Laboratory of Ultrafast Optics and Photonics

Established in 2000 at Faculty of Physics, Yerevan State University.

Areas of research are Physics, Ultrafast Optics, Laser Physics, and Photonics.

The subjects of our research are related to nonlinear and ultrafast optics / laser physics. The objectives are the development and introduction of new effective methods of optical signal analysis and syntheses on the femtosecond timescale for the needs of the large spectrum of contemporary science and technology: ultrafast optics and photonics, spectroscopy, chemistry, biology, medicine, optical communication, information technologies, etc.The following issues are the subjects of our research:generation of broadband similariton and its potential applications,similariton pulse compression and femtosecond pulse shaping,spectral compression and fine frequency tuning in the similariton-induced temporal lens,suppression-filtering of the radiation noise through similariton pulse temporal and spectral compression,similariton-referencing spectral interferometry (SI) for femtosecond pulse characterization, similariton-referencing temporal lensing and spectrotemporal imaging,reverse problem for nonlinear-dispersive similariton in view of femtosecond pulse characterization, similariton based chirped CARS spectroscopy and microscopy.

The advanced progress of ultrafast laser physics attracts many fields of contemporary science and technology to apply the ultrafast optics methods. The commercial femtosecond laser sources are now widespread in imaging technologies (biology, etc), non-contact probing of materials, for localized optical alteration of linear and nonlinear optical properties of bulk device, in precision drilling, telecommunication etc. The femtosecond signal generation opens new opportunities for investigation of ultrafast processes, and especially, for information transmission and processing. Along with it, transition to the new timescale demands the elaboration of new methods and design of new fast tools for the signal synthesis and analysis (coding and decoding) for large spectrum of contemporary science and technology. In ths context, similariton pulses recently attract the attention of researchers, due to fundamental interest and prospective applications in ultrafast optics and photonics, especially in combination with an original approach based on the concept of spectral compression – temporal lensing, developed in our prior studies in the frames of NATO Science for Peace project 978027. The spectral compression of ultrashort pulses in a dispersive delay line followed by single-mode fiber is a temporal analogue of diffracted beam collimation in a light-induced lens. The temporal lens, has a more general feature of Fourier transformation (FT), leading to the conversion of temporal information to the spectral domain. In our prior studies we demonstrated the following prospective applications of temporal Kerr lensing: spectral imaging of pulse for direct real-time femtosecond pulse measurements and fine frequency tuning of radiation along with spectral compression, generation of dark solitons, nonlinear-optical filtering of radiation noise. Additionally, the material characterization D-scan technique – a temporal analogue of the Z-scan method, and the femtosecond pulse undistorted delivery method based on spectral compression have been proposed. 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 new method of parabolic temporal lensing / spectral compression and spectrotemporal imaging, providing the method with principal advantages of self-referencing and aberration free performance.

We anticipate the elaboration of a series of novel techniques in the result of our research. Below we justify each project with the anticipated technique concretely:

Generation of broadband similariton in view of its potential applications in ultrafast optics and photonics, i.e. for femtosecond signal generation, manipulation, delivery, and characterization. By the use of similariton, any method requiring a reference pulse becomes self-referencing. However, the signal analysis and synthesis problems on the femtosecond time scale demand the application of a broadband similariton. E.g., the efficiency (ratio) of the similariton pulse compression is given practically by the spectral broadening. The resolution of the femtosecond scale measurements, through the signal spectrotemporal imaging in the similariton-induced parabolic lens, is given by the bandwidth of similariton. For the similariton-based SI, the application range is as large as broadband the similariton-reference is. The similariton-based CARS also demands broadband similariton. In our prior studies, we generated broadband nonlinear-dispersive similaritons of ~50-THz bandwidth (>100 nm at 800 nm wavelength), coupling the 100-fs pulse radiation of a standard commercial laser (~76 MHz repetition rate) of a few 100-mW average power into a short piece of standard single-mode fiber (~1 m). The generation of any kind of broadband similaritons, experimental studies of their distinctive properties in view of potential applications to ultrafast optics and photonics, are an urgent subject of this sub-project and the project overall. The progress in this direction is expected by studying dispersion decreasing and photonic crystal fibers, as well as the similariton fiber lasers,

Similariton pulse compression. The application of similariton essentially improves the techniques of pulse compression and shaping, leading to accurate, aberration-free methods, since the chirp of similariton is linear and its spectrotemporal profile is smooth and bell-shaped. We generate broadband nonlinear-dispersive similariton and compress it in a conventional prism compressor down to < 20fs for the average power of ~500 mW, comparable with the parameters of commercial 10-fs lasers. The use of a grism-line or chirped mirrors or special fibers, free of high-order dispersion, instead of the prism compressor, will compress broadband similariton down to a few femtoseconds providing few-cycle pulses on the frontier of optics.

Spectral focusing in similariton-induced spectrotemporal lens. Similariton-induced parabolic temporal lens provides an effective aberration-free spectral compression, in the analogy of beam collimation in the space domain. This method is based on the dispersive stretching of the pulse and afterwards cancellation of the dispersion-induced phase by adding a reference parabolic phase in a nonlinear process. The method can be implemented in the frequency mixing processes, such as sum- or difference-frequency generation, CARS, etc, using the similariton as a reference pulse generated from a part of the signal. Experimentally, we achieve an effective (up to 22X) aberration-free spectral compression through sum-frequency generation. This type spectral focusing is of special interest for short pulse delivery as well as for CARS spectroscopy in view of its resolution improvement. Spectral control of signal in the similariton-induced temporal lens takes place through the temporal delay between the interacting similariton and dispersively stretched signal pulses leading to the frequency shift of the spectrally compressed radiation. This technique of spectral focusing and fine frequency tuning of the signal in the similariton-induced parabolic temporal lens can serve for optical communication and for resonant spectroscopy. This technique allows also to measure the similariton chirp, and can be used for the measurement of material dispersion (e.g., fiber), where the similariton is generated. Suppression-filtering of the radiation noise in the similariton-induced temporal lens is possible, since the similariton regulates the radiation parameters, and thus, also the parameters of the compressed pulse. The noise filtering of radiation is prospective also through spectral focusing.

Similariton-based chirped CARS spectroscopy and microscopy. The use of broadband femtosecond laser pulses in CARS microscopy with high spectral resolution was demonstrated by the use of pulse chirping and spectral focusing, providing both spectral tuning and high contrast imaging. Another approach of special interest is based on the periodical amplitude-modulation of broadband radiation with high-repetition rate, in resonance with the Raman oscillations of medium. The application of broadband similariton, with the mentioned two approaches, is prospective-promising for CARS microscopy in view of the exploitation of a single laser only, and for a substantially simplified setup.

Pulse spectrotemporal imaging in similariton-induced temporal lens, i.e. conversion of the temporal information to the spectral domain for both the intensity and phase. The temporal lens serves as a processor, which performs the mathematical operation of FT in optics. Direct, real-time, high-resolution temporal measurements are carried out through the spectral imaging of temporal pulse in the parabolic, aberration-free similariton-induced temporal lens, leading to the development of femtosecond optical oscilloscope. The resolution of measurements is given by the transfer function of the similariton's spectrum, and a similariton-reference of the bandwidth of a few tens of nanometers provides the direct measurement of temporal pulse in a spectrometer, exceeding the resolution of the achievement of silicon-chip-based ultrafast optical oscilloscope by an order of magnitude. Experiments for few-cycle pulses, involving high-technological materials / tools (chirped mirrors, grisms, photonic crystal fibers, etc.), will allow to examine the application range of the method, and pass to engineering issues of the device design (pass from the laboratory prototype to the commercial one).

Similariton-based self-referencing spectral interferometry for femtosecond pulse complete characterization. The classic SI is based on the interference of the signal and reference beams spectrally dispersed in a spectrometer. The SI measurement is accurate as any interferometric one, but its application range is restricted by the bandwidth of the reference. We improve the method by generating the broadband similariton (with the known phase given by the fiber dispersion) from a part of the signal and using it as a reference. Thus, the similariton-based SI combines the simplicity of the principle and configuration of the classic SI with the self-referencing performance. Our comparative experiments of similariton-based SI and spectrotemporal imaging, carried out together with autocorrelation measurements, evidence the quantitative accordance and high precision of both the similariton-referencing methods for accurate femtosecond-scale temporal measurements. Research in this direction demands detailed studies on the application range of the method, and the development of the user-friendly software.

Reverse problem of the nonlinear-dispersive similariton generation in view of femtosecond pulse characterization. The nonlinear-dispersive similariton asymptotically has a linear chirp, independent of the pulse initial parameters; practically, only the fiber dispersion determines the chirp slope. Thus, the information on the initial pulse parameters is transferring to the intensity profile, which can be measured by a spectrometer due to the self-spectrotemporal imaging of the similariton. The solution of the reverse problem of the generation of such a similariton, with the measured spectrum and known phase, can provide complete information about the initial signal. This way a short piece of fiber can serve as an alternative to the FROG device.

The results of these projects will lead to the development of novel techniques and high-technological tools for ultrafast optics and photonics.

Currently our Laboratory is equipped with the following contemporary devices / tools, which serve as a technical background for our research:

Verdi V10 + Mira 900F femtosecond laser system, Antares 76-S + Satory 774 pico-femtosecond laser system, Ando OSA 6315 optical spectrum analyzer, APE pulse Check autocorrelator, optcal and mechanical elements/ tools of the Newport, ThorLabs companies, etc.

This type collaboration serves as a good example for Academy-Industry relationship and as a background for the commercialization of innovations.

We are developing our collaboration with the scientific partners of our NATO Science for Peace 978027 project:

XLIM Institut de Recherche, Dnpartement Photonique, Limoges, France; COPL, Universitn Laval, Qunbec, Canada; ULB, Service d'Optique et d'Acoustique, Bruxelles, Belgium; University of California, Irvine, Department of Chemistry, USA; Technology & Applications Center, Newport Corporation, Irvine, USA; Laser Technology-Pyrkal (Armenia).

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