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Ultra-flat SPM-Broadened Spectra in a Highly Nonlinear Fiber using a Fiber Bragg Grating based parabolic pulse shaper

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Abstract *We demonstrate the generation of ultra-flat broadened spectra by seeding a nonlinear fiber with parabolic pulses shaped using a fiber grating. Applications in pulse compression and spectral slicing are shown.*

Introduction

Recent progress in supercontinuum generation (SCG) in optical fibers has enabled a wide range of applications, including amongst others, dense wavelength multiplexed optical communication systems based on spectral slicing [1], and various all optical data processing schemes besides [2]. For many applications, optimising the spectral density for a given pump power whilst maintaining a flat spectral profile is critical, for others maintaining a high degree of coherence is a primary concern.

Broad optical spectra can readily be generated by exploiting nonlinear effects in high nonlinearity fibers (HNLFs). Although broadened spectra can be achieved in both dispersion regimes the use of normally dispersive fibers allows the generation of pulses with flatter spectra [1] and higher coherency. The main limits to spectral pulse quality in this regime is the spectral ripple that arises from SPM of the sech shaped pulses characteristic of many short pulse lasers, and the effects of wave-breaking which can lead to a severe transfer of energy into the wings of the spectrum. However, such effects can in principle be avoided by using pulses with a parabolic temporal intensity profile [2]. SPM induces a perfectly linear chirp on such pulses ensuring that they remain parabolic during propagation resulting in spectrally flat, highly-coherent pulses. However, it remains an key issue as to how to reliably generate parabolic pulses in the first instance. Parabolic pulses can be generated under certain conditions within normally dispersive optical fiber amplifiers by exploiting the interplay between gain, nonlinearity and dispersion, however this makes for a complex system [3]. Recently however, we demonstrated a simple parabolic pulse source based on reshaping soliton pulses into parabolic pulses using a suitably designed Superstructured Fiber Bragg Grating (SSFBG). In this paper we show that it is possible to use such a source to generate spectrally broadened pulse with a low spectral ripple with a high proportion of the incident energy retained within the usable 3dB spectral bandwidth. We demonstrate the benefits of the flat spectrum for spectral slicing source applications at telecommunications wavelengths, and demonstrate the high coherence of the output in pulse compression experiments.

Experimental set-up

The experimental set-up is shown in Fig. 1.a. 2 ps sech pulses generated by a mode-locked erbium fibre ring laser (EFRL) are used as the input to the SSFBG parabolic pulse shaper. The grating is designed to produce shaped pulses with a parabolic envelope (FWHM of ~10 ps) apodized by a 5th order super-Gaussian profile. We characterised the quality of the shaped pulses using an electro-absorption modulation frequency-resolved gating technique (EAM-FROG). Fig.1.b shows the temporal profile of the measured shaped pulses, fitted with an idealised parabolic pulse, showing an excellent agreement between the two. The phase is shown to be nearly constant across the width of the pulse. These pulse were then amplified and fed into 500 m of a HNLF dispersion -0.87 ps/nm/km, dispersion slope -0.0006 ps/nm^2/km and nonlinear coefficient ~19 W^{-1}km^{-1} before being passed through either an arrayed waveguide grating (AWG) or a length of single mode fiber (SMF) depending on the end-application needs.

System Results and Applications

In order to assess the spectral broadening of the parabolic pulses, we compare it with that induced by

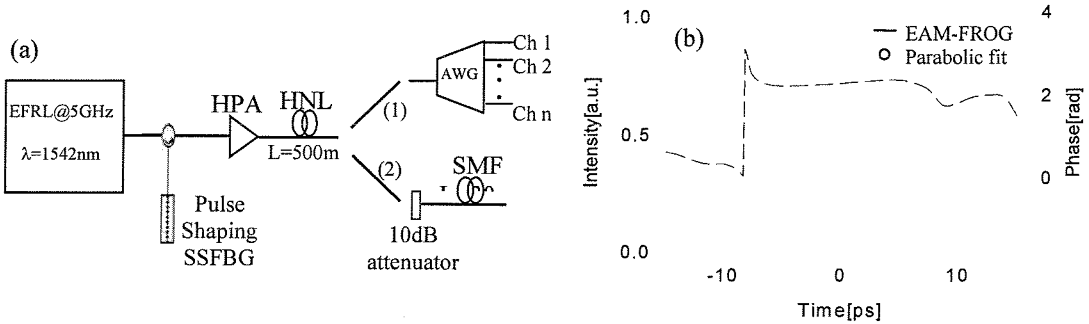

Figure 1: a) Experimental set-up. b) Intensity of the parabolic pulse measured using the Frequency Resolved electro-absorption gating technique, its correspondent phase and ideal parabolic pulse.

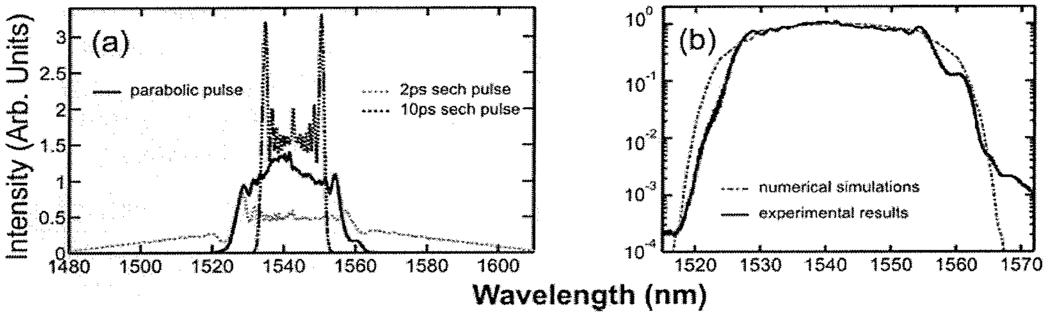

Figure 2: a) Experimental spectra after the HNLF for parabolic pulses, 10ps and 2ps sech. Spectral traces are normalized with respect to their total energy. .b) Experimental and simulated spectra of the parabolic pulse.

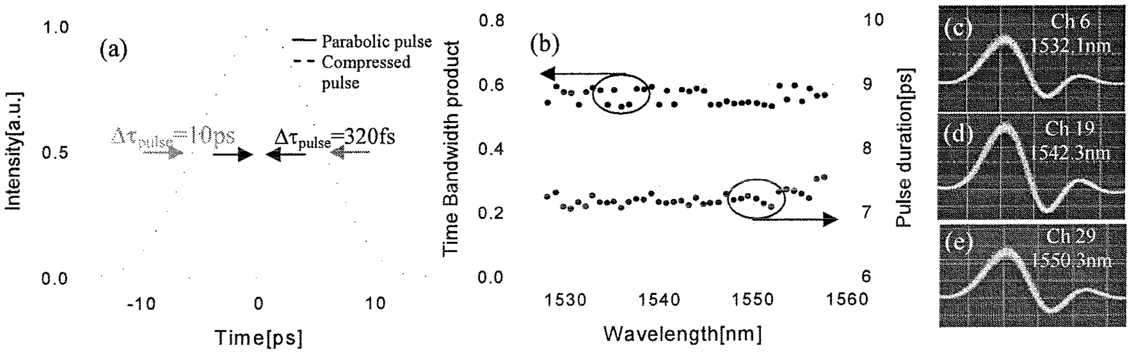

Figure 3: a)Autocorrelation traces of the initial parabolic pulse and compressed pulse. b)Measured values of the pulsewidths and time-bandwidth product for the filtered channels. c)Oscilloscope traces of three channels.

sech pulses of different two pulse widths (2ps and 10ps) for the same initial pulse energy, ~100pJ. Fig.2.a shows the corresponding experimental spectra measured after the HNLF. The 2ps sech pulses experience the greatest spectral broadening, (~33nm 3dB bandwidth). However, wavebreaking effects are severe with only half of the energy remaining in the central region of the spectrum. The 10ps sech pulses do not exhibit such an energy transfer to the spectral wings, but the spectral broadening reaches only ~17nm at 3dB, and a high relative ripple depth is observed. These effects can compromise the quality of the processed signal, for example in terms of unequal WDM channels amplitudes after slicing of the SC spectrum. Parabolic pulses show the optimum performance in terms of spectral broadening (~28.5nm at 3dB), similar to the 2ps sech case, and the proportion of energy within the spectral 3dB width is as high as 92%, as for the 10ps sech pulses. Fig.2.b shows the good agreement between the spectrum of the measured and ideal parabolic, plotted on a logarithmic scale. Note the flat top spectrum and the characteristic rapidly falling edges characteristic of the parabolic pulse form.

Pulse of such a spectral bandwidth should be useful for pulse compression applications provided that coherence is preserved across the pulse. To test this we launched the pulse into a few meters of SMF (Fig.1.a). High quality compressed pulses with a FWHM duration down to 320fs were obtained (Fig 3a). This represents a compression factor of more than 30 relative to the initial 10ps parabolic pulses highlighting the quality of the linear chirp generated in the HNLF.

The flat spectrum and optimised spectral density are attractive for spectrally sliced source applications. To show this we filter out the broadband spectrum using an AWG (Fig.1.a). The channels are generated in the 1528-1558nm-wavelength range. The pulsewidth of each individual channel together with the time bandwidth were subsequently characterized demonstrating the homogeneous pulse quality across the full wavelength operating range (Fig.3.b). Oscilloscope traces of three randomly chosen channels are shown in the inset of the same figure to confirm the good noise performance of the system.

Conclusions

In conclusion, we have experimentally demonstrated the application of SSFBG-based parabolic pulse shaping for the generation of ultra-flat broadened spectra in normal dispersive HNLF. These parabolic pulses provide optimum performance in terms of spectral flatness and density as compared to sech^2 pulses of various pulse widths. We have also demonstrated potential applications including spectrally sliced pulse source generation and efficient pulse compression.

References

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