Output power saturation of ytterbium-erbium doped fiber laser

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One of the effects limiting the output power in lasers based on erbium and ytterbium-erbium doped active media is saturation, which was theoretically predicted in the works [1,2]. In both works, the effect is explained by the existence of a "bottleneck" that restricts the transmission of excitation to the working level. In [1] it is said that the bottleneck is the transition between the levels of erbium $^4I_{11/2} \rightarrow {}^4I_{13/2}$.

This paper presents for the experimental observations of this effect in an ytterbium-erbium doped fiber laser, and a convenient formula for estimating saturation power is theoretically derived.

Figure 1 shows the scheme of the experiment. Three lasers consisting of ytterbium-erbium doped active fiber supporting polarization, fiber brag gratings, and fiber polarizers were studied. The parameters of the used active fibers are shown in Table 1. The lasers were pumped at 1065 and 1070 nm by single-mode radiation into the core of the active fiber.

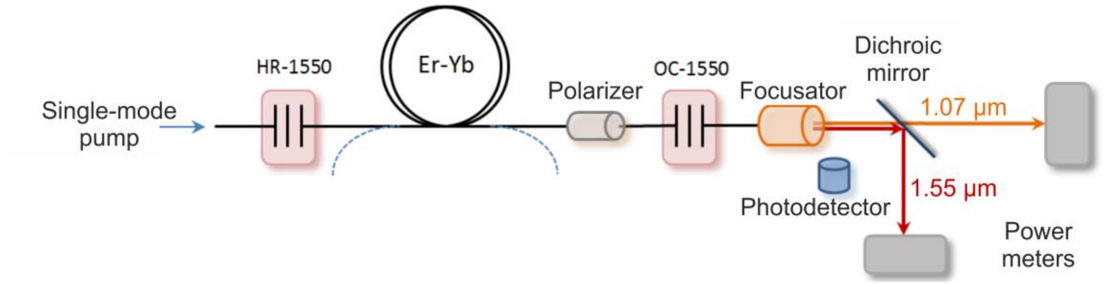

Fig.1. Scheme of the experiment.

Figure 2 shows the watt-watt characteristic of a laser with 5 m length active fiber. The signal power of 1550 nm at low pump power increases with a differential efficiency of 27% and reaches saturation at ~15W. The saturation effect is observed for each laser. The corresponding values are shown in table 2.

The output power of the laser system is limited, since the number of erbium ions involved in generation is limited, and there is a finite time in which the ion can receive energy and transfer part of it to the external environment in the form of electromagnetic radiation.

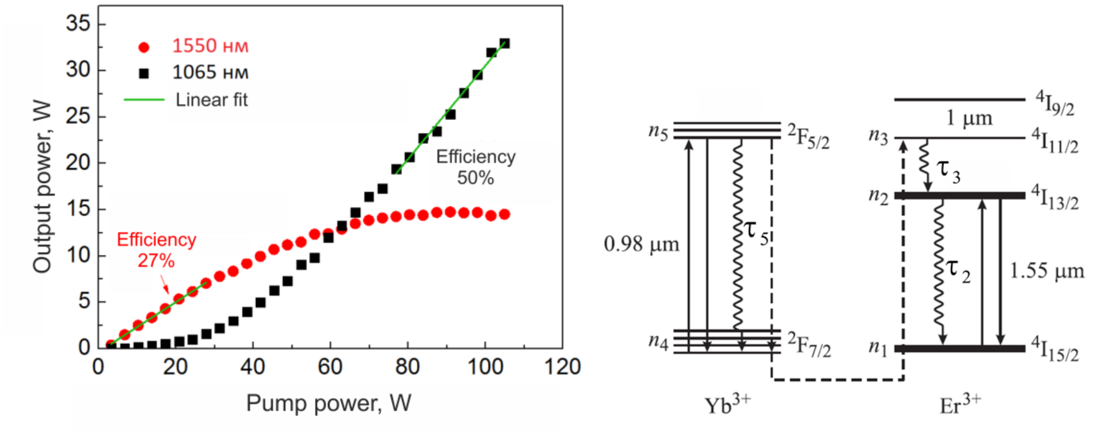

Fig.2. The dependence of the received output power at 1550nm and the unabsorbed pump at 1065nm on the pump power (left) and the scheme of energy levels in the ytterbium-erbium active medium (right).

Based on the assumption that the generation bottleneck is the transition $^4I_{11/2} \rightarrow {}^4I_{13/2}$ (Fig.2) a formula for the saturation power can be obtained P_{sat}:

$$P_{sat} = \frac{hc}{\lambda_s}\frac{N_{Er}}{\tau_3}\left(1+\frac{\sigma^e_{Yb}}{\sigma^a_{Yb}}\left(1+\frac{\sigma^a_{Er}}{\sigma^e_{Er}}\right)\right)^{-1}$$

Where N_{Er} - number of erbium ions in the medium, τ_3 - lifetime at the level $^4I_{11/2}$, λ_s - the wavelength of the signal, $\sigma^a_{Er}, \sigma^e_{Er}, \sigma^a_{Yb}, \sigma^e_{Yb}$ - absorption and luminescence cross sections of the working levels of erbium and ytterbium, respectively, h – Planck's constant, c – speed of light.

Based on experimental data and the proposed formula, we estimated the lifetime of the level $^4I_{11/2}$ (Tab.1). It can be seen that the saturation powers P_{sat} differ significantly for lasers with different amounts of erbium ions and pump wavelengths, however, the restored lifetimes τ_3 have approximately the same values. In the world literature, this time for phosphate glass media is in the range 1-3 μs [1,3].

Table.1. Active fiber parameters and experimental results

Active fiber length, m	Active fiber core diameter, μm	Erbium ions concentration, ppm	Pump wavelength, nm	P_{sat}, W	τ_3, μs
4	9,1	230	1070	1,7	1,53
6	9,1	230	1070	2,5	1,56
5	18	300	1065	15	1,38

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