Novel Soliton-Similaritonic Methods of Signal Analysis and Synthesis in Femtosecond Timescale

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Urgent problems of ultrafast optics and photonics stimulate the interest in soliton- and similariton-effects in optical fibers due to their prospective applications, particularly, to femtosecond signal generation, manipulation, delivery and characterization. The concept of time lens, in conjugation with the soliton- and similariton-effects, is more prospective for solutions of many problems of ultrafast photonics. The nonlinear process of temporal lensing - spectral compression of ultra-short pulses in dispersive delay line followed by single-mode fiber [1,2] is a temporal analogue of diffracted beam collimation in a light-induced lens [3]. The time lens, like the spatial one, has more general feature of Fourier transformation (FT), leading to the conversion of temporal information to the spectral domain [3,4]. A large number of temporal Kerr-lens applications were demonstrated [3]: pulse spectral imaging for direct femtosecond scale measurements and fine frequency tuning of radiation along with spectral compression, generation of dark solitons, nonlinear suppression of radiation noise, D-scan technique of material characterization, as an analogue of Z-scan [5], and the femtosecond pulse undistorted delivery method [6] based on spectral compression. This approach becomes more promising by the use of similariton for inducing parabolic aberration-free temporal lens. Particularly, our studies permit us to develop a method of parabolic temporal lensing / spectral compression and spectrotemporal imaging through phase addition in the sum-frequency generation process, instead of self- or cross-modulation by the Kerr effect, providing the method with the principal advantages of self-referencing and aberration free performance [7].

The following soliton-similaritonic applications to signal synthesis and analysis in femtosecond timescale, based on our experiments and supported by the concept of time lens, are in the focus of this review.

- *Solitonic spectral self-compression.* The nonlinear process of spectral self-compression in a medium with anomalous dispersion, a spectral analogue of the soliton-effect compression, is demonstrated experimentally and analyzed numerically for coherent and partially coherent pulses.

- *Broadband similariton.* The demand of signal synthesis and analysis on femtoÂňsecond time scale can be satisfied by broadband similariton-based devices. BroadÂňband nonlinear-dispersive (NL-D) similaritons are generated with ∼80 THz-bandwidth (>150nm at 800 nm waveÂňlength), by coupling 100-fs pulses into a short piece of standard single-mode fiber (∼1 m).

- *Pulse compression.* Applications of similariton essentially improve the techniques of pulse compression and shaping, leading to accurate, aberration-free methods, since the chirp of similariton is linear (the phase is parabolic) and its spectrotemporal profile is smooth and bell-shaped. The broadband similaritons are further compressed in a conventional prism compressor down to 15-20 fs with average powers of 300-500 mW, comparable with the parameters of commercial 10-fs lasers. The use of a hybrid prism-grating compressor or grism-line, free of third-order dispersion, would provide even shorter pulses, down to a few femtoseconds, starting from similaritons of 80 THz bandwidth.

- *Spectral focusing/compression.* Similariton-induced parabolic temporal lens provides an effective aberration-free spectral compression method, in analogy with the beam collimation in space domain. The method can be implemented with various frequency mixing processes, such as sum- or difference-frequency generation, CARS, etc. Experimentally, an effective (up to 23 times) aberration-free spectral compression through sum-frequency generation has been achieved. This type of spectral focusing is of special interest for CARS spectroscopy in view of its spectral resolution improvement.

- *Spectral control of signal in the similariton-induced temporal lens.* A delay between the similariton and the stretched signal pulses leads to a frequency shift of the spectrally compressed radiation in the sum frequency process. The combination of spectral focusing with a fine frequency tuning in the similariton-induced parabolic temporal lens can serve for resonant spectroscopy and optical communication. This technique also allows to measure the similariton chirp and the dispersion of the material where the similariton is generated.

- *Pulse spectrotemporal imaging*, i.e. conversion of the pulse temporal profile to the spectral domain for both the intensity and phase. The temporal lens serves as an optical processor, which performs the operation of time-to-frequency FT, in analogy with the space-to-wavevector FT achieved by a spatial lens. Direct, real-time, high-resolution temporal measurements are carried out through the spectral imaging of temporal pulse based on an aberration-free similariton-induced temporal lens, leading to the development of a femtosecond optical oscilloscope [7,8]. The resolution of measurements is given by the bandwidth of similariton, and it is at the level of ∼5 fs for 80-THz bandwidth similariton.

- *Similaritonic self-referencing spectral interferometry* for complete electric field characterization of femtosecond pulse. The classic spectral interferometry (SI) is based on the interference of the signal and reference fields in a spectrometer, giving a spectral fringe pattern caused by the difference of spectral phases. The SI measurement is accurate, but its application range is restricted by the need of a reference pulse with a suited bandwidth. The method is improved by using a similariton for reference and by its generation from a fraction of the signal to be measured. Thus, the similariton-based SI exhibits the performance of the classic method with the benefit of self-referencing [8]. Our comparative experiments of similariton-based SI and spectroÂňtemporal imaging, carried out together with autocorrelation measurements, evidenced the quantitative agreement and high precision of both methods for accurate femtoÂňsecond-scale temporal measurements.

- *Reverse problem of NL-D similariton generation* in view of femtosecond pulse characterizaÂňtion. The NL-D similariton asymptotically has a linear chirp independent of the pulse initial parameters. The chirp slope is determined only by the fiber dispersion. Therefore, the mapping of the pulse time profile in the spectral domain (the self-spectrotemporal imaging) of the similariton is quantitative with a fixed coefficient. Hence, the initial pulse intensity profile can be measured by a simple spectrometer. Based on the measured spectrum module, together with the spectral phase, which is known, computation of the reverse propagation provides complete information about the input field. In this way, a short piece of fiber can serve as an alternative to the FROG device [9]. The solution of the reverse problem for such a similariton generation process is also helpful for femtosecond pulse delivery [10].

These results lead to the development of new techniques and tools for ultrafast photonics.

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