New regimes of pulse evolution in a fiber laser with semiconductor optical amplifier

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Abstract— We examine a possibility to exploit nonlinear properties of semiconductor optical amplifier (SOA) to manipulate spectral characteristics of fiber laser. We demonstrate that the interplay involving nonlinear dynamics in the laser cavity and SOA allows to control the wavelength of the generating pulses, shifting it from red to blue side of the spectrum depending on the width of the tunable intracavity filter. The filter bandwidth below 10 nm leads to red shift, while bandwidth increase up to 50 nm results in the spectral blue shift of more than 30 nm.

Keywords— fiber mode-locked laser, semiconductor optical amplifier, wavelength tunability, nonlinear pulse evolution

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I. INTRODUCTION

Properties of many types of modern fiber lasers are defined by the nontrivial nonlinear dynamics introduced by the Kerr effect in the fiber resonator. Nonlinearity, while not easy to control, might offer rich possibilities for developing a variety of new laser sources. Recently we demonstrated both numerically and experimentally, that semiconductor optical amplifier (SOA) can be used as nonlinear device [1], which can shift the central wavelength of subpicosecond pulses to a blue part of the spectrum, opposite to the Raman-induced redshift. The initial Gaussian pulse should be negatively chirped to acquire a blue-shift after amplification. In this work we combine fiber Kerr nonlinearity and nonlinear effects in the SOA to demonstrate new mode-locked regimes of lasing.

II. NUMERICAL MODEL

The laser cavity is comprised of polarization maintaining dispersion compensating fiber (PM DCF), polarization maintaining single-mode fiber (PM SMF), semiconductor optical amplifier, semiconductor saturable absorber mirror, output coupler and tunable spectral filter. The central wavelength of the filter was equal to 1550 nm, the bandwidth varied from 2 to 50 nanometers. The cumulative cavity dispersion was anomalous $\beta_2^{cum} = -0.0625\ \text{ps}^2$. Pulse propagation inside the fibers is described by the nonlinear Schrödinger equation. The model of SOA includes equations for the power and phase of the optical field after amplification, and differential equation for time-dependent gain [2].

III. RESULTS

The proposed scheme leads to generation of asymmetric pulses (Fig.1, left), as the leading pulse edge experiences larger gain in SOA than the trailing edge. Remarkable feature of the intracavity field evolution is alternating group velocity of light along the fibers. Temporal pulse delay in DCF is turned into advance in SMF due to nonlinear frequency chirp acquired after amplification (Fig.1, right). Figure 2 shows how the pulse central wavelength depends on the filter width. It was found, that wavelength of the output laser pulse can be shifted from red to blue side of the spectrum relatively to the central wavelength of the filter. For example, 50 nm filter results in the spectral shift of 30 nm. The larger filter bandwidth, the better wavelength tunability can be reached.

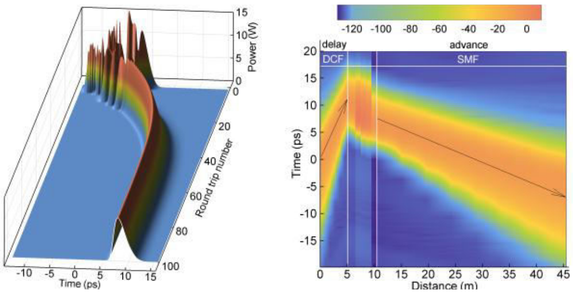

Fig. 1. Evolution of temporal shape of the generating pulse at the fiber output (left) and along the fiber sections (right).

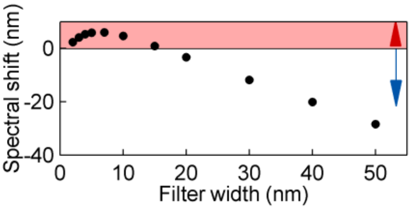

Fig. 2 Dependance of spectral shift of the output pulse on the spectral filter bandwidth.

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REFERENCES

[1] A. E. Bednyakova, D. Khudozhitkova, A. Kokhanovskiy, and S. K. Turitsyn, "Nonlinear spectral blueshift in semiconductor optical amplifiers," Opt. Lett. **46**, 4757-4760 (2021).

[2] G. Agrawal and N. Olsson, “Self-phase modulation and spectral broadening of optical pulses in semiconductor laser amplifiers,” IEEE Journal of Quantum Electronics, vol. 25, no. 11, pp. 2297–2306, 1989.