Amplitude and phase investigation of non-soliton pulse compression in dispersion-decreasing fiber

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Abstract: We employ pulse-propagation modeling (split-step Fourier method) and experiments (frequency-resolved optical gating) to investigate the behavior of non-soliton pulses subject to adiabatic pulse compression.

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Laser sources that produce picosecond pulses are needed for high-bit-rate optical communication systems. One method of producing short pulses in the 1-ps regime is the adiabatic compression of longer pulses produced from fiber lasers [1] or gain switched laser diode [2] sources. Although theoretical efforts assume transform-limited initial pulse characteristics [3], in practice this is not assured. We report an experimental and numerical investigation of non-transform-limited initial pulses in the adiabatic pulse compression process. Experimentally, we quantitatively assess the compression of non-soliton chirped pulses in dispersion-decreasing fiber (DDF) using second-harmonic-generation frequency-resolved optical gating (SHG FROG) [4]. Thus, we are able to compare the amplitude and phase of the pulse (before and after compression) with our numerical study based on solving the nonlinear Schrödinger equation (NLSE).

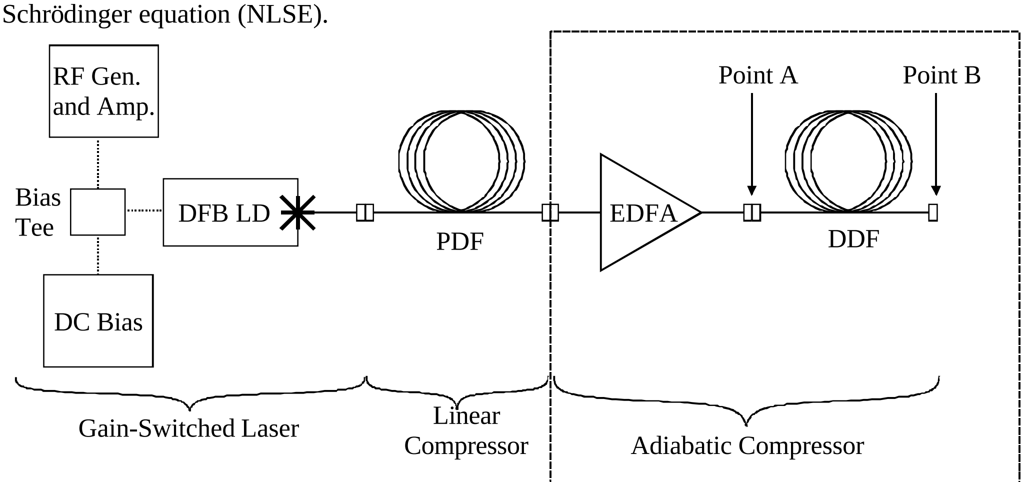

Fig. 1. The pulse source and device under test. The amplitude and phase of the optical pulse are characterized at Points A and B. DFB LD = distributed-feedback laser diode. PDF = positive-dispersion fiber. EDFA = erbium-doped fiber amplifier. DDF = dispersion-decreasing fiber.

The input pulse is provided by a gain-switched laser diode (LD) followed by a linear pulse compressor (Fig. 1). The distributed-feedback (DFB) LD, operating at 1548 nm and a 5-GHz repetition rate, produces a 30-ps pulse with strong negative chirp. The linear compressor consists of a positive-dispersion fiber (PDF) which compresses the negatively chirped pulse to 6.2 ps.

The adiabatic compressor is composed of an erbium-doped fiber amplifier (EDFA) followed by 11 km of DDF. The negative dispersion of the DDF decreases in magnitude along its length, changing from 10.5 ps/nm-km to ~0 ps/nm-km [5]. In an ideal adiabatic compressor, the EDFA amplifies each pulse so that it is a fundamental soliton upon entering the DDF. The diminishing dispersion causes the pulse to temporally shorten to maintain soliton order. Since soliton behavior is central to the compression process, it is important to understand how adiabatic compression is affected when an ideal soliton cannot be provided.

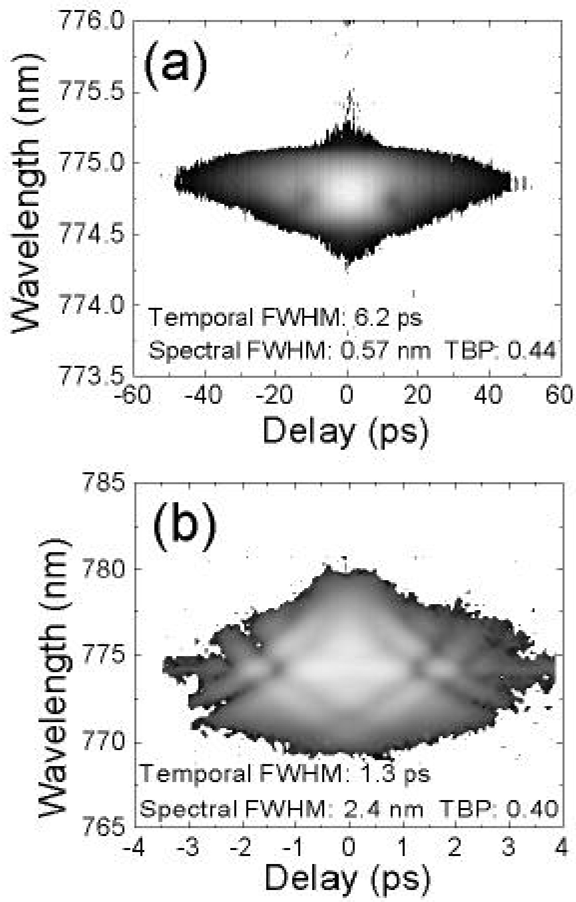

Fig. 2. FROG spectrogram of the pulse before (a) and after (b) propagation through the DDF. The retrieved temporal and spectral full width at half maximum (FWHM) along with the time-bandwidth product (TBP) is noted in the figure. The retrieved FROG spectrogram of (a) had an error of G= 0.005 while for (b) the error was G=0.009.

Figure 2 shows the measured FROG spectrogram before and after adiabatic compression. Although the compressed pulse exhibits a time-bandwidth product of 0.40, the pulse also contains temporal and spectral structure (Fig. 2b) and is therefore not a fundamental soliton. Note that this structure is often obscured in autocorrelation measurements. The compression is assessed via the retrieved temporal intensity (Fig. 3). The 6.2-ps input pulse (Fig. 3a) is compressed to 1.3 ps (Fig. 3b) in the DDF. The negative chirp of the input pulse is concomitantly increased as the pulse propagates. Thus we show explicitly that a chirped input pulse leads to a non-soliton output pulse.

The pulse compression in the DDF is modeled by solving the NLSE using the split-step Fourier method (SSFM) [6]. The measured amplitude and phase of the pulse prior to adiabatic compression are used in the SSFM. The output field determined by FROG is in agreement with the solution of the NLSE including only the effects of absorption, quadratic dispersion and self-phase modulation. This result is also numerically compared to the ideal case of adiabatic compression with a perfect soliton. We have assessed the impact of the initial phase on adiabatic compression and demonstrate that access to the phase is essential to optimizing the compression.

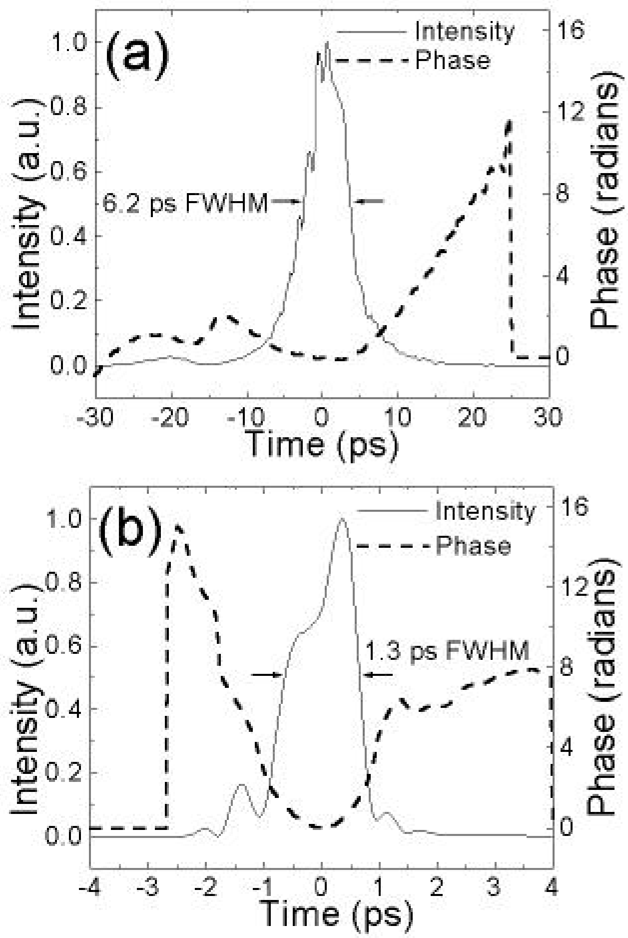

Fig. 3. Retrieved temporal intensity and phase before (a) and after (b) propagation through the DDF. The pulse is compressed from 6.2 ps to 1.3 ps. Note the order of magnitude difference in the temporal scale between (a) and (b).

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