Propagation simulation of ultra-short high-power pulse in birefringent single mode optical fiber

V.A. Burdin

Povozhskiy State University of Telecommunications and Informatics

E-mail: burdin@psati.ru

Femtosecond lasers are now increasingly being used in various industries. The variety of their applications requires different forms, duration and power of optical pulses. Often development of lasers with necessary parameters of pulses and means of pulse delivery to the place of application requires the development of special optical fibers. However typical designs of quartz fibres can also be used quite often for these purposes. Moreover, optical polarization-maintaining fibers are especially in demand. Concept, based on solving the coupled nonlinear Schrödinger equations, which often lead to Manakov's equations, are well established to describe optical propagation processes pulses in birefringent optical fibers taking into account nonlinearity, dispersion and mode coupling. As a rule, this system is solved by splitting into physical processes. The method has some advantages, providing acceptable error at relatively low requirements for computing resources. Also, the chromatic dispersion of the third order and Raman scattering effect must be taken into account, when modeling propagation of ultrashort optical pulses of duration less than 10 ps in optical fibers. At the same time, the equations of the system are introduced additional terms. As a result, the nonlinear operator includes derivatives of functions from complex time envelope, when solving a given system of equations by the method of splitting by physical processes. This is the main problem of implementing the split method by physical processes to solve a system of coupled nonlinear Schrödinger equations with components to take into account the Raman effect.

In papers [1], [2] it is proposed a nonlinear operator to lead to a system of Madelung equations and execute it by solving this system of differential equations on each step. It is shown that this approach provides stable solutions in contrast to direct calculation of a nonlinear operator with derivatives from complex time envelope calculated directly by numerical methods or using the Fourier transform. At the same time, the following options for calculating derivatives using the Fourier transform were considered:

$$|A|^2 F^{-1}\left[j\omega F\left(A\right)\right] \text{ and } F^{-1}\left[j\omega F\left(|A|^2\right)\right].$$

Here F and F^{-1} – a forward and inverse Fourier transform operator, respectively; A – complex envelope; ω – angular frequency; j – imaginary unit. In paper [3] it is proposed to calculate the intensity derivative as follows:

$$\mathrm{Re}\left\{F^{-1}\left[j\omega F\left(|A|^2\right)\right]\right\}.$$

This option was used in this work, but here nonlinear coefficient component before the first derivative of complex time envelope was not taken into account unlike paper [3]. Previously, applied algorithm for implementing the split method by physical processes to solve the Schrödinger system of coupled nonlinear equations, describing high-power optical pulse propagation process in single mode birefringent optical fiber, was tested on an example with known experimental data.

In particular, the propagation of the optical pulse with a duration of 12 fs and a peak power of 175 kW in birefringent a butterfly type single mode fiber at a wavelength of 798 nm is simulated. Results of response calculations on optical fiber output matched well enough with experimental data in both time and spectral domains. At the same time, unlike paper [1], the proposed algorithm eliminated the need solving an additional system of differential equations at each step of solution, and the number of Fourier transforms, which needed for direct calculation of the nonlinear operator of the splitting method by physical processes, have been halved. Subsequently, the simulation was carried out for longer optical fiber samples depending on beat length of polarization-maintaining fiber and optical power distribution between modes at input. Example of the simulation results, obtained for propagation of optical pulse with a duration of 12 fs in the optical fiber, is shown in figure 1. Presented in the work simulation results demonstrate significant dependency of pulse distortion in birefringent fiber from beat length and input conditions.

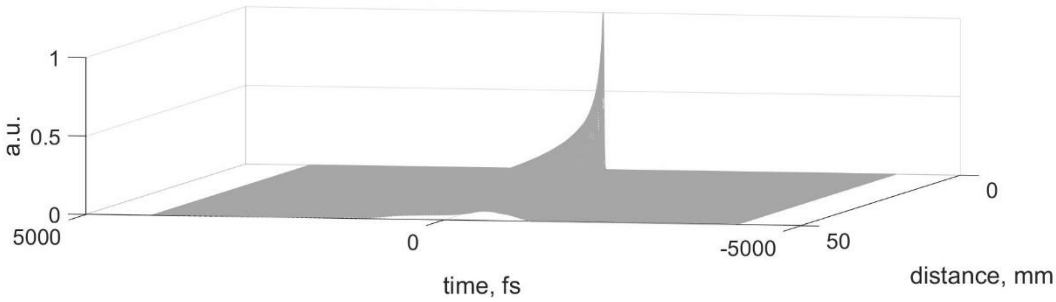

Fig. 1. Evolution of high-power femtosecond pulse over birefringent single mode optical fiber.

Reference

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