ISSN 1054-660X, Laser Physics, 2010, Vol. 20, No. 2, pp. 341–343.

Femtosecond Er Laser System Based on Side-Coupled Fibers

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Received June 15, 2009

Abstract—A possibility of the femtosecond laser system with a pulse duration of about 300 fs and an energy of 150 nJ in a range of 1.6 μm based on side-coupled fibers one of which is doped with erbium and is pumped through cladding is demonstrated. The parameters of a ring master oscillator and an amplifier that make it possible to generate femtosecond pulses with a peak power of up to 450 kW are presented.

DOI: 10.1134/S1054660X1004002X

INTRODUCTION

The technology of the side-coupled cladding-pumped GTWave fibers [1, 2] opens prospects for the creation of improved fiber laser systems. One of the advantages of such fibers in lasers and amplifiers lies in the possibility of the high-power multimode pumping and, hence, the generation of high-power radiation or high-energy pulses in master oscillators and amplifiers.

In spite of wide application of side-coupled cladding-pumped fibers in cw laser systems [3–6], the use of such fibers in short-pulse (femtosecond and picosecond) systems is relatively rare [7, 8]. This circumstance is related to the fact that the distributed cladding pumping necessitates a relatively long (>5–10 m) active fiber and the application of the GTWave fibers in master oscillators or fiber amplifiers of femtosecond systems can lead to a significant dispersion broadening of the pulses. However, the dispersion broadening in the fibers with lengths of 5–10 m remains relatively low at pulse durations of hundreds of femtoseconds or several picoseconds. Thus, the side-coupled cladding-pumped fibers can be employed in short-pulse systems at pulse durations of no less than several hundreds of femtosecond (300–500 fs) even in the absence of the compensation for the dispersion of the fibers.

In this work, we report on an original femtosecond fiber system that is based on side-coupled fibers one of which is doped with erbium.

EXPERIMENT

Figure 1 demonstrates the scheme of the all-fiber erbium-doped master oscillator. The ring cavity of the oscillator contains a 9-m-long segment of the side-coupled fiber, a 5-m-long segment of an SMF-28 fiber, a polarization controller, and a polarization outcoupler of the output radiation. The master oscillator is pumped by a multimode laser diode with a wavelength of 975 nm. The pumping radiation is delivered via the passive coreless fiber with a diameter of 125 μm of the side-coupled fiber. The mode-locking of the fiber laser results from the nonlinear rotation of the polarization [9, 10]. For the initial tuning of the laser to the mode-locking regime, we employ the polarization controllers placed in front of and behind the fiber polarization beam splitter. In the subsequent working sessions, the mode-locking regime is activated automatically. The output pulse duration is no greater than 270 fs (Fig. 2) at a repetition rate of 14 MHz, a mean radiation power of up to 250 mW, and a wavelength of 1.6 μm. The spectral width of the radiation is 10 nm (Fig. 3), so that the output pulses are close to bandwidth-limited pulses. Note that, in such a configuration, the central wavelength of the output radiation is red-shifted by about 50 nm relative to a standard wavelength of 1550 nm. The maximum pulse energy of the

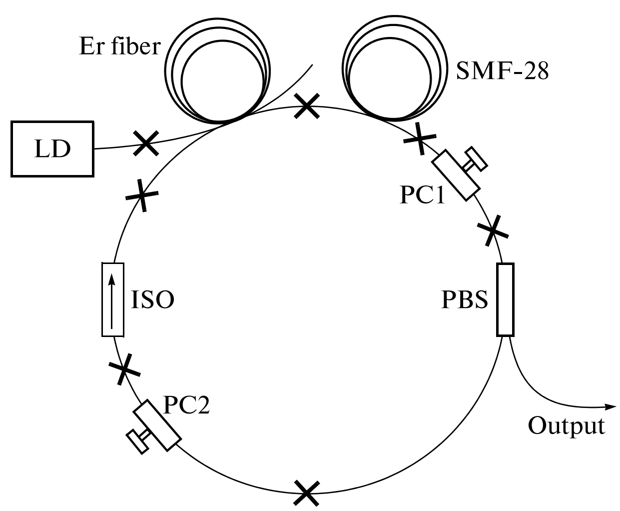

Fig. 1. Scheme of the all-fiber erbium laser: LD pumping laser diode, PC1 and PC2 polarization controllers, ISO optical isolator, and PBS polarization beam splitter.

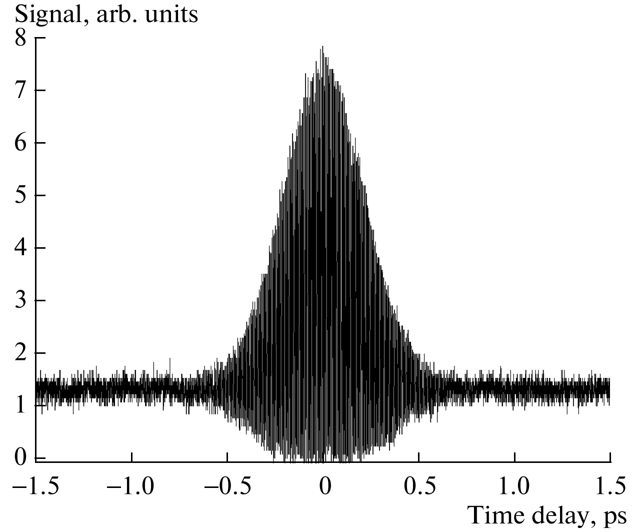

Fig. 2. Autocorrelation function of the output pulses of the Er master oscillator.

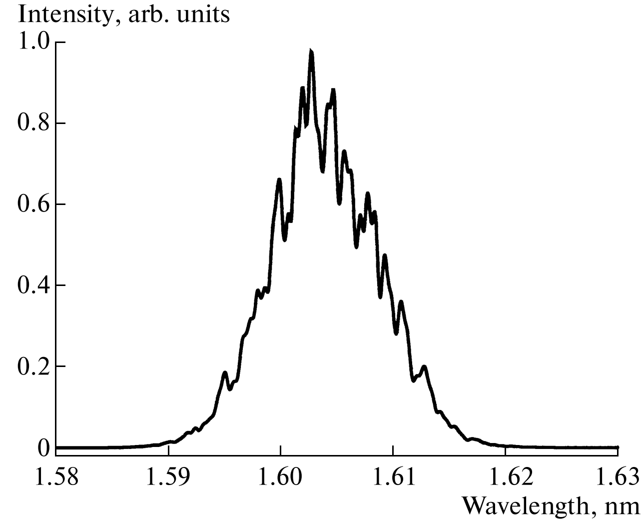

Fig. 3. Spectrum of the output radiation of the Er master oscillator.

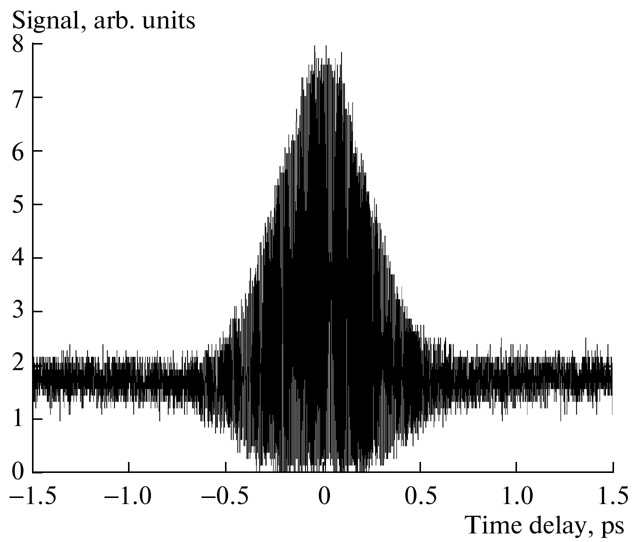

Fig. 4. Autocorrelation function of the amplified pulses of the fiber system.

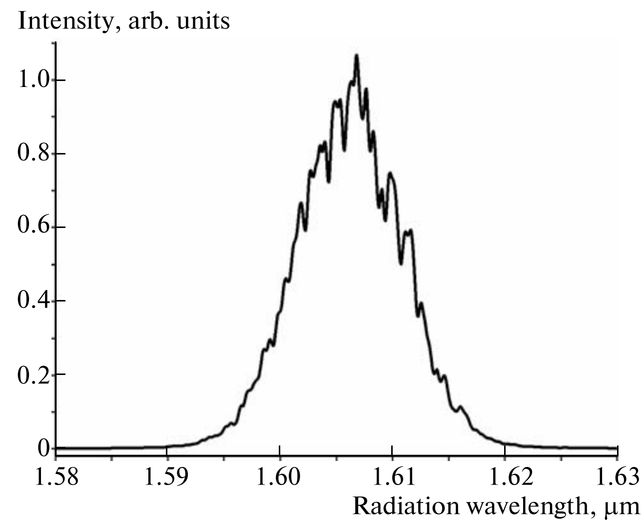

Fig. 5. Spectrum of the output radiation of the fiber system.

master oscillator is up to 20 nJ, and the peak power is 65 kW.

For the pulse amplification, we employ similar side-coupled fibers with a length of 14 m and a core diameter of the erbium-doped fiber of about 20 μm. The amplifier is pumped by a laser diode with a wavelength of 975 nm and a power of 12 W. The pulse duration at the exit of the amplifier increases to 360 fs (Fig. 4), and the mean power, the pulse energy, and the peak power increase to 2 W, 150 nJ, and 450 kW, respectively. Figure 5 shows the spectrum of the output pulse of the amplifier, which is almost identical to the spectrum of the output pulse of the master oscillator accurate to a minor (several nanometers) red shift of the center. The absence of the spectral broadening of ultrashort pulses upon the amplification [9] is due to a relatively large mode area of the amplifying erbium-doped fiber.

Note that the spectral irregularities of the output radiation of the master oscillator are reproduced by the amplifier. Such a roughness of the radiation spectrum is observed in several mode-locked lasers with the anomalous dispersion of the cavity. In accordance with [10], the peaks on the wings of the radiation spectrum of a soliton laser with the nonlinear polarization mode-locking can be related to the fact that the polarization state is reproduced over several round trips rather than a single round trip of the cavity.

CONCLUSIONS

For the first time, we demonstrate a possibility of the all-fiber femtosecond laser system with a pulse duration of about 300 fs and a pulse energy of up to 150 nJ at a wavelength of about 1.6 μm based on side-coupled fibers one of which is doped with erbium and is pumped through the cladding. The structure of the proposed system allows a further increase in the pulse energy of the master oscillator and the amplified pulse energy at the pulse duration retained at a level of 300 fs owing to the application of relatively cheap multimode pumping lasers with higher powers.

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