Numerical Modeling of Octave Supercontinuum Generated in Highly Nonlinear Fibers with Complex Dispersion Profiles

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Nowadays, supercontinuums, as well as octave supercontinuums, generated in different types of fibers are widely used in experiments and applications [1]. However, the diversity of laser sources, fiber types and principle scopes cause to solve multiple problems achieving the required parameters of supercontinuum (SC). This particular work is devoted to the numerical modeling of octave supercontinuum generation in highly nonlinear fibers (HNLF) with complex dispersion profiles, i.e. dispersion flattened fiber (DDF), dispersion decreasing fiber (DDF) and fibers with variable dispersion [2]. Femtosecond comb is a part of the mobile femtosecond clock (MOC) on the Nd:YAG/I₂ optical frequency standard and whole-fiber system. The general system parameters are as follows: 550 fs laser pulses with 17 MHz repetition rate and central wavelength 1560 nm, the average laser power reaches 40 mW, pump power 40 mW, pump wavelength 1480 nm.

Spectral broadening in HNLF, while it is mostly driven by self-phase modulation, usually spreads in long wavelengths due to Raman scattering and four-wave mixing, remaining relatively narrow in short wavelengths. Thus, for example, both experiment and simulation with Dispersion Flattened HNLF with dispersion varying from -1.0 ps/(nm·km) to +1.5 ps/(nm·km) in the range 1540 nm – 1560 nm gave us octave supercontinuum in range of 1.2÷2.2 μm. Since MOC expect femtosecond comb in range of 1÷2 μm, we had to perform numerical simulations with complex dispersion profiles. Calculations showed that with some dispersion decreasing and varying dispersion fibers it is possible to obtain supercontinuum in range 0.9÷2.1 μm.

The other problem to be solved is femtosecond comb stability. In order to study spectral changes due to various noise factors such as amplitude fluctuations and timing jitter, laser radiation was modulated (numerically) before HNLF fiber [3]. Since radiation in fiber can be treated as a femtosecond pulse train with certain fluctuation type, numerical model assumes solution of propagation problem using nonlinear Schrödinger equation (NLSE) or Ginzburg-Landau equation for each pulse of the train with its unique parameters (i.e. with fluctuations), then calculation of a complex pulse train spectrum has to be performed. For calculation we used trains consisted of up to 10³ pulses. Simulations show that depending on the certain dispersion profile laser power fluctuations can dramatically reduce femtosecond comb amplitudes, i.e. signal-to-noise ratio, when relative peak power deviations are about 10⁻². While other profiles seem to be rather stable. Comparison of a perfect pulse train spectrum and a perturbed one shows that not only spectral envelope is different but total power of perturbed spectrum is considerably less than in the case of a perfect one. This is due to the fact that spectra show only peak amplitudes of the comb, while in fact decrease of the spectral amplitudes in unstable pulse trains is compensated by individual comb components broadening. Thus, to obtain stable octave supercontinuum with reasonable signal-to-noise ratio this should be taken into account.

All simulations were performed by use of nonlinear Schrödinger equation (NLSE) and Ginzburg-Landau equation. NLSE was solved using split-step Fourier method of the first, second and fourth approximation order and some finite difference methods [4,5].

In conclusion, we present results of the numerical investigation of the octave supercontinuum for mobile femtosecond clock by use of highly nonlinear fibers with varying dispersion, in order to find an optimal fiber parameters to provide stable spectral broadening in range of 1÷2 μm. We also discuss problems of femtosecond comb stability and signal-to-noise ratio in presence of fluctuations.

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References: