Waveform-dependent laser spectral compression through pulse propagation in a dispersion-increasing fiber

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Abstract: Waveform dependence of laser spectral compression in a dispersion-increasing fiber is investigated. Experimentally, record-high spectral compression ratios of 35.3 and 41.7 are respectively achieved using a stretch-pulse mode-locked fiber laser and an all-normal dispersion laser.

OCIS codes: (320.7140) Ultrafast processes in fibers; (190.5530) Pulse propagation and temporal solitons.

1. Introduction

Laser sources with high spectral power density are essential in frequency metrology and spectroscopies. However, typical fs and supercontinuum sources suffer from low power density due to the inherent wide bandwidth. External spectral compression offers an interesting solution where the power density can be increased through the redistribution of the laser energy into a narrow user-desired spectral region. Such spectral narrowing effect has been investigated through pulse propagation in various types of optical fibers [1-3]. However, the spectral compression ratios (SCRs) achieved typically fall below 10. Recently, a comb-profiled fiber was used to achieve a SCR of 25.9 [1]. On the other hand, the waveform dependence (parabolic pulses) over the SCR within a normally dispersive photonic crystal fiber was addressed [3].

In this paper, we first present numerical analyses over the sensitivity of spectral compression to input waveforms within a dispersion-increasing fiber (DIF). Spectral compressions using input sech pulse and that derived from an all-normal dispersion (ANDi) laser [4] of same temporal duration are compared. Our numerical results indicate that the ANDi laser pulse can provide a SCR greater than 40. Experimentally, record-high SCRs of 35.3 and 41.7 are achieved by launching input pulses derived from a stretched-pulse mode-locked fiber laser and a quasi-ANDi laser into a DIF, respectively.

2. Numerical analysis

The waveform-dependence of spectral compression within the DIF is first numerically assessed. The calculations are performed by solving the generalized nonlinear Schrödinger equation using the split-step Fourier method with 2000 computational steps. The DIF is modeled using a linear dispersion ramp of 0.6 to 13.5 ps/nm/km from the input to the output, an input dispersion slope of 0.02 $ps/nm^2/km$, a loss coefficient of 0.4 dB/km, along with the nonlinear and Raman coefficients of 3.5 $(W\text{-}km)^{-1}$ and 3 fs, respectively.

Figures 1(a) and 1(b) show the input (black) and spectrally compressed output (blue) spectra when a 121 fs FWHM duration sech pulse and ANDi laser pulse are launched into the DIF, respectively. The temporal intensity shapes are shown as the inset. The spectrum and the temporal waveform of the ANDi laser are obtained by solving the cubic-quintic Ginzburg-Landau equation [4]. The SCR is defined by the ratio of the FWHM spectral bandwidth of the input spectrum to that of the DIF output spectrum. From our numerical results, ANDi laser pulses can give a SCR of 43, while the sech pulse only provides a SCR of 22. These results indicate that spectral compression is sensitive to the input waveform, and can be easily conceived as the FWHM spectral bandwidths giving the same pulse temporal duration but of different shape can indeed have a wide variance.

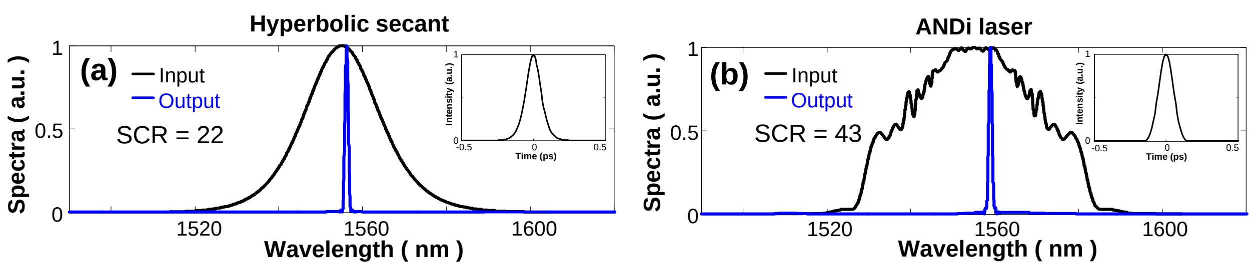

Fig. 1. Spectral compression using 121 fs input pulses of (a) sech shape and (b) derived from an ANDi laser. Inset: temporal intensities.

3. Experimental results

Figure 2(a) shows the schematics of our experimental setup. The optical sources are a passively mode locked fiber laser (MLFL) with 100 MHz repetition-rate [5] and a quasi-ANDi laser with 8 MHz repetition-rate [6], respectively. The dispersion compensator is used to ensure nearly transform-limited pulses are launched into the DIF. For the MLFL, the dispersion compensator is a segment of dispersion-compensating fiber; for the ANDi laser pulse, a home-made pulse shaper [7] was employed for spectral phase corrections. An optical attenuator (ATT) is used to provide the input power tuning ability for SCR optimization. The intensity autocorrelator (IA) is used to verify that the pulses launched into DIF are near transform-limit. The DIF employed in this experiment is 1 km in length, with a linear dispersion ramp from 0.6 to 13.5 ps/nm/km. The spectra before and after the DIF are measured with an optical spectrum analyzer (OSA, Yokogawa AQ6370C).

Figure 2(b) shows the experimental DIF input (black), output (blue) and calculated spectrally compressed (light blue) spectra for the 112 fs MLFL with input pulse energy of 15.4 pJ. In our calculation, the input waveform is derived using the experimental MLFL optical spectrum. The MLFL input bandwidth is 34.8 nm, and the DIF output bandwidth is 0.98 nm, giving a SCR of 35.3. Figure 2(c) shows the experimental DIF input (black), output (blue) and calculated spectrally compressed (green) spectra for the 113 fs ANDi laser with input pulse energy of 61.3 pJ. The ANDi input bandwidth is 37.0 nm, and the DIF output bandwidth is 0.89 nm, giving a SCR of 41.7. For both input pulses, the experimental spectrally compressed spectra are in perfect agreements as compared to the calculations.

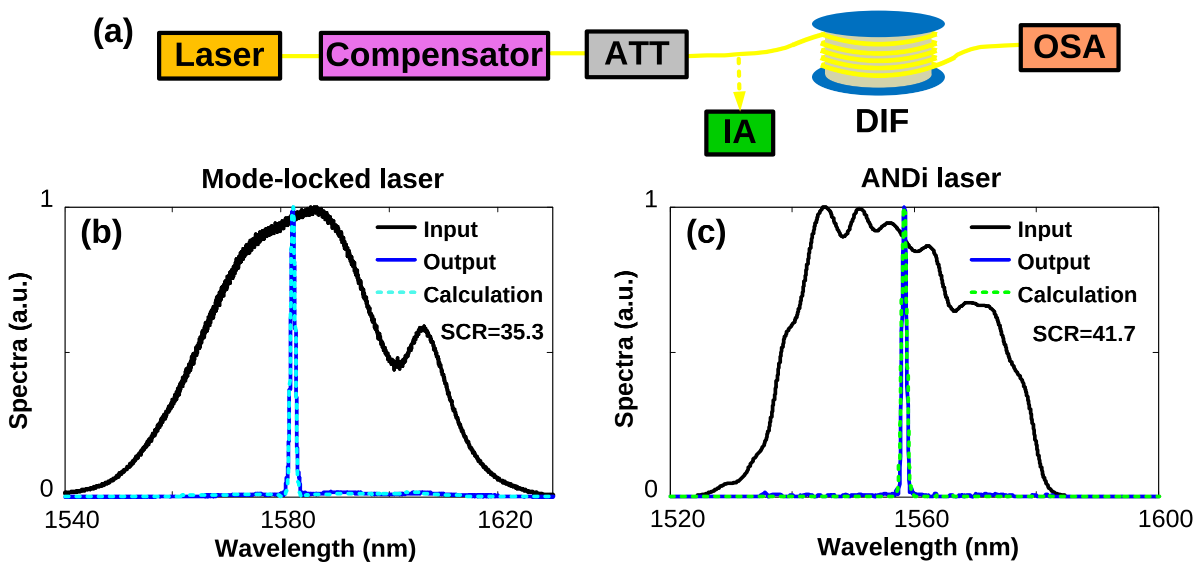

Fig. 2. (a) Schematics of the experimental setup. (b) Experimental DIF input (solid black curve), output (solid blue curve) and calculated compressed (blue dash line) spectra of 112 fs mode-locked fiber laser with SCR of 35.3. (c) Experimental DIF input (solid black curve), output (solid blue curve) and calculated compressed (green dash line) spectra of 113 fs ANDi laser with SCR of 41.7.

4. Conclusion

In summary, the waveform-dependence of spectral compression is studied both numerically and experimentally. Through nonlinear pulse propagation in a 1-km dispersion-increasing fiber, record-high spectral compression ratios of 35.3 and 41.7 are experimentally achieved using a mode-locked fiber laser and an all-normal dispersion laser, respectively. We anticipate interesting integration of spectral compression with optical pulse shaping [8]. This work was supported by the National Science Council in Taiwan under Contract NSC 100-2112-M-007-007-MY3 and the National Tsing Hua University in Taiwan under grant 102N2081E1.

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