Diode end-pumped 1123-nm Nd:YAG laser with 2.6-W output power

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Received December 1, 2004

We present a compact and high output power diode end-pumped Nd:YAG laser which operates at the wavelength of 1123 nm. Continuous wave (CW) laser output of 2.6 W was achieved at the incident pump power of 15.9 W, indicating an overall optical-optical conversion efficiency of 16.4%, and the slope efficiency was 18%.

OCIS codes: 140.0140, 140.3460, 140.3480.

Nd:YAG is a very superior material for diode-pumped high-power lasers due to its excellent thermal properties and output characteristics. Generally, Nd:YAG laser operates at the most commonly used wavelengths of 1064, 1319, and 946 nm. However, in recent years there has been a great interest in 1123-nm Nd:YAG laser with high-power output[1−4] due to its wide applications. For example, the 1123-nm laser can be used as a pumping source for thulium upconversion fiber lasers to generate blue laser emission at 481 nm[5]. The blue lasers are required for red/green/blue (RGB) color displays, printing, and data recording. The 1123-nm laser also can be used for double frequency to generate yellow laser, which is desirable in medical and dermatology applications, bio-fluorescence experiments, and holographic storage etc.[6]. The key technique to make 1123-nm oscillation is to suppress the parasitic oscillation at 1064 nm, because the stimulated emission cross section for the 1123-nm transition is only 3×10^{-20} cm^2, which is approximately 15 times smaller than that for the 1064-nm line[7].

Previously, Moore *et al.* have demonstrated a diode-pumped continuous wave (CW) Nd:YAG laser at 1123 nm with 1.7-W output power[4]. Chen *et al.* have reported a passively and actively acousto-optical Q-switched diode-pumped 1123-nm Nd:YAG lasers, whose average output powers are 150 mW and 3 W, respectively[2,3]. Here, we report a compact CW 1123-nm Nd:YAG laser with 2.6-W output power.

The cavity we used is a plano-concave coupled-cavity resonator as depicted in Fig. 1. The Nd:YAG crystal has a Nd^{3+} doping concentration of 1.0 at.-% and a dimension of 5×5 (mm) in cross-section and 3 mm in length. In order to suppress the parasitic oscillation at 1064 nm, we carefully specified the coating for introducing high loss to the wavelength of 1064 nm. The laser crystal was coated for high reflection at 1123 nm ($R > 99.5\%$), high transmission at 1064 nm, and antireflection (AR) at 808 nm on one end surface. On the other end, a concave mirror (radius of curvature = 50 mm) was used as an output coupler, which has 2% transmission at 1123 nm. The other surface was AR coated for both 1123 and 1064 nm. The crystal was wrapped with indium foil and tightly mounted in a water-cooled copper holder. The holder temperature was maintained at 14 °C during the operation.

The pump laser was a fiber-coupled diode laser array at a wavelength of 808 nm (Lingyun Photoelectronic System Co., Ltd.). The diameter of the fiber bundle is 400 μm and the numerical aperture is 0.22. A 1 : 1 coupling system with 75% efficiency was used to image the pumping spot into the laser crystal.

In diode end-pumped solid-state laser, the laser gain medium absorbs the pump laser energy, and the thermal loading leads to a lensing behavior in the gain medium. Especially in the high-power end-pumped laser, the thermal lensing effect is serious and the resonator must be carefully considered to optimize the stable region. To study the dependence of the laser performance on the cavity length L and thermal lensing, we calculated the dependence of fundamental mode radius in the laser crystal on the magnitude of thermal lensing for cavity lengths of 30 and 40 mm, respectively, by using the standard $ABCD$ matrix formalism. The calculation results were shown in Fig. 2. We can see that the stable region of 30-mm cavity length was broader than that of 40 mm. Therefore we expect that the resonator of 30 mm

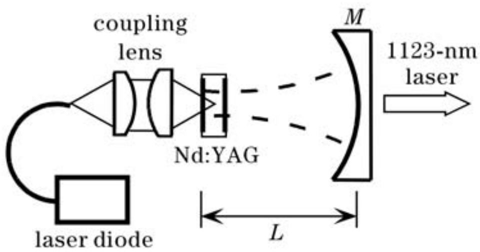

Fig. 1. Schematic of the diode-pumped Nd:YAG laser at 1123 nm.

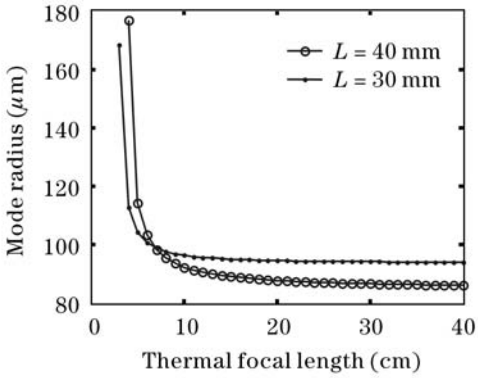

Fig. 2. The mode radius as a function of the thermal lens for different cavity lengths.

should have a higher output power than that of 40 mm under high pump power.

The output power as a function of the incident pump power is shown in Fig. 3. For the cavity length of 40 mm, the maximum output power was 2.39 W at the incident pump power of 14.2 W. The output power decreased with further increasing the pump power. When the cavity length is 30 mm, the oscillation threshold was reduced to 0.6 W, and the maximum output power of 1123-nm laser was as high as 2.6 W at the incident pump power of 15.9 W, which corresponds to an overall optical-optical conversion efficiency of 16.4%, and the slope efficiency was 18%. When we further increased the pump power, the coating of the crystal was damaged. It is reasonable that if the coating quality can be improved, the output power may be higher than the present results.

For the low pump power, we can see that the output powers of the laser with the cavity lengths of 30 and 40 mm were a little different under the mostly incident pump power, though the fundamental mode radius was quite different as shown in Fig. 2. This may be due to the thermal induced diffraction losses in high-power end-pumped solid-state laser[8,9]. In this kind of lasers, the thermal induced diffraction losses increase with the increase of the pump power. For the cavity length of 30 mm, a large TEM_{00} mode will experience larger thermal induced diffraction losses and degrade the output power of the laser.

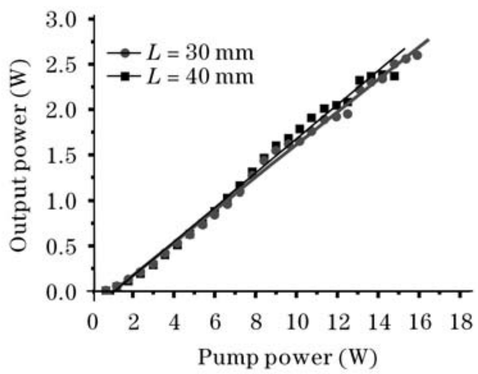

Fig. 3. Output power with respect to the incident pump power at 1123 nm for the different cavity lengths.

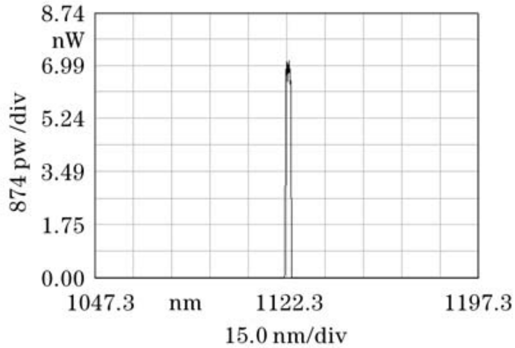

Fig. 4. Spectrum of the Nd:YAG laser at 1123 nm.

The laser spectrum was measured with a fiber coupled spectrum analyzer (Agilent 86142B, USA) as shown in Fig. 4. Clearly, the central wavelength is exactly 1123 nm, and the oscillations of 1064, 1112, and 1116 nm were not observed.

In summary, we demonstrated an end-pumped CW Nd:YAG laser at 1123 nm with a plano-concave resonator. At the cavity length of 30 mm, the maximum output power of 2.6 W was obtained at an incident pump power of 15.9 W, which corresponds to an overall optical-optical conversion efficiency of 16.4%, and the slope efficiency was 18%.

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