High power CW diode-side-pumped Nd:YAG rod laser

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We report on the characterization of a diode-side-pumped Nd:YAG rod laser operating at high CW output power. A four-fold pump configuration is designed and the pump light is directly coupled into the Nd:YAG rod without the help of any cylindrical lenses. The distribution of pump light in the Nd:YAG rod has been calculated by using ray tracing program. The thermal lens effect of the Nd:YAG rod has been experimentally measured. A maximum output power of 800 W at 1064 nm in multimode operation is obtained for a pump power of 2400 W with 33% optical-optical efficiency. At the same time, the maximum beam parameter product of 25 mm·mrad is achieved.

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Nd:YAG lasers operating at high CW power level are attractive sources for various applications in materials processing. Low power end-pumped solid-state lasers have demonstrated many advantages over lamp-pumped solid-state lasers for many years[1−4]. Among its advantages are high efficiency, high reliability, compactness and long operation lifetime. But power-scaling possibilities of end-pumped configuration are limited because of the thermal induced stress fracture of laser materials. Therefore side-pumped configuration using Nd:YAG rod has to be used for high output power.

Several techniques in delivering pump light from laser diodes (LDs) to the Nd:YAG rod have been proposed in order to achieve high efficiency and high beam quality of diode-side-pumped lasers[5−10]. Cylindrical lenses are widely used for coupling the pump light into the Nd:YAG rods with a loss of nearly 10%. This loss leads to low efficiency of the diode-side-pumped lasers. The cylindrical lenses also make the structure of laser head rather complicated and hard to align the optics.

In this letter, we report an investigation of a 800-W output power of CW side-pumped Nd:YAG rod laser, especially its directly coupling configuration of pump light without using any optical lenses, which carried out a 33% optical-optical efficiency. The laser performance, thermal properties and power scaling of the laser at 1064 nm are discussed.

In order to achieve a high spatial overlap of the pump light distribution with the laser mode, a four-fold configuration of pump module as shown in Fig. 1 is designed. Four pump units are distributed symmetrically around the Nd:YAG rod. Each pump unit consists of 12 linear active-cooled LDs with a nominal CW output power of 50 W each at 808 nm. The pump module comprises of 48 LDs and the maximum pump power is 2400 W. For directly cooling, the Nd:YAG rod (diameter 6mm, length 180 mm, Nd doping 0.8 at.-%, end face flat/flat) is mounted inside a flow tube (OD 12 mm, ID 10 mm). Because of the mounting the effectively pumped length of the Nd:YAG rod is 160 mm. Hence a linear pump power density inside the Nd:YAG rod of 150 W/cm is available. Reflector with gold coating is mounted around the flow tube to reflect the transmitted LDs radiation back into the Nd:YAG rod again to increase the absorption efficiency of pump light. Four narrow windows have been opened on the reflection (as shown in Fig. 1) and the emitting windows of LDs are positioned very close to the narrow windows. The pump light goes into the reflector through the four narrow windows and is coupled into the Nd:YAG rod directly without any reflection loss. A symmetrical resonator consists of two flat mirrors is used in our experiments.

The pump light distribution inside the Nd:YAG rod has been calculated by using ray tracing program. For simplifying the calculation, we neglected the internal reflection of reflector. It means that pump light traverse

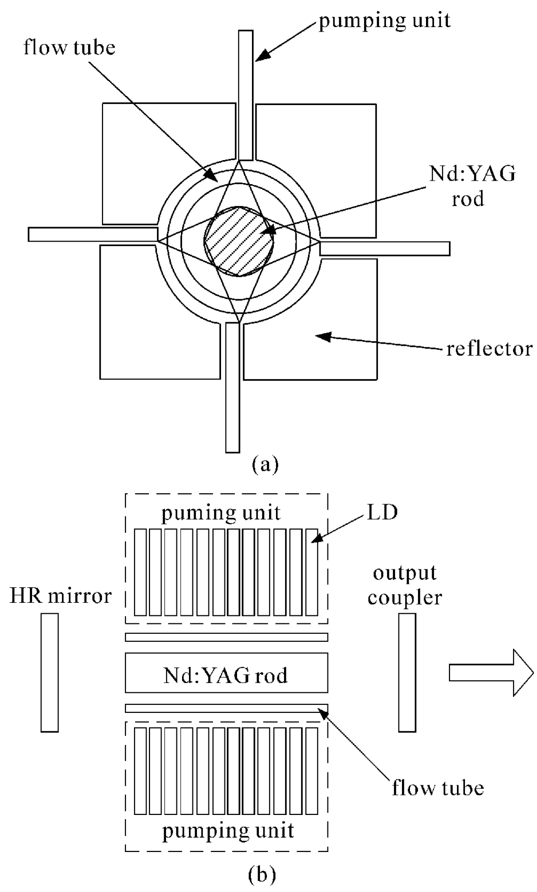

Fig. 1. Pumping configuration of the side-pumped Nd:YAG laser system. (a) Traverse view; (b) side view.

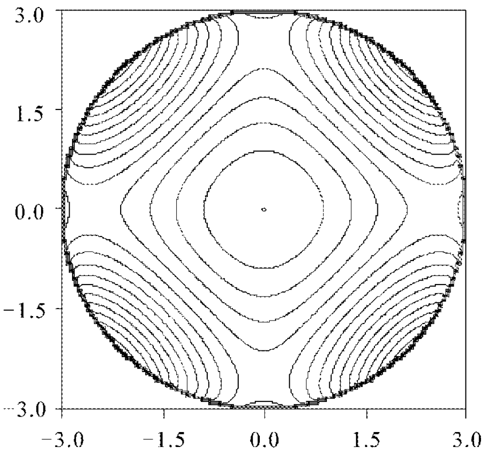

Fig. 2. Calculated pump light distribution in the Nd:YAG rod.

the Nd:YAG only once. A Gaussian intensity profile of the LD radiation is assumed perpendicular to the p-n junction, and a constant intensity profile is assumed parallel to the p-n junction in the calculated. The computer calculated light profile inside a Nd:YAG rod with a diameter of 6 mm illustrates a nonuniform distribution with a peak at the center and four sub-peak at the entrance of LDs radiation, as shown in Fig. 2. The nonuniform distribution is caused by the four-fold pumping configuration. If we consider the reflection of reflector, the distribution should be much uniform.

Due to the narrow absorption band width of the Nd:YAG rod, the spectrum shift of LDs radiation would lead to instability of the diode-pumped laser system. The variation of the spectrum shift is a function of the temperature at p-n junction of the LD. Electrical input and temperature of cooling water are two key factors that affect the temperature at p-n junction as the flow rate of cooling water is fixed[11]. So the temperature of cooling water is controlled to regulate the temperature of the LDs within an accuracy of ±0.2°C. LDs with similar wavelength were selected within 806±3 nm in order to match the Nd:YAG absorption band near 808 nm. The flow rate of cooling water is 0.5 L/min for each LD and the total flow rate for whole pump module is 50 L/min.

The temperature difference between center and surface of the Nd:YAG rod causes thermal lens effect. The beam quality of the Nd:YAG laser deteriorates with the increase in the pump power due to the thermal lens effect[12]. The thermal focal length was measured by using a collimated He-Ne laser beam. During the measurement the Nd:YAG laser does not operate. Figure 3 shows thermal focal length is proportional to the inverse of the pump power. At the maximum pump power of 2400 W a focal length of 100 mm, or refracting power (inverse of thermal focal length) of 10 m^{-1} is observed. The value of refracting power per kw of pump power is 4 m^{-1}.

The output power of side-pumped Nd:YAG laser operating at a wavelength of 1064 nm is investigated in a symmetrical plane-plane resonator. The cavity mirrors are separated by 360 mm and the temperature of cooling water is set as 25°C. The transmission of output coupler is 40%. A maximum output power of 800 W in

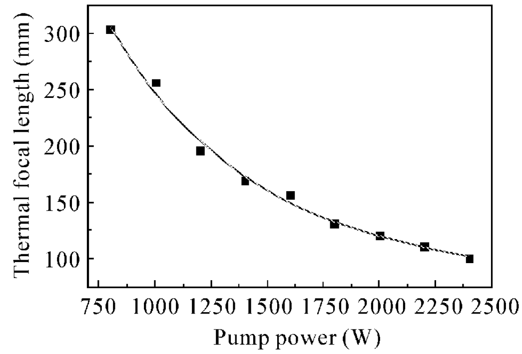

Fig. 3. Thermal focal length versus pump power.

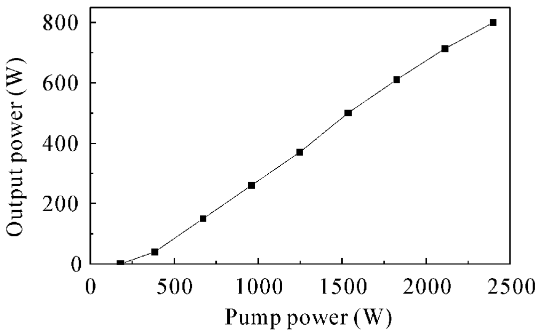

Fig. 4. Output power of Nd:YAG laser as a function of the pump power.

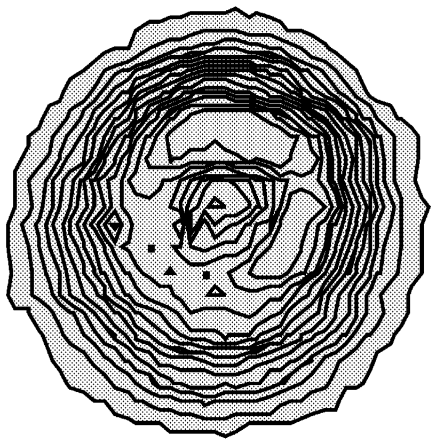

Fig. 5. Spatial profile of a multimode output beam detected with a laser beam diagnostic system.

multimode operation is achieved. The laser output power relative to the pump power is plotted in Fig. 4. The output power is proportional to the pump power. From these data we obtained a maximum optical-optical efficiency of 33% for 2400 W pump power. And the overall electrical efficiency of 16% is achieved. The threshold of the laser is 210 W. With a laser beam diagnostic system (Prometec model UFF 100) the beam parameter product is determined to approximately 25 mm·mrad. The multimode beam profile observed at 800 W output power is depicted in Fig. 5.

In summary, a diode-side-pumped 800-W CW Nd:YAG laser with an optical-optical efficiency of 33% and an overall electrical efficiency of 16% has been demonstrated. The directly close-pumping configuration without using any optical lenses is helpful to increase efficiency of the diode-pumped laser system and simplifies the structure of the laser head.

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