Output characteristic of Yb^{3+}-doped fiber laser at different temperatures

Jixin Chen (陈吉欣)[1,2], Zhan Sui (隋 展)[2], Fushen Chen (陈福深)[1], and Jianjun Wang (王建军)[2]

[1] *Key Laboratory of Optical Fiber, School of Communication and Information Engineering, University of Electronic Science and Technology of China, Chengdu 610054*

[2] *Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang 621900*

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The output characteristics of Yb^{3+}-doped fiber laser at different temperatures are investigated. When temperature is increased from 13 to 95 °C, the center wavelength of laser changes from 1084.9 to 1096.3 nm, the output laser power decreases from 0.95 to 0.58 W, and the slope efficiency drops from 30.7% to 25.5%.

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Compared with traditional solid state laser, fiber laser has many advantages, such as high efficiency, high beam quality, good reliability, and good heat dissipation[1]. Yb^{3+}-doped fiber laser has been attracted great attention due to simple energy level, no excited state absorption, and wide band tunable range[2]. Some papers about temperature effect of Er^{3+}-doped fiber laser and amplifier were reported[3,4]. This paper demonstrates output characteristics of Yb^{3+}-doped fiber laser at different temperatures.

Temperature can affect the absorption and emission cross sections. The absorption and emission cross sections increase with increasing temperature. The absorption and emission cross sections are related by[5]

$$\sigma_{\mathrm{es}} = \sigma_{\mathrm{as}} \exp\left[\left(\varepsilon - h\nu\right)/kT\right], \tag{1}$$

where σ_{as} and σ_{es} are absorption and emission cross sections respectively, ε is active energy and depends on temperature T. h is Planck constant, ν is the light frequency, and k is Boltzmann constant.

Active energy ε is given by[6]

$$\frac{N_1}{N_2} = \exp(\varepsilon/kT), \tag{2}$$

where N_1 and N_2 are Yb^{3+}-doping concentrations at upper and lower energy levels, respectively.

Transition in Yb^{3+}-doped fiber laser can occur between ${}^2F_{5/2}$ and ${}^2F_{7/2}$ Stark energy levels, as shown in Fig. 1. According to Boltzmann distribution, we can obtain

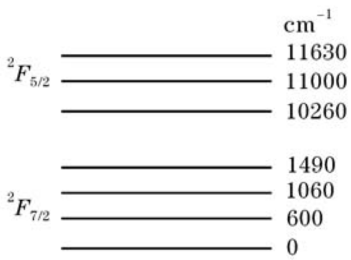

Fig. 1. Energy diagram of Yb^{3+}-doped fiber laser.

$$\frac{N_1}{N_2} = \frac{\sum\limits_{j=1}^{4} \exp(-E_{1j}/kT)}{\sum\limits_{j=1}^{3} \exp(-E_{2j}/kT)}, \tag{3}$$

where E_{1j} and E_{2j} are sub-level energies at lower and upper energy levels, respectively.

Using the absorption cross section[2,7,8], the emission cross section can be obtained from Eqs. (1), (2), and (3). Neglecting scattering loss and the variation of z direction, the small signal gain can be expressed as

$$G\left(\lambda\right) = \Gamma_{\mathrm{s}}\left[\left(\sigma_{\mathrm{as}} + \sigma_{\mathrm{es}}\right)N_2 - \sigma_{\mathrm{as}}N\right]L, \tag{4}$$

where Γ_{s} is the overlapping factor of laser, L is the fiber length, N is the total Yb^{3+} concentration.

Figure 2 shows the gain at $T = 300$ K and $T = 370$ K. In the calculation, $N = 4 \times 10^{25}$ m^{-3}, $\Gamma_{\mathrm{s}} = 0.82$, $L = 55$ m, $N_2 = 0.02N$. With the increase of the temperature, the range of positive gain moves to a longer wavelength, and gain drops. Therefore, the output laser wavelength shifts to a longer wavelength, and the output laser power and slope efficiency decrease with increasing the temperature.

The experimental setup is shown in Fig. 3. A laser diode (LD) is used, whose central wavelength is about

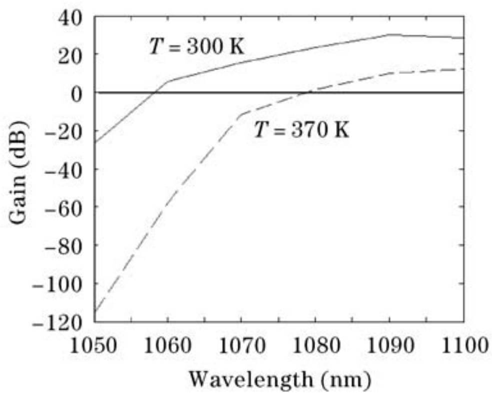

Fig. 2. Gain at different temperatures.

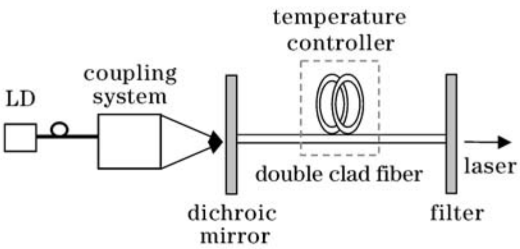

Fig. 3. Setup of double clad fiber laser.

975 nm and the maximum output power is about 6 W. The coupling system consists of six aspheric lens, and can collimate and focus the pump light. The inner cladding of double-clad Yb^{3+}-doped fiber is D shape of 320×400 (μm) with a numerical aperture (NA) of 0.35. The core is 3.5-μm diameter with a NA of 0.152. The absorption coefficient of 975 nm is about 0.1 dB/m. The fiber length is 55 m. A dichroic mirror (975 nm, $T > 95\%$; 1050—1100 nm, $R > 99\%$) is touched to the front fiber end tightly. A filter (975 nm, $R > 99\%$; 1050—1100 nm, $T > 90\%$) is attached to the back fiber end. The fiber is placed on two five-dimensional (5D) adjusting shelves which can adjust the position of fiber end precisely. The temperature controller is a small water tank whose temperature can be changed exactly. In a stable case, the temperature fluctuates less than 1 °C for a longer time, and the fiber can be heated uniformly.

Firstly, we investigate the fiber laser at room temperature (13 °C). The central wavelength is 1084.9 nm, and no 975-nm pump light is observed obviously. At room temperature, the output power is 0.95 W, and the slope efficiency is 30.7%. Secondly, we place the fiber in the temperature controller carefully, and observe and record the laser spectrum at different temperature. At the same launched pump power of 3.3W, with the increase of temperature, the central wavelength shifts from 1084.9 to 1096.3 nm (see Fig. 4), the output power decreases for 0.95 to 0.58 W (see Fig. 5), the slope efficiency drops from 30.7% to 25.5% (see Fig. 6).

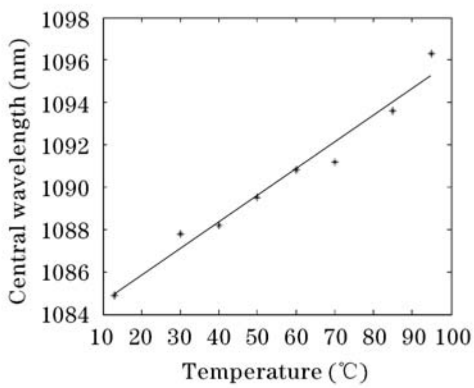

Fig. 4. Central wavelength versus temperature.

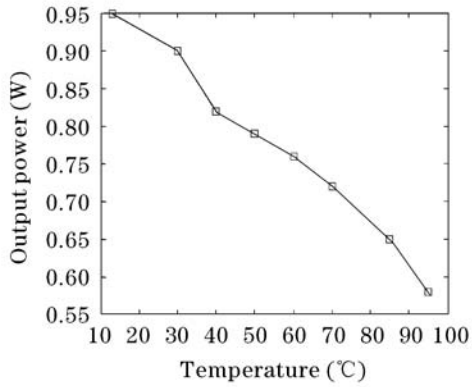

Fig. 5. Output laser power versus temperature.

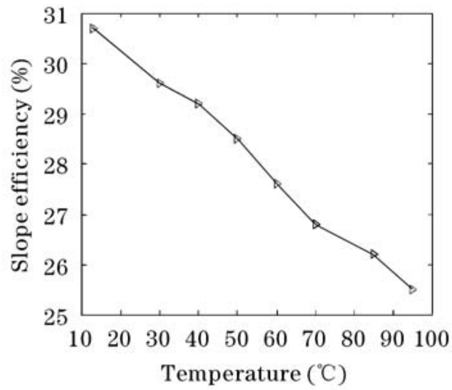

Fig. 6. Slope efficiency versus temperature.

In conclusion, we have studied output characteristics of Yb^{3+}-doped fiber laser at different temperatures. The output power and slope efficiency fall and the central wavelength shifts to a longer wavelength with increasing the temperature.

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