Abstract

"Generation and dynamics of ultrashort pulses in all-normal dispersion fiber lasers"

Ultrafast science and technology strongly depend on the development of novel ultrafast sources. Reliable, cost-effective and environmentally-stable all-fiber ultrafast laser architectures attract attention of the scientific and industrial community because of their potential applications. This dissertation is devoted to a subject of ultrashort pulse generation and dynamics in all-normal dispersion all-fiber oscillators.

In this thesis we present new constructions of ultrashort pulse laser sources incorporating artificial saturable absorbers. For the first time Nonlinear Optical Loop Mirror (NOLM) and Nonlinear Polarization Evolution (NPE) artificial saturable absorbers were used for passive mode-locking in all Polarization Maintaining (PM) laser cavities. Using only PM fibers and PM fiber components substantially increases environmental stability of the all-fiber oscillator. In all developed oscillators an Yb-doped fiber was used as an active medium and the central wavelength of generated pulses was set at approximately 1030 nm.

The thesis begins with a detailed description of ultrashort pulse propagation in single mode optical fibers. We describe the role of linear and nonlinear effects in ultrashort pulse propagation as well as dispersion characteristics of optical fibers. The next part is devoted to the theory of ultrashort pulse generation with active and passive mode-locking techniques. Next, we define ultrashort pulse parameters measured during pulse characterization procedures. The definitions of pulse parameters are used to properly describe experimental results in the following experimental parts of the thesis. In the next part we present a theoretical description of different mode-locking regimes which define pulse dynamics inside the cavity. Special attention is paid to dissipative soliton regime which is characteristic for all-normal dispersion oscillators. Further we describe real and artificial saturable absorbers used in all fiber cavities to start pulse formation. Saturable absorber is an optical component which is characterized by nonlinear transmission dependent on the pulse intensity. Parameters of real saturable absorbers are defined by the properties of the used material. In case of the artificial saturable absorbers, the transmission through element is defined by the change of nonlinear phase of the pulse during propagation in nonlinear medium. The advantages and disadvantages of real and artificial saturable absorbers are presented and discussed. The explanation of NOLM and NPE artificial saturable absorbers operation finalizes the chapter.

The following chapter covers experiments and simulations of pulse generation using NOLM in all-normal dispersion all-PM-fiber oscillators. We present a novel configuration of environmentally stable all-PM fiber oscillator generating ultrashort pulses despite mechanical perturbation or harsh temperature changes. The NOLM optimization procedure depending on pulse parameters inside the cavity is presented. By carefully changing the length of NOLM and analyzing the pulse spectrum reflected from the loop we achieved a broader pulse spectrum and shorter pulse duration at the output of the laser. Another factor investigated during the experiments was the spectral filtration influence on intra-cavity pulse dynamics. By changing the transmission shape of spectral filter inside the cavity we achieved pulses with various parameters. We proved that spectral filtration with steep edges results in high fluctuations in spectral and temporal intensity of the pulse. Finally, we used averaged spectral phase

measurements with SPIDER apparatus together with shot to shot spectra measurements with dispersive Fourier transform technique to investigate the influence of stimulated Raman scattering process on the pulse destabilization in all-normal dispersion cavity. We proved that only the wavelengths longer than the central wavelength of the pulse are affected in SRS process. All presented oscillators generated pulses with positive chirp which was compensated outside the cavity with grating compressor. The shortest compressed pulses duration was 160 fs with pulse energy 2 nJ.

The process of NPE is based on a temporal filtration of the pulse polarization state affected by a self-action due to the Kerr nonlinearity. To work properly, most NPE based architectures of fiber lasers contain pieces of standard optical fibers or bulk optical elements, which makes them susceptible to temperature changes and mechanical perturbations. We present a novel NPE mode-locker implementation based on PM fibers resolving this problem. We investigated numerically and experimentally pulse propagation dynamics in birefringent fibers, which resulted in a new design of PM NPE saturable absorber. We showed that proper fiber segmentation in PM NPE design allows to achieve symmetrical nonlinear phase difference for a broadband ultrashort pulse. Changes in transmission of PM NPE saturable absorber due to various intensity split ratio between axes of PM fibers were presented. Additionally, the influence of fiber segment lengths inaccuracies or changes in splice angle values were investigated. We used linear and reflective configuration of PM NPE saturable absorbers in two novel all-PM-fiber laser configurations. The reflective design of PM NPE saturable absorber required using additional phase shifter based on Faraday rotator which was developed and incorporated into the cavity. By using the phase shifter we increased the transmission of saturable absorber for a small signal together with reducing pulse peak intensity required for reaching the transmission maximum. Described oscillators generated positively chirped pulses compressed to the shortest pulse duration of 150 fs and energy of 0,85 nJ.

The final part of the thesis consists of a comprehensive summary of presented results together with main conclusions. This part also presents directions and ideas for future research.

The thesis contains three supplementary materials. The first and second describe apparatus developed for ultrashort pulse characterization. The design and theoretical description of grating compressor and SPIDER apparatus were presented. The third is devoted to Jones matrix formalism for non-reciprocal phase shifters based on Faraday rotators.