Simple Diagnostics of Femtosecond Pulses by the Use of Nanosecond Oscilloscope

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Abstract: We determine the duration of femtosecond pulses by coupling them into a passive fiber, generating the nanosecond duration nonlinear-dispersive similaritons and recording them by an oscilloscope. This diagnostics has real-time performance.
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We report our studies on the similaritonic technique for femtosecond pulse duration measurements based on the spectral properties of the nonlinear-dispersive (NL-D) similariton [1]. Such a similariton generated in a fiber without gain under the combined impact of Kerr nonlinearity and second-order dispersion has bell-shaped spectral and temporal profiles and a parabolic phase (linear chirp) independent from the input pulse characteristics.

We studied both numerically and experimentally the spectral peculiarities of NL-D similaritons, in particular, the dependence of its spectrum from the input pulse duration. The spectral bandwidth of the similariton generated from Gaussian-shaped seed pulses is inversely proportional to the square root of the input pulse duration [1]: the root mean-square (RMS) bandwidth of the similariton $\Delta\lambda_{RMS}$ and the seed pulse duration Δt_{RMS} are related as $\Delta\lambda_{RMS} \sim \sqrt{E / \Delta t_{RMS}}$, where E is the pulse energy. The coefficient in this relation is given by the fiber parameters and is independent of the shape, chirp or spectrum of the seed pulse. This allows us to develop the similaritonic technique for determination of the pulse duration by the measurements of spectrum and energy of the generated NL-D similariton. Our numerical studies show that for the bell-shaped seed pulses there is an analogous relation $\Delta\lambda_{RMS} \sim \sqrt{E / \Delta t}$ for the similariton bandwidth $\Delta\lambda$ measured at the -10dB level and the seed pulse FWHM duration Δt.

In the experiment, we first dispersively stretch (and chirp both positively and negatively) the laser pulses with 100 fs initial duration, 800 nm central wavelength and ~10 nm FWHM spectral bandwidth. We used a prism pair-based dispersive delay line (DDL) to obtain pulses with different durations and measured the pulse durations by a commercial autocorrelator (AC). Afterwards, we coupled the radiation into passive single-mode fiber (SMF) (Thorlabs-780HP), where the NL-D similariton was generated (Fig. 1). The bandwidth of the NL-D similariton $\Delta\lambda$ and the radiation average power $\overline{p}$ were measured by an optical spectrum analyzer and a power meter. We also measured the similariton pulse duration with a photodiode and an oscilloscope. For this we stretched the similariton pulse up to few nanosecond duration. The duration of such a pulse depends linearly on the similariton bandwidth and the fiber length, since the chirp after the fiber is linear. This allows to implement the technique by acquiring temporal measurements with an oscilloscope, instead of using a spectrometer, allowing the pulse duration measurements in real-time.

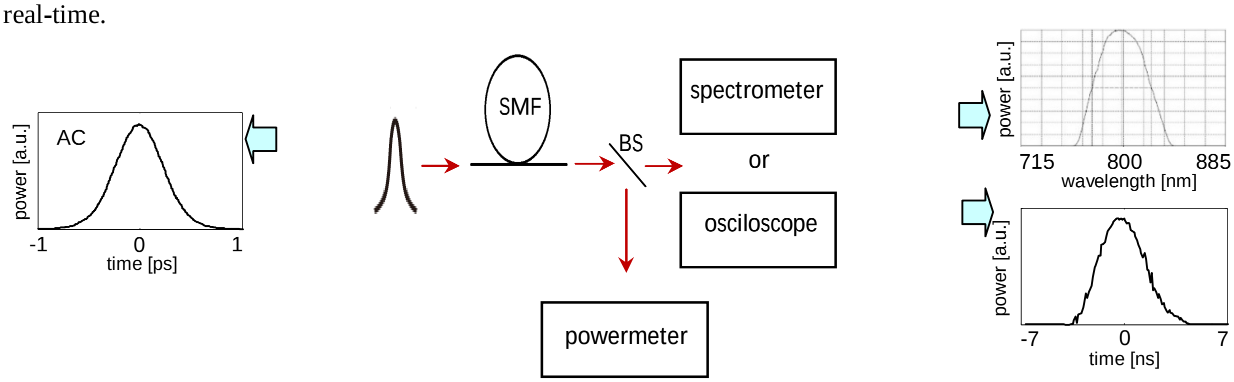

Fig. 1. Experimental setup of the similaritonic technique of duration measurements.

The results of both spectrometer and oscilloscope measurements are in a good agreement with our numerical prediction (Fig. 2). The green triangles and blue squares are the similariton bandwidth and duration, respectively. The blue line is a linear approximation. We have conducted the experiments for input pulses with 146-550 fs AC duration at FWHM and 160-550 mW average power, generating similaritons with 69-117 nm spectral bandwidth and 6.2-9.1 ns duration at -10dB level (similaritons with larger spectral bandwidth correspond to shorter seed pulse). The maximum relative error from the linear approximation did not exceed ~1.7% for both spectral and temporal measurements.

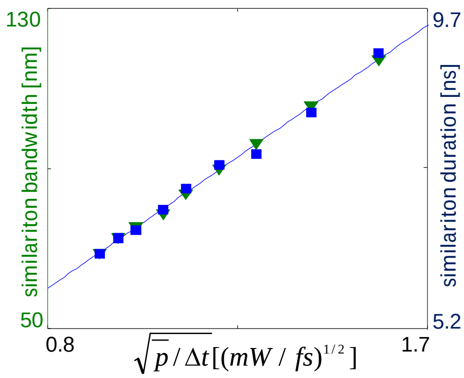

Fig. 2. Experimental results on the similaritonic technique for pulse duration measurements for stretched laser pulses. The green triangles and blue squares correspond to spectral and temporal measurements of the similariton, respectively.

Thereafter, we experimentally checked application range of the technique testing it for the pulses with a few-10fs duration (by compressing the 100-fs laser pulses) and for the pulses with complex temporal shapes. For these pulses, both the spectral and temporal widths are measured in terms of RMS. We first compressed the laser pulses down to ~40-50 fs in a pulse compressor consisting of a short piece (~38 cm) of SMF (Thorlabs-780HP), and a pair of gratings with the 300mm^{-1} groove density (grating compressor). By changing the amount of chirp from the grating compressor, we obtained pulses with 64-160 fs AC durations with both positive and negative chirps. We characterized these pulses by the autocorrelator. Afterwards, we generated an NL-D similariton in an LMA-5 photonic crystal fiber, with a core size of ~5 μm, which provides stronger nonlinearity than one for the standard SMF. We measured the average power of the radiation, AC trace of the compressed pulse, and the spectrum of similariton generated from compressed pulse**.** Experimental results show that $\Delta\lambda_{RMS}$ depends linearly on the inverse of the square root of Δt_{RMS} (Fig. 3a). To compare the results for the compressed and laser pulses, we also generated NL-D similaritons from the compressed pulses in Thorlabs-780HP SMF. Figure 3(b) shows that the results for compressed pulses and stretched laser pulses are in a good agreement with each other, regardless of the initial spectral bandwidth and initial chirp of these pulses.

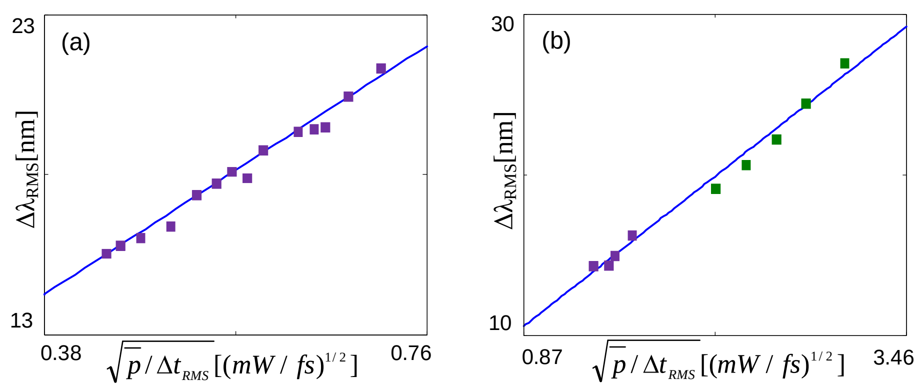

Fig. 3. (a) experimental results on the similaritonic technique for pulse duration measurements for compressed pulses, and (b) comparison of the similaritonic technique for compressed pulses and laser pulses.

To conclude, we have examined both experimentally and numerically a similariton based technique, which allows the real-time measurements of femtosecond pulse duration, independently from pulse shape. The technique can be implemented with a power meter, a spectrometer or an oscilloscope, and a single-mode fiber, standard tools in an optical laboratory. Thus, our similaritonic technique can be used for pulse duration measurements on femtosecond time scale, as an alternative to the autocorrelation technique, with two advantages: independence of the measurements from the pulse shape; real-time performance of measurements with an oscilloscope.

[1] A. Zeytunyan, G. Yesayan, L. Mouradian, P. Kockaert, P. Emplit P, F. Louradour, and A. Barthelemy, "Nonlinear-dispersive similariton of passive fiber", J. Europ. Opt. Soc. Rap. Public. 09009, 2009, v.4