Theoretical and Experimental Study of Signal Gain in Er-doped fiber

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Abstract: We propose the analytical method to estimate the saturation power and small signal gain of Er-doped fiber from the simple experimental measurements. The results may be useful for numerical simulation of fiber laser systems.

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1. Introduction

Propagation of a signal in an active fiber in mode-locked fiber lasers is governed by the generalized nonlinear Schrödinger equation (NLSE) with the gain saturation term [1, 2]:

$$\frac{\partial A}{\partial z} = -i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} + \frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3} + i\gamma|A|^2 A + \frac{g_A}{1+E/(P_{\mathrm{sat}}\cdot T_R)}A - \alpha_A A, \tag{1}$$

where $A(t,z)$ denotes the complex envelope of the radiation, β_2 and β_3 are the dispersion coefficients, γ is the nonlinearity, α_A denotes fiber losses, E is the pulse energy, T_R is the round-trip time, g_A is the small signal gain, and P_{sat} is the saturation power.

It should be noted that to apply formula 1 and to carry out the numerical experiment it is necessary to know the saturation power and the small signal gain. However, the fiber specifications usually detail only the absorbtion coefficient at the pump wavelengths. Thus, the only way to obtain P_{sat} and g_A is to derive them analytically from experimental results.

In this work, we have obtained the dependence between the gain coefficient and the input signal power based on the experimental measurement of the signal gain in an Er-doped fiber for different fiber lengths and pump powers. We have also developed the theoretical algorithm to find P_{sat} and g_A of the Er-doped fiber for different lengths and different pump powers without needing to carry out additional experimental measurements.

2. Experimental setup

The measurement scheme of the erbium fiber gain is shown in figure 1. It consists of the gain medium (i.e. the erbium-doped fiber), the CW laser source, the variable attenuator, the multiplexer, the pump diode, and the spectrometer.

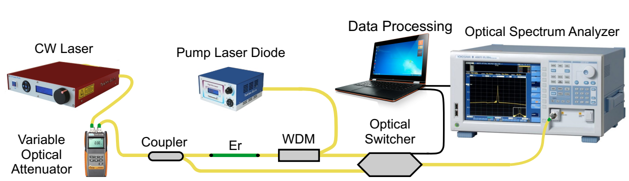

Fig. 1. The scheme of the experiment.

The pump of the erbium fiber is produced by a laser diode at 980 nm. Before the pump signal reaches the erbium fiber, it passes through the multiplexer. The maximum pump power is 400 mW. To generate the input signal, the continuous radiation of 15 mW generated by a CW-laser at 1550 nm is used. Using the described scheme, the experimental dependence of the gain coefficient on the input power has been obtained for different fiber lengths and different pump powers.

3. Theoretical approximation

Let us theoretically derive the small signal gain and the saturation power as a function of the pump power and the fiber length. This dependence is derived from the experimental data and theoretical formulae [3, 4] that enable to estimate the average power at the input of the active fiber. In [3, 4], the input power is represented as a function of the fiber length, fiber losses, the saturation power, and small signal gain. Figure 2a demonstrates the experimental (dots) and the theoretical (solid lines) dependence of the gain coefficient on the input power. As it can be seen from figure 2a, the theoretical results are in a good agreement with the experimental results.

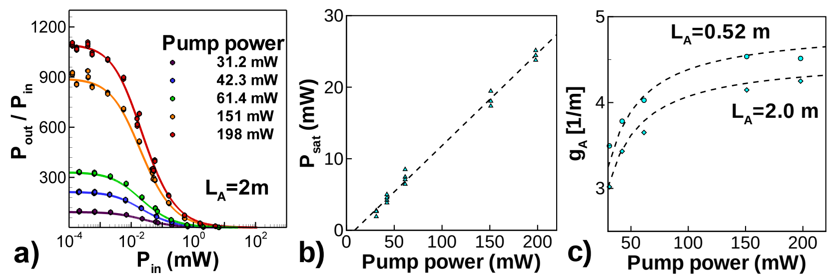

Fig. 2. a) The comparison of theoretical and experimental dependence of the gain coefficient on the input power, the active fiber length is 2 m; b) The dependence of P_{sat} on the pump power; c) The dependence of a small signal gain on the pump power for different fiber lengths.

Figure 2b shows the dependence between the saturation power and the pump power. Figure shows that the saturation power depends linearly on the pump power and does not depend on the active fiber length.

In figure 2c the dependence of the small signal gain on the fiber length and pump power is depicted. It can be seen from figure 2c that the small signal gain reaches the following limit for large pump powers:

$$g_A\,[1/\text{m}] = \frac{A + B\cdot P_{\text{pump}}}{1 - C\cdot P_{\text{pump}}\exp(-DL_A)}. \tag{2}$$

Here coefficients $A = -2.25\cdot 10^5$ 1/m, $B = 2.3\cdot 10^4$ 1/(mW·m), $C = -4.54\cdot 10^3$ 1/mW, and $D = 0.05$ 1/m. The formula presented above was derived from two-level effective gain model [5].

4. Conclusion

The dependence of the gain coefficient on the input power has been found experimentally for different fiber lengths and pump powers. The theoretical method to estimate the saturation power and the small signal gain of the Er-doped fiber has been proposed. The results may be useful for optimization of the fiber laser systems by means of numerical simulation. The work was supported by the Russian Ministry of Education and Science (project RFMEFI57814X0029).

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