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Picosecond pulses generation by fiber laser with semiconductor optical amplifier in 1.06 μm spectral range

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Picosecond optical pulses generation in a ring fiber laser with a semiconductor optical amplifier was investigated. Optical spectrum width is minimal at a fundamental resonant repetition frequency of 45 MHz, corresponding to a fiber resonator length of 4.5 m. As the frequency increases, the spectral width increases by an order of magnitude while the pulse duration decreases to 18 ps, and the power increases to 0.5 W. The power of picosecond optical pulses at the output of the semiconductor amplifier is 7 times higher than in the CW mode due to the carrier accumulation effect that occurs with short pump pulses.

Keywords: Semiconductor optical amplifier, Fiber ring laser, Gain-Switching.

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Sources of laser pulses in 1.06 μm range are widely used in time-resolved scanning systems [1], tomography of biological media [2], optical communication devices based on GaAs-components [3]. This is due to the fact that radiation in the range $0.9-1.2\,\mu$m is weakly absorbed by many practically important media, and also because semiconductor and rare-earth lasers are available in this range. One of the simplest ways to obtain short optical pulses is their generation by semiconductor lasers in the gain modulation or Q-factor modulation mode [4]. At the same time, there are methods for generating short pulses in ring fiber lasers based on semiconductor optical amplifiers (SOAs), which make it possible to obtain a shorter duration. In paper [5] pulses with width of 4 ps at a frequency of 10 GHz were obtained on the basis of this method. It was also noted there that to obtain pulses with width determined by the width of the spectrum, it is necessary to use an optical fiber with dispersion compensation and a spectral filter. For practical applications an important factor is that SOAs have a significant spectral amplification range; therefore, in ring lasers based on them, wavelength tuning can be tens of nanometers in the range 1060 nm [6].

Pulse width of a few picoseconds in ring lasers with SOA is usually achieved by using regenerative amplification with optoelectronic feedback. Such diagram is quite complicated, while the pulse repetition rate is usually high (10 GHz or more [5]), and the peak output power is low (about 10 mW). At such frequency tens and hundreds of pulses simultaneously exist in the resonator, i.e. the laser emits at a high harmonic of the main frequency. In practical applications the lower frequency and the higher power of optical pulses are often required [1], this can be realized when operating at the main frequency of the resonator.

The purpose of this paper is to implement and to study the ring fiber laser in the picosecond pulse generation mode, as well as to increase the peak power at pulse ratio of more than 10^2.

The diagram of the ring laser with SOA is shown in the insert to Fig. 1, *a*. The feedback necessary for laser generation occurred due to the fact that 10

When the pumping pulse repetition period coincides with the time of the ring resonator round trip by optical pulses, the laser generation condition is satisfied. This condition is satisfied near the resonant frequency f_0, when pumping is overlapped by laser pulses. A rough estimate of the relative frequency tuning can be $\Delta t/T$, where Δt is the pumping duration and T is the repetition period. The optical pulse width is shorter than the pumping pulse due to the fact that the leading edge of the traveling wave removes the inverse population and is amplified more than the trailing one. The temporal pulse shape at the frequency above the central one is shown in Fig. 1, *a*. As the frequency increases, the optical pulse begins to lag and hits the trailing edge of the pumping, where the gain is greater than at the leading edge. Therefore, the width of optical pulses is shorter at frequency slightly higher than f_0. This is illustrated in Fig. 2, in which the curve corresponding to the pulse width dependence on frequency is strongly asymmetric relatively to the center. The minimum duration is reached in the detuning range $\Delta f \approx 5\cdot 10^{-4} f_0$ above the center frequency f_0. Taking into account the detector response time, the minimum width of the laser pulse is 18 ps. The pulse energy reaches its maximum value (Fig. 2) also in the range Δf; the corresponding power exceeds 0.5 W, which is one or two orders of magnitude higher than the power of high-frequency ring lasers with SOA [5]. This is due to the fact that at a high repetition rate the carriers do not have time to accumulate, and the pulse energy decreases with frequency increasing. At the amplifier output the power is even greater, since Fig. 2 shows the data for the energy after the splitter,

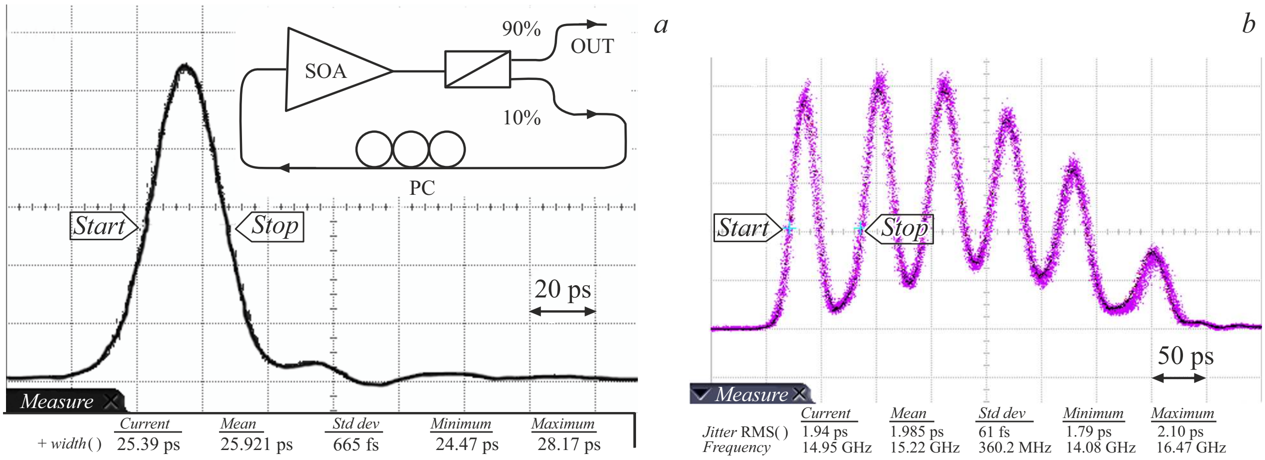

Figure 1. *a* — oscillogram of a laser pulse at average (370 mA) pumping level at frequency of $f_0 + 2 \cdot 10^{-4} f_0 \approx 45$ MHz. On the insert there is laser diagram. *b* — oscillogram at high (600 mA) pumping level.

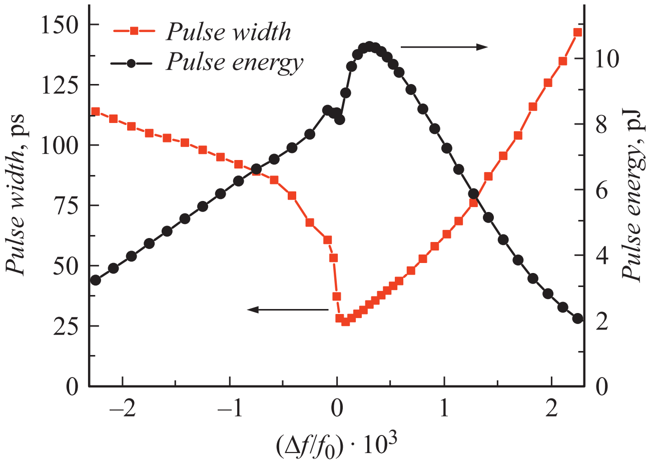

Figure 2. Duration and energy of pulses vs. relative detuning from the resonant frequency f_0.

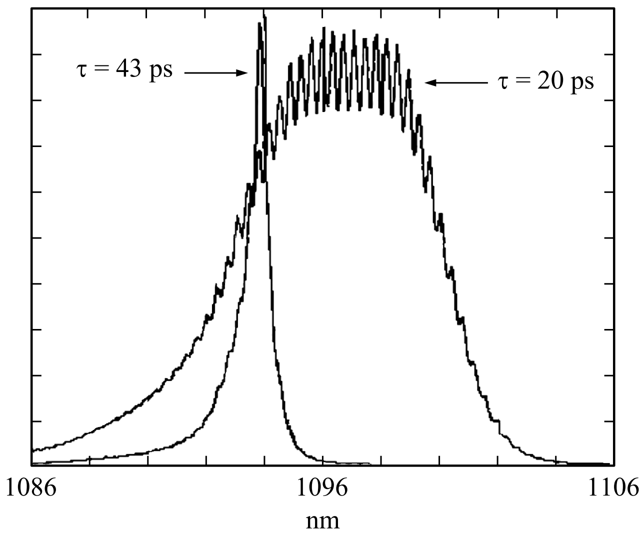

Figure 3. Laser spectra at resonant frequency f_0 (duration 43 ps) and detuning from resonance $f_0 + 1.5 \cdot 10^{-4} f_0$ (duration 20 ps).

which has losses. In the continuous mode the output power of the amplifier is about 0.1 W at current of 0.7 A, i.e. in the picosecond pulse mode it is by 7 times larger, taking into account losses in the output splitter. The reason for this is the accumulation of carriers responsible for the inverse population when the pumping duration is shorter than the lifetime of non-equilibrium carriers. With a multiple change of the repetition frequency by $2f_0$, $3f_0$, the parameters of optical pulses changed insignificantly, which is a common effect for resonant systems.

As the pumping current increases, the laser pulse consists of several peaks, the interval between them is about 70 ps (Fig. 1, *b*). This mode was not studied in the paper, but it was found that the interval between the peaks decreases with pumping increasing, and depends on the frequency of the current pulses.

The emission spectrum changes radically when passing over the resonant frequency (Fig. 3), at the same time the width decreases by ~ 2 times. As the frequency increases by a small value $\sim 1.5 \cdot 10^{-4} f_0$ and more, the spectrum width increases from 0.7 to 7 nm. This indicates the operating mode change. At the resonant frequency the laser operates in the mode of partial modes synchronization of the ring resonator, which is characterized by a narrow spectrum. When detuned from resonance, the spectral modes are not synchronized, and the laser operates in a hybrid mode of gain modulation and a regenerative amplifier. The distance between the modes of the ring resonator is so small that it cannot be resolved by diffraction spectrometers, and a small modulation of the spectrum is associated with residual reflection from the resonator elements.

As a conclusion, note that the generation of high-power picosecond pulses in a regenerative fiber ring laser based on a fiber semiconductor amplifier was studied. It is shown that the shortest duration 18 ps at a power exceeding 0.5 W is achieved at a frequency above the resonant one. On the contrary, the minimum width of the optical spectrum is realized at a longer duration (~ 40 ps) at the resonant frequency of the ring resonator.

Acknowledgments

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Conflict of interest

The author declares that he has no conflict of interest.

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