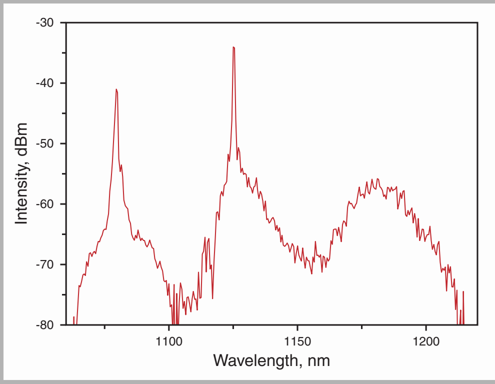
Abstract: For the first time we have suggested and realized passive Q-switched Yb-doped fiber laser with a saturable absorber based on Ho-doped fiber laser. The pulse duration was of 250 ns, the pulse energy – 70 μJ, the peak power – 300 W. The laser is perspective for technology processes. Possible ways of laser characteristics improving are discussed.



Output spectrum of Yb-Ho pulsed fiber laser

All fiber Yb-Ho pulsed laser

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At present CW Yb-doped fiber lasers [1] have found different applications. Q-switched fiber lasers due to high pulse energy allow one to increase a number of applications including medicine, material processing, range finding etc. Q-switched oscillation can be obtained using outer electro- or magnetomechanical devices [2,3], however all fiber pulsed lasers are of special interest since they keep all advantages of fiber lasers, namely compactness, absence of mechanical elements, long time stability etc. Up to now several schemes of such lasers were proposed and realized. One of them is self Q-switched fiber laser where to avoid CW lasing, a continuous feedback is suppressed by the isolation of the output laser end. In this scheme lasing is provided by the input Bragg grating and dynamic feedback caused by stimulated Brillouin scattering [4,5] or Rayleigh scattering [6]. Output energy of 0.17 mJ was achieved when the additional amplification of the laser emission was applied [7]. Disadvantage of this approach consists in instability of the train frequency and the pulse amplitude. Also there is a requirement to suppress the reflection from the output end that complicates laser applications. Another approach consists in the application of a fiber saturable absorber within the laser cavity.

Thus, Cr-doped fiber was used as absorber in Nd-doped fiber [8]. In [9] it was demonstrated that a placing of Sm-doped fiber in the cavity of Yb-doped fiber laser allows one to get the pulse generation occurring in extremely stable manner with pulse energy of approximately 20 μJ. A Q-switch pulse had a nearly perfect pulse shape with a $\sim$650 ns FWHM. The interesting approach was applied in [10], where Bi-doped fiber played a role of the saturated absorber. In contrast to Cr and Sm-doped fibers, Bi

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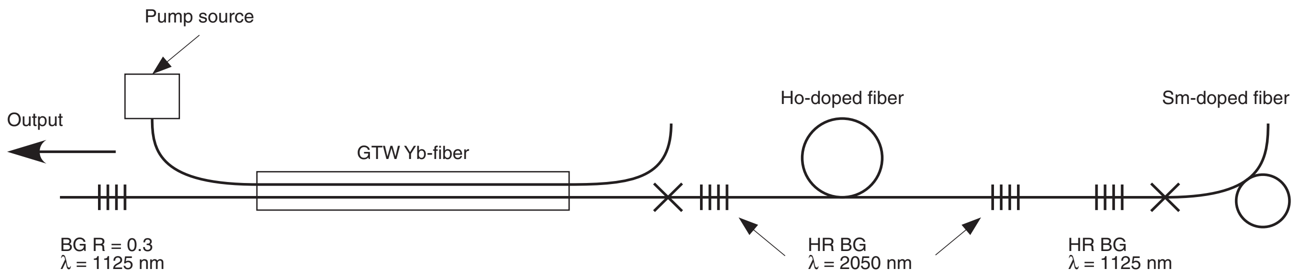

Figure 1 (online color at www.lphys.org) Configuration of the Yb-Ho fiber pulsed laser

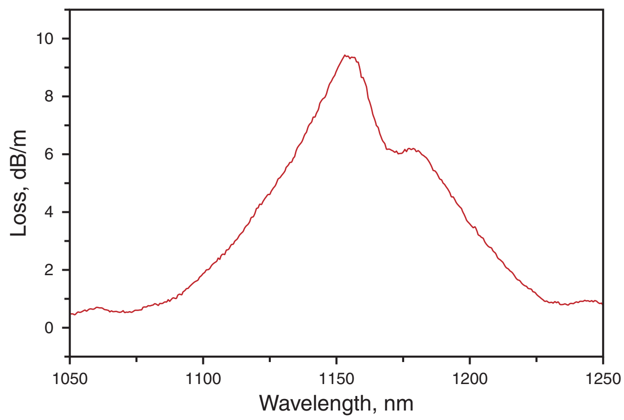

Figure 2 (online color at www.lphys.org) Absorption band of Ho-doped fiber

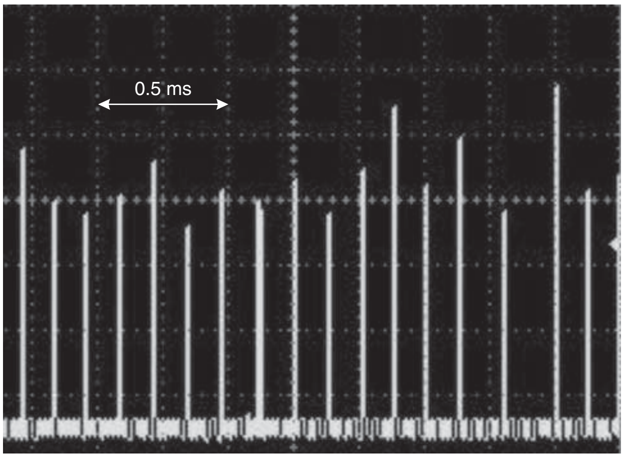

Figure 3 (online color at www.lphys.org) Oscillogram of the obtained pulse train

active centers have the long lifetime, ∼ 1 ms. To solve this problem Bi-doped fiber was placed in a separate cavity to achieve a laser action at its wavelength and consequently to decrease the lifetime of the active centers in the excited state. That allowed authors to demonstrate the stable pulsed lasing with the pulse energy up to 0.1 mJ and the pulse duration in a range of approximately 1 – 2 μs.

There are other codopants giving absorption bands in the oscillation spectrum range of Yb-doped fiber laser. In this paper we propose a new scheme of the passive Q-switched laser where Ho-doped fiber is used as the saturated absorber. Earlier this fiber type was used to get a lasing in a range 2 μm [11,12]. For these active ions the lifetime in the excited state is also long, namely approximately of 0.5 ms and we suggest close Ho-doped fiber by Bragg grating reflectors forming a separate cavity.

Laser scheme is shown in Fig.1. Yb fiber lasers were made using GTWave Yb-doped alumosilicate fiber with a length of 25 m. GTWave fiber was drawing in FORC RAS. Cladding pumping of the Yb-doped fiber was performed by a diode laser operating at 975 nm with a power up to 10 W. Laser cavity was closed by two Bragg gratings written in germanosilicate fibers spliced with the active medium. The Ho-doped fiber laser was used as a saturated absorber. The resonator was closed by two Bragg gratings having a high reflection at 2050 nm. To avoid a reflection from the unused laser end it was spliced with a piece of Sm-doped fiber, providing the absorption in a wide spectral range. Oscillation wavelength of Yb laser was chosen to be inside the absorption band of Ho-doped fiber centered at 1150 nm. The corresponded spectrum of Ho-ions absorption is shown in Fig. 2. It should be noted that the operation wavelength of 1150 nm is not "comfortable" for Yb-doped fiber laser [13] then we closed its cavity by Bragg gratings with the resonance wavelength at 1125 nm. The length of Ho-doped fiber was of 2.8 m that corresponds to the absorption of 10 dB at the emission wavelength of Yb laser.

Without Ho-doped fiber laser absorber we observed the stable CW operation of Yb-doped fiber laser at 1125 nm. Maximum output power has achieved 5.6 W for a pump power of 10 W. After splicing with Ho-doped fiber having one input grating only we get CW oscillation at 2050 nm with the output power up to 0.2 W. Pulsed oscillation was observed when Ho-doped fiber closed by two high reflective Bragg gratings was installed inside a cavity of Yb-

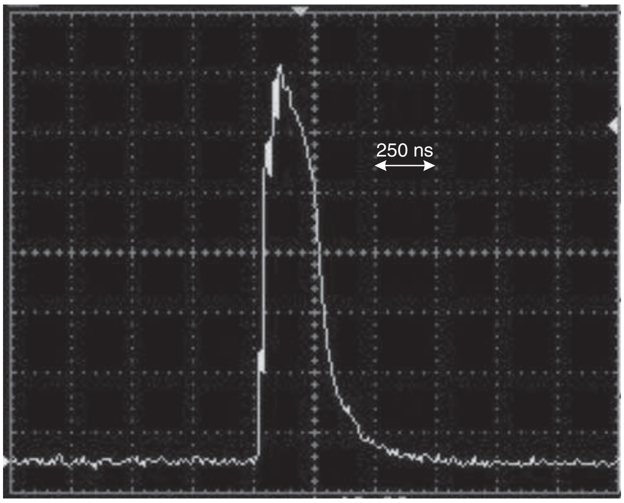

Figure 4 (online color at www.lphys.org) Shape of the individual pulse

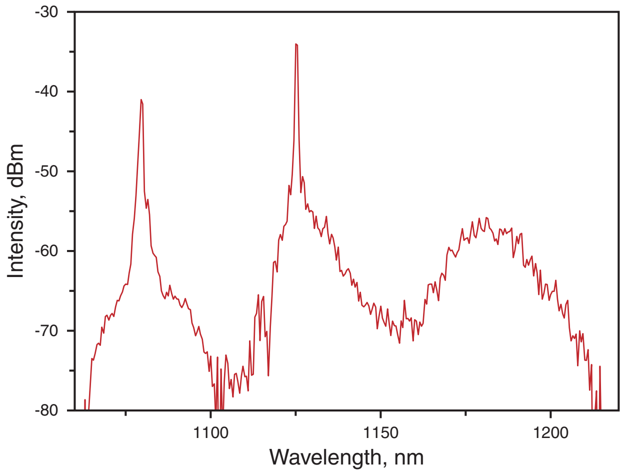

Figure 5 (online color at www.lphys.org) Output spectrum of Yb-Ho pulsed fiber laser

doped fiber laser. Typical observed pulse train is shown in Fig. 3. Fig. 4 illustrates the pulse shape. One can see that the pulse duration is of approximately 250 ns, that is shorter than in the case of lasers with Bi- or Sm-doped fiber absorber. Investigation of the output spectrum of the laser has shown that it contains three spectral bands of the oscillations. The correspondent spectrum is presented in Fig. 5. Main peak at 1125 nm is provided by resonance of Bragg gratings. The emission at 1080 nm can be explained by the spontaneous lasing in a range of the maximum amplified spontaneous emission. The wide band centered near 1180 nm corresponds to Stokes component of the main emission. Dynamic properties of the different components were studied using spectral decomposition of the output emission by the diffraction grating. It was observed that the temporal behavior is similar for all spectral components. Also we have measured that 75% of the total power is contained in the main peak at 1125 nm.

Threshold of the lasing was approximately of 2 W of pump power. Maximum of the average output power was of 0.55 W and maximum repletion frequency – 8 kHz. Pulse energy can be estimated as 70 μJ, and peak power – as 300 W. In spite of the relatively small output average power, the peak power is in few times higher than for Q-switched lasers with Bi- or Sm-doped fiber absorber (70 W and 30 W correspondingly) due to the smaller train frequency and shorter pulse duration. We have proved that achieved power if sufficient for the resistor trimming and drilling of thin steel plates.

It should be noted that the main reason of a lost of the lasing efficiency consists in the incomplete bleaching of Ho-doped fiber. Fig. 6 illustrates the transmission coefficient of the used Ho-doped fiber with a length of 3 m vs. introduced power at the wavelength of 1125 nm. One can see that the transmission is saturated at the level of

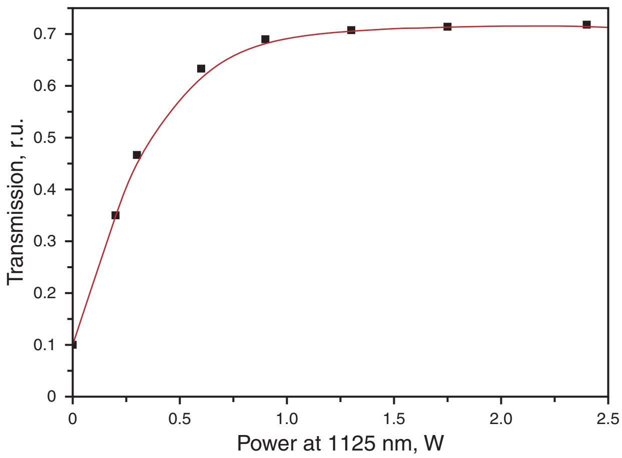

Figure 6 (online color at www.lphys.org) Transmission of Ho-doped fiber vs. introduced power

0.7. It means that in the Yb laser cavity there is a loss of 1.5 dB regardless of the pump power. We can believe that an origin of this incomplete bleaching consists in a the clustering of Ho-ions due to a high concentration. Similar effect is well known for Er-doped fibers [14]. Then, an efficiency improving can be achieved through the decreasing of Ho-ions concentration. On the other hand the relatively small average power with the high peak power give a good possibility for amplification of the obtained emission since requirements for an isolator between laser and amplifier will be not so strong. To avoid the spontaneous lasing near 1080 nm it is possible to modify the laser scheme and pump pulsed laser into the core by Yb-doped fiber laser emitting in a spectral range of 1070 – 1090 nm [15].

Thus for the first time we have suggested and realized the passive Q-switched fiber laser with a saturable absorber based on Ho-doped fiber laser. Energy characteristics of the laser allow on applying it for some technological process. Output power and energy can be increased through the additional fiber amplifier.

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