Features of passive mode-locking in a heavily-doped ytterbium fiber laser

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We have investigated features of the all-fiber heavily doped ytterbium laser operating in passive mode-locked regime with a repetition rate of ultrashort pulses of 456 MHz without the use of additional nonlinear optical elements. The generation dynamics of the heavily-doped ytterbium fiber laser assembled according to the classical Fabry-Perot scheme with two mirrors under continuous direct core pumping at the 976 nm wavelength was studied. The formation of ultrashort pulses as a result of passive mode-locking was shown [1]. Passive mode-locking is explained by saturation of the absorption, while the role of the saturable absorber was played by the active fiber itself with a high content of ytterbium ions. The principle of the created laser operation is similar to lasers operating in the passive mode-locking regime with the use of saturable absorbers [2,3].

The laser was created using a fiber with a high ytterbium oxide content, with a relatively low concentration of large cluster, which made it possible to avoid a high level of "gray" losses in the active fiber [4] (plasma chemical method). The absorption coefficient at the wavelength of 976 nm was about 2.4 dB / mm (Fig. 1). The ytterbium content in the glass corresponding to the measured absorption coefficient was 0.84 mol.% Yb_2O_3 [5]. The difference in the refractive index of the core and shell was 0.009, the core diameter was about 4 microns. The laser was assembled according to the classical Fabry-Perot scheme with an output (0.9) and high reflective (0.999) mirrors in the form of fiber Bragg gratings (FBG) with a maximum reflection at a wavelength of 1067.7 nm. A polarization controller (PC) was used to control birefringence in the laser cavity.

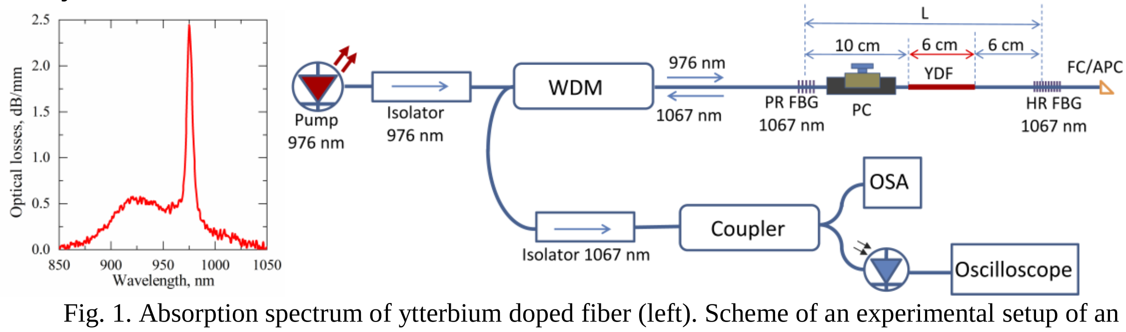

Fig. 1. Absorption spectrum of ytterbium doped fiber (left). Scheme of an experimental setup of an ytterbium fiber laser (right). OSA-optical spectrum analyzer, WDM-multiplexer, PC-polarization controller, L-resonator length

It is shown that depending on the pump power, the laser operates in three different regimes of passive mode-locking. At a low pump power (≈25-50 mW) a stable passive mode-locking regime (CW ML) was achieved, which is characterized by the stable in time ultrashort pulses amplitude (Fig.2a,b). The repetition rate of the ultrashort pulses for a 21.9 cm laser cavity was 456 MHz. The period of the pulses in the train coincides with the time of the cavity pass, which is consistent with the generally accepted theory of passive mode-locking [6]: $\Delta t=2nL/c$ (where L is the length of the cavity, n is the refractive index, and *c* is the speed of light). The observed passive mode-locking in the scheme under consideration can be explained by nonlinear absorption in the active fiber itself, which works similarly to saturable absorbers. The effect occurs on a weakly pumped section of the fiber, in which the population inversion and consequently the absorption level depends on the intensity of the stimulated emission in the cavity.

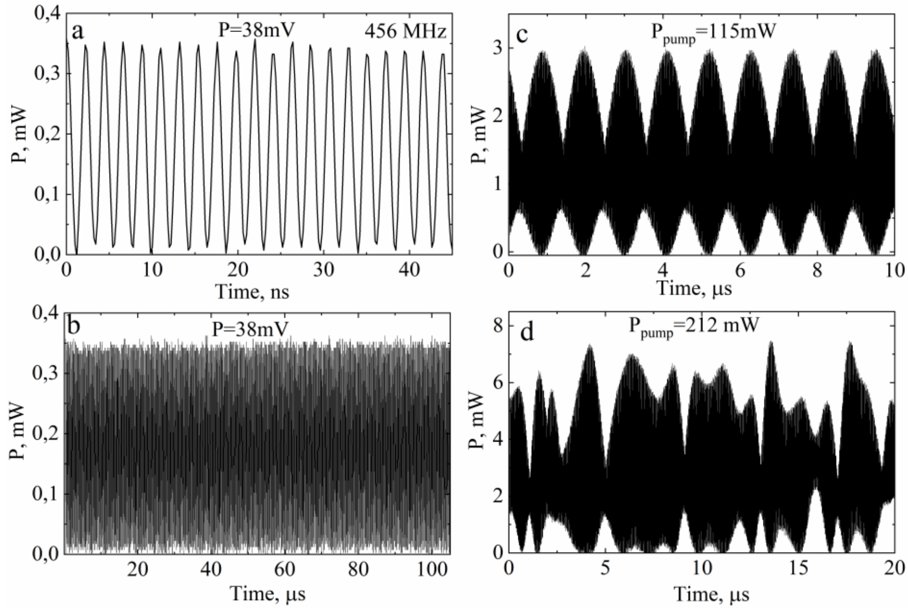

Fig. 2. Ytterbium laser generation power as a function of time at a pump power of 38 mW (stable passive mode-locking regime) at 40 nanosecond (a) and 100 microsecond scale (b), at a pump power of 115 mW (c) (beat mode) and at a pump power of 212 mW (d) (transient chaotic beat mode).

With pump power increase to ≈50-200 mW low-frequency beats occurred in the form of amplitude modulation of the generation intensity envelope (Fig.2c). The detected beats were explained by the dynamics of the elliptically polarized pulse train formation with rotating polarization components for group-velocity-locked vector solitons, which are also called polarization rotation vector solitons (PRVSs) [7]. With a further increase in the pump power (≈200-310 mW), transient chaotic beats (TC ML) appeared (Fig. 2d).

References

[1] A.M. Smirnov, O.V.Butov, *Optics Letters* **44**, 5065-5068 (2019)
[2] U. Keller, *Nature* **424**, 831-838 (2003)
[3] A. J. DeMaria, D. A. Stetser, H. Heynau, *Appl. Phys. Lett*. **8**, 174-176 (1966)
[4] K. Golant, *Proceedings of XXI International Congress on Glass*, L13 (2007)
[5] A.A. Rybaltovsky, O.V. Butov, *et al*, *Tech. Phys. Lett.* **42**, 498–500 (2016)
[6] P.G. Kryukov, *Quantum Electronics* **31**, 95-119 (2001)
[7] B.C. Collings, S.T. Cundiff, *et al*, *JOSA B* **17**, 354-365 (2000)
[8] I. Hartl, X.D. Li, C. Chudoba *Opt. Lett.* **26**, 608-610 (2001)
[9] O. Boyraz, J. Kim et al, *J. Lightwave Technology* **18**, 2167-2175 (2000)