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Diode-Pumped Nd:GGG Laser at 937 nm under Direct Pumping[1]

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Abstract—A diode-pumped 937 nm Nd:GGG laser operating on the quasi-three-level under direct pumping at wavelength of around 882 nm is demonstrated, and its performances are investigated. A maximum output power of 358 mW at 937 nm was achieved at absorbed pump power of 4.8 W. The optical-to-optical conversion efficiency and the slope efficiency relative to absorbed power were 7.5 and 11.2%, respectively.

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1. INTRODUCTION

Nd:GGG crysal was first fabricated by Linares with CZ method in 1964 [1]. It has many advantages compared to Nd:YAG, for example, with the conventional growth method it can be grown with higher Nd^{3+} ion without the considerable luminescence quenching due to its bigger segregation coefficience (0.52) relative to that of Nd:YAG (0.2) [2]. Nowadays, the Nd:GGG is known for its extensive use in the solid state heat capacity laser owing to available large size and high optical properties [3, 4].

The quasi-three-level laser transition of Nd^{3+} lasers around 900 nm has many applications. For example, it has been recognized as an effective way to realize blue laser by intra-cavity frequency doubling. Nd:GGG can emit 937 nm laser under the quasi-three-level operation [5]. However, there are few reports relevant to Nd:GGG laser so far because the $^4F_{3/2} \longrightarrow {}^4I_{9/2}$ transition at 937 nm is difficult to obtain due to the spectroscopic properties of the quasi-three-level such as serious re-absorption loss and very small stimulated emission cross section compared with the $^4F_{3/2} \longrightarrow {}^4I_{11/2}$ transition at 1.06 μm, and most of the operations were under the conventional pumping at around 808 nm [6–12].

As is well known, conventional pumping at around 808 nm for the Nd^{3+} lasers has been widely used owing to the large-absorption cross section of the transition $^4I_{9/2} \longrightarrow {}^4F_{5/2}$. But pumping at around 808 nm into the $^4F_{5/2}$ level above the upper laser level $^4F_{3/2}$ will generate heat inside the laser material due to Stokes shift, quantum efficiency and other parasitic effects such as upconversion and concentration quenching, which will induce the thermal effect inside the laser material and influence the laser output power and the beam quality at least to some extent. Recently, the direct pumping first demonstrated in 1968 [13] has received many attentions [14–21] because of its efficient lasing and reducing the heat about 30–40% inside laser material compared to conventional pumping. For Nd-doped crystals, the direct pumping has two specific types: ground-state direct pumping and thermally boosted pumping. The ground-state direct pumping corresponds to the transition from the first Stark sublevel Z1 of the ground manifold $^4I_{9/2}$ of Nd^{3+} to the upper laser level; thermally boosted pumping corresponds to the transition from the second Stark sublevel Z2 of the ground manifold $^4I_{9/2}$ to the upper laser level [22, 23]. In this paper, we present the successful operation of 937 nm Nd:GGG laser under thermally boosted pumping at the wavelength of about 882 nm for the first time to the best of our knowledge; the output power of 358 mW at 937 nm is obtained under an absorbed pump power of 4.8 W; the optical-to-optical conversion efficiency and slope efficiency relative to absorbed power are 7.5 and 11.2%, respectively.

2. EXPERIMENTAL SETUP

The experimental layout of a simple linear resonator is shown in Fig. 1. The pump source was a high-brightness fiber-coupled diode laser with a fiber core diameter of 400 μm and numerical aperture of 0.22. The central wavelength of the pump source was 885 nm. A 2:1 coupling system was used to inject the pump laser beam into the Nd:GGG crystal.

The absorption spectrum of the Nd:GGG crystal with Nd^{3+} concentrations of 0.5 at % in the region of 780–900 nm were measured as shown in Fig. 2. From

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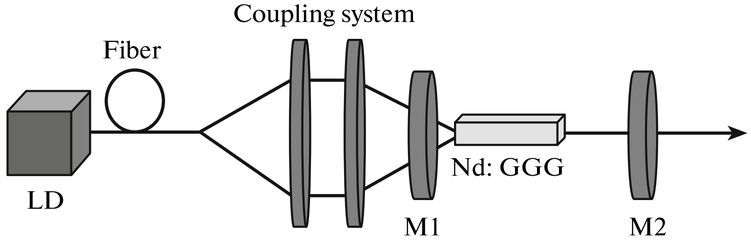

Fig. 1. Setup of the diode-pumped 937 nm Nd:GGG laser under direct pumping.

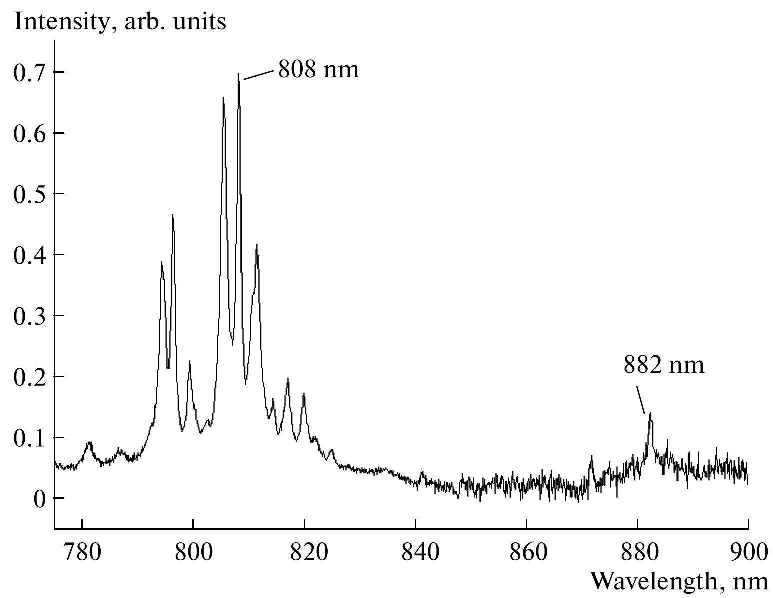

Fig. 2. Absorption spectrum of Nd:GGG crystals.

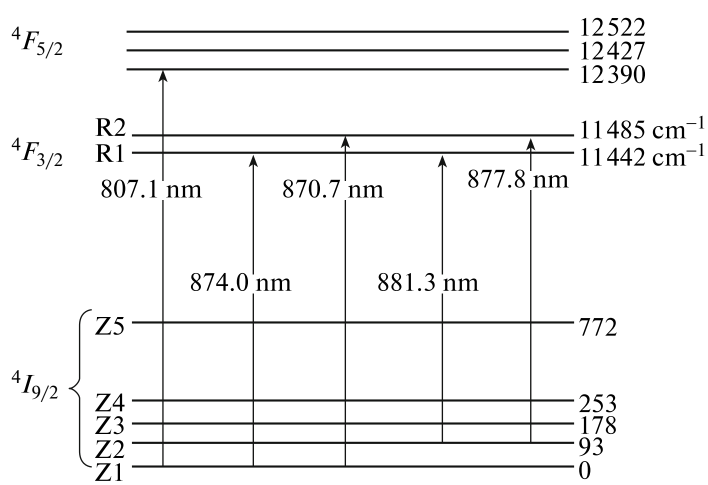

Fig. 3. Energy level diagram of Nd:GGG at room temperature.

Fig. 2 we can see that the Nd:GGG has an absorption peak at around 882 nm besides 808 nm. Figure 3 is the energy level diagram of Nd:GGG. Comparing Fig. 3 with Fig. 2, we can find that 882 nm just corresponds to the transition Z2 $\longrightarrow$ R1 of Nd^{3+}. Thus, on one hand, in order to improve the efficiency of the pump

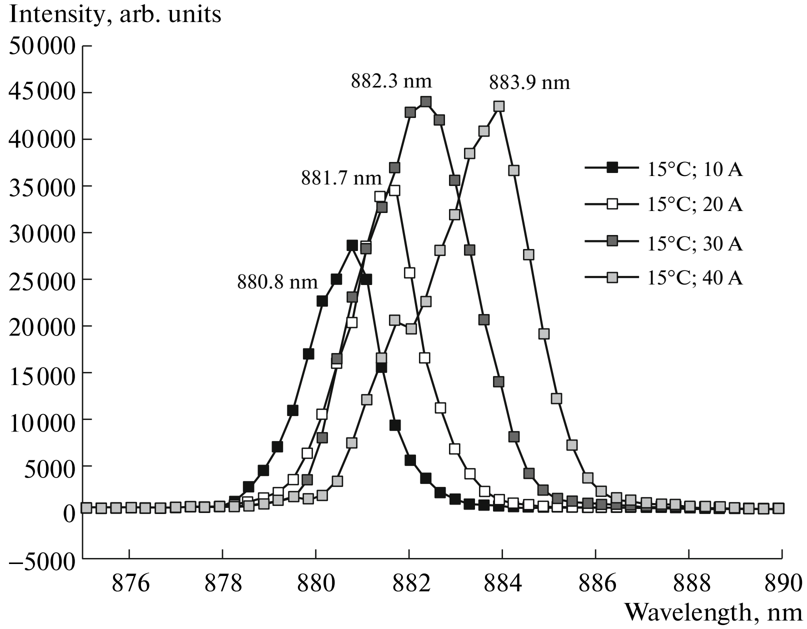

Fig. 4. Pump wavelength of the pump source under different pump powers with the temperature of the LD at 15°C.

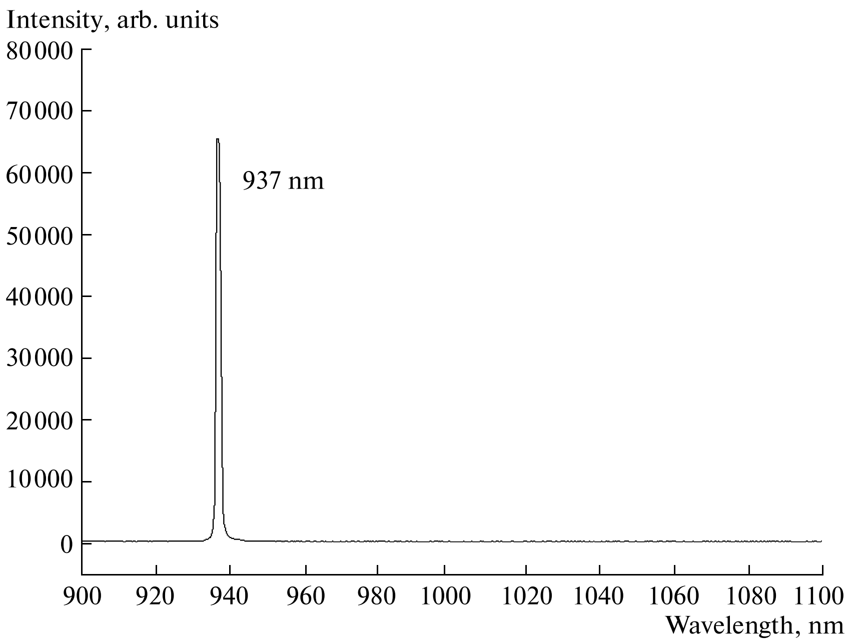

Fig. 5. Spectrum of the diode-pumped Nd:GGG laser at 937 nm.

power, we tried to set the pump wavelength near to 882 nm by deduce the temperature of the LD. On the other hand, in order to avoid the damage of LD, we kept the temperature at 15°C. The dependence of pump wavelength on the pump power is shown in Fig. 4.

We totally used 3 Nd:GGG crystals in our experiment, one 0.5 at % doping with dimensions of 3 × 3 × 5 mm^3; two 1.0 at % doping with sizes of ϕ 5 × 5 and ϕ 5 × 7 mm^3, respectively. To keep a stable and efficient output, the Nd:GGG crystals were mounted in a water-cooled heat sink. To decrease the loss in the cavity and prevent parasitic oscillations in the Nd:GGG crystal, both sides of the Nd:GGG crystals were coated for antireflection (AR) at 882, 937 nm, 1.06 and 1.34 μm wavelengths. Flat mirror M1 served as an

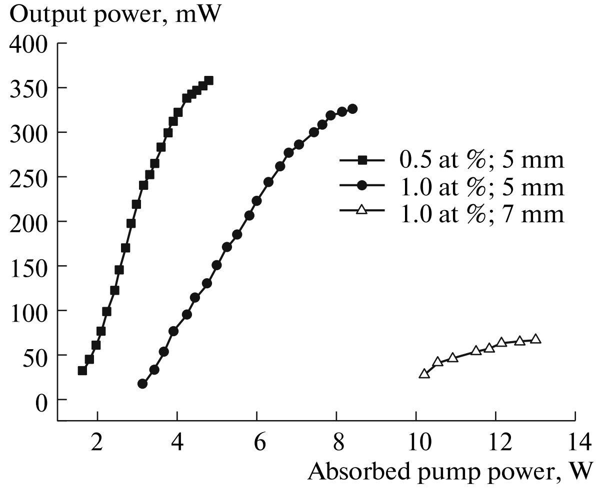

Fig. 6. Output power of the 937 nm laser versus the absorbed pump power with temperature of 10°C for different Nd:GGG crystals.

input coupler, which has high reflection (HR) coating at 937 nm and high transmission (HT) coating at 882 nm, 1.06 and 1.34 μm. M2 was a concave mirror with curvature radius of 80 mm and transmission of 3.2% at 937 nm.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The output spectrum of the laser is shown in Fig. 5, where only one emission peak at 937 nm is presented and it is implying that the four-level laser transition is prevented effectively.

The output power of the 937 nm laser versus the absorbed pump power at 10°C for different Nd:GGG crystals is shown in Fig. 6. From Fig. 6 we can see that better result was obtained for the 0.5 at % Nd-doped Nd:GGG crystal with dimensions of $3 \times 3 \times 5$ mm^3, for which the laser threshold (relative to absorbed power) was 1.6 W. The maximum output power was 358 mW at the absorbed pump power of 4.8 W, the optical-to-optical conversion efficiency and slope efficiency (relative to absorbed power) were 7.5 and 11.2%, respectively. The optical-to-optical conversion efficiency and slope efficiency (relative to absorbed power) were not very high in our experiment which could be caused by several reasons. Firstly, the relative absorption intensity at about 882 nm of the Nd:GGG crystal was smaller than that at 808 nm, as shown in Fig. 2 obviously. In addition though we tried to realize the matching of the pump wavelength and the absorption wavelength of the Nd:GGG crystal by reducing the temperature of the LD to 15°C, from Fig. 4 we can see that the deviation still existed, i.e., the central wavelength of the pump source departed about 2 nm from the central wavelength (882 nm) of the absorption bands of the Nd:GGG crystal at higher pump power. It was unfavorable for the utilization of the incident pump power and result in the low efficiency. Secondly, the 937 nm laser emission belongs to the quasi-three-level laser transition. The lower laser level is in the thermally populated ground state which will lead to a significant re-absorption loss at room temperature. Thirdly, the output is related with many parameters of the cavity such as the length of the cavity, the transmission and the curvature radius of M2. Restricted by available experimental condition at hand the highest output power we got was just that can be optimized at existing condition. By improving experimental conditions better result is hopeful.

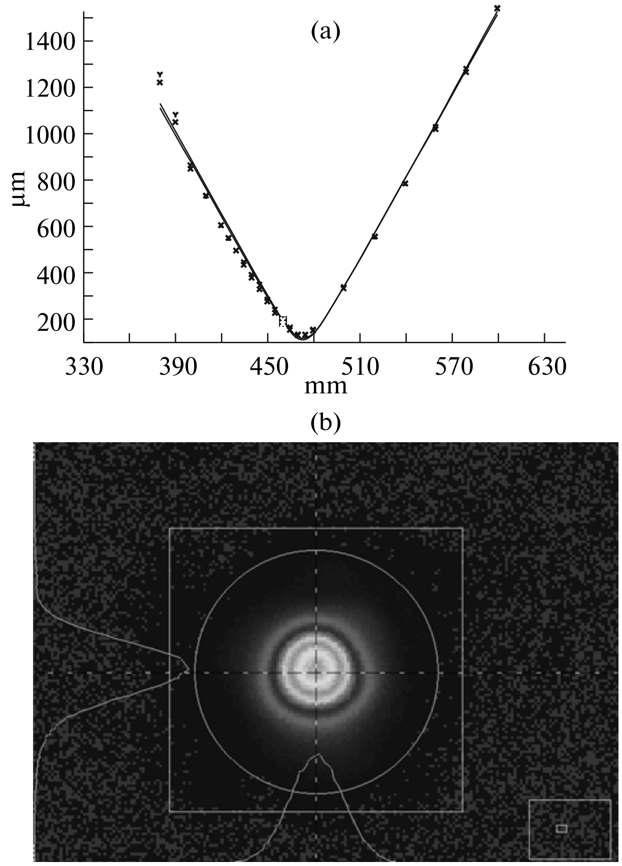

Fig. 7. (a) Beam quality of the 937 nm emission at the output power of 358 mW. (b) Laser beam profile at the output power of 358 mW.

The beam quality of the 937 nm laser at output power of 358 mW was measured by using an M^2 factor measurement. According to the measured data the fitted result is shown in Fig. 7a, from which we can see that the laser was oscillated in the fundamental transverse mode. The value of the M^2 was about 1.1. Typical beam profile was also measured and which is shown in Fig. 7b, and it can be seen that the laser intensity distribution was very symmetrical.

4. CONCLUSIONS

In conclusion, we have realized the successful operation of the 937 nm laser under direct pumping. Output power of 358 mW was obtained under absorbed pump laser of 4.8 W. The optical-to-optical conversion efficiency and slope efficiency (relative to absorbed power) were 7.5 and 11.2%, respectively. Better result will be obtained with optimizing experiment condition.

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