussian and hyperbolic secant pulses. Very recently, a new kind of optical pulses has been introduced to linear optics [3]. These pulses have their temporal waveforms described in terms of the Airy function. Like Airy beams that self-bend on propagation in free space and resist spatial perturbations and scattering, temporal Airy pulses resist dispersion and self-heal their dominant intensity features should they be selectively distorted or blocked. Airy pulses have been recently studied experimentally in both linear [4] and nonlinear [5] regimes.

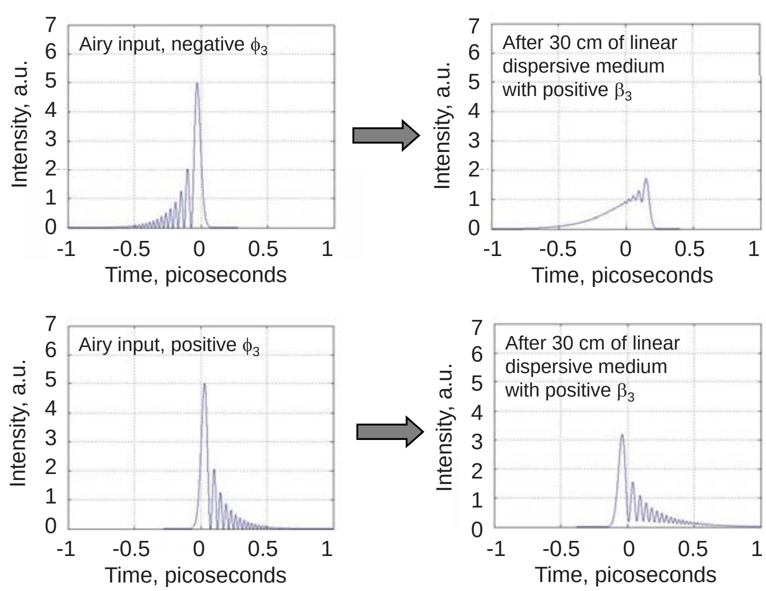

Fig. 1. Numerically simulated input Airy pulse and output pulse waveform after linear propagation through a dispersive medium representing the microstructured optical fiber used in the experiments. The range of distortion-free propagation of the pulse depends on the sign of the initial cubic spectral phase.

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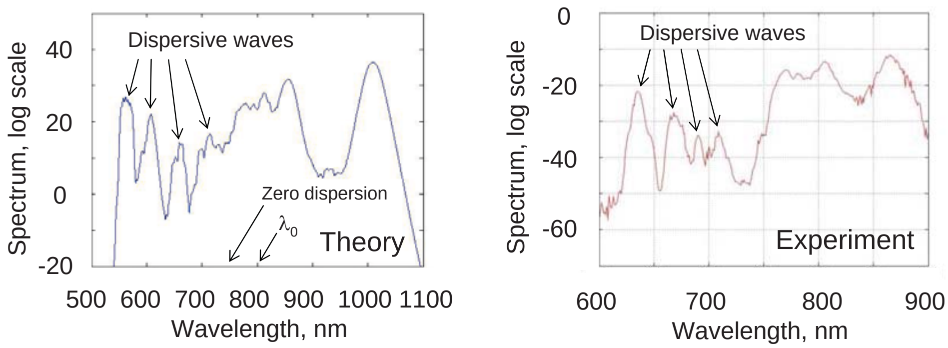

Fig. 2. Calculated (left) and measured (right) supercontinuum spectrum generated after propagation of an input Airy pulse with peak power of 1.6kW through 1 m of highly nonlinear fiber. The effective mode size of the fiber is 2μm and zero dispersion wavelength is 750 nm. The center wavelength of the input pulse is 800 nm.

In this contribution, we report experiments and computer simulations of propagation of Airy pulses in dispersive and nonlinear microstructured fiber. To create temporal Airy waveforms, we start with 30 fs-long Gaussian pulses generated by a modelocked Ti:Sapphire laser source and apply cubic phase modulation to the pulse spectrum via a commercial pulse shaper system (Silhouette$^{\mathrm{TM}}$ by Coherent). The magnitude of the cubic phase imposed onto the pulses can be continuously varied between -6×10^4 fs^3 and 6×10^4 fs^3. Temporal waveforms of the generated pulses are measured with a Frequency-Resolved Optical Gaiting (FROG) system. The overall throughput of our pulse-shaping setup is about 30%, and the maximum average power attainable from it is about 100 mW, at 76 MHz pulse repetition frequency.

The generated Airy pulses are launched into a highly nonlinear optical fiber that has 2 μm effective mode diameter and zero dispersion wavelength at 750 nm. The input spectrum of the Airy pulses is centered at 800 nm, and the fiber dispersion for the input pulses is anomalous. The spectrum of the generated supercontinuum at the output of the fiber is measured with an optical spectrum analyzer.

To simulate propagation of Airy pulses in our setup, we use a generic pulse propagator code copied from [2]. To model fiber dispersion, we fit the dispersion curve provided by the fiber manufacturer with a 10-order polynomial in optical frequency. The nonlinearity is modeled by the inclusion of the instantaneous Kerr and delayed Raman contributions.

By simulating pulse propagation in the linear regime (with the nonlinear terms dropped from the code), we found that third-order dispersion of the fiber affects the range of the distortion-resistant propagation of Airy pulses considerably. If the input cubic phase of the Airy pulse and the third-order fiber dispersion have same signs, the distortion-free propagation of the pulse is extended. If the two contributions have opposite signs, the range of the distortion-free propagation is shortened (Figure 1).

Simulations of the nonlinear propagation of Airy pulses in the fiber reveal a complex pulse evolution scenario. As the pulse enters the fiber, its main intensity peak quickly reshapes into a soliton which drifts away from the waveform. The main peak is then recreated by the rest of the waveform. The reconstructed peak forms another soliton, etc. This cycle repeats itself several times as the pulse propagates through the fiber. In the spectral domain, each soliton-formation event leaves a distinct dispersive-wave feature. The input optical power and both sign and magnitude of the cubic phase of the input Airy pulse affect the number of the generated solitons and the timing of their generation.

The above pulse-propagation scenario was confirmed by measurements of spectra of the generated supercontinua. The input cubic phase was directly input through the pulse-shaper control software, and the input optical power was varied by defocusing the coupling optics used to launch the input beam into the fiber. An example of the simulated and measured spectra for the case of input cubic phase equal 6×10^4 fs^3 is shown in Figure 2.

The authors acknowledge helpful discussions with Miroslav Kolesik. This work was supported by the US Air Force Office of Scientific Research through grants FA9550-10-1-0237 and FA9550-10-1-0561.

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