Vol 14 No 4, April 2005
1009-1963/2005/14(04)/771-03

Chinese Physics

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1.15kW continuous-wave generation by diode-side-pumped two-rod Nd:YAG laser*

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(Received 8 October 2004; revised manuscript received 29 November 2004)

A high power and high efficiency laser head with five dual-line diode arrays for the side-pumped Nd:YAG rod is developed. By mounting two laser heads of this kind and a quartz 90° rotator into a thermally-near-unstable symmetrical flat–flat resonator, a continuous-wave power output of 1157W at 1064nm is obtained with a beam quality factor M^2 of ∼39. To the authors' knowledge, this is the highest power output at 1064 nm for the diode-side-pumped two-rod Nd:YAG laser.

Keywords: Nd:YAG laser, diode-pumped, solid-state laser
PACC: 4255D, 4260B, 4260D

1. Introduction

High power continuous-wave (cw) all-solid-state laser operation has long been an active area of development. A considerable effort has been made to study laser resonators for achieving a high power output.[1−7] To date, Nd:YAG has been one of the most promising materials for high-power laser operation because of its good optical and mechanical features, high reliability and robustness.[4−7] For a large output, the diode-side-pump configuration is commonly used.[2,5,6,8] It has been proved that the polarization-dependent bifocusing compensation is effective for the enhancement of the performance of a high-power rod laser by inserting a 90° quartz rotator between two rods.[3−5,9] For example, Lee *et al* obtained a cw power output of 776 W based on a diode-side-pumped two-rod Nd:YAG with a beam quality factor of $M^2 \sim 72$.[5] However, to our knowledge, no one has reported so far on the more than 1kW cw power output generated by the diode-pumped two-rod Nd:YAG laser.

In this paper, by optimizing the laser head design and the cavity configuration, we have achieved a highest cw power output of 1157W at 1064nm from a diode-side-pumped two-rod Nd:YAG laser with a beam quality factor of M^2 ∼39. In order to scale the power output, the first step in our investigation is to design the laser head, which consists of five diode arrays and a low doping concentration rod to ensure a uniform gain distribution in the laser rod. Moreover, a thermally-near-unstable symmetrical flat–flat cavity with dual laser heads is used to improve the beam quality as well as the power output.[10]

2. Experiments

The optical pumping process in a solid-state laser material is associated with the generation of heat, so a uniform pumping is important for a laser head. Otherwise, nonuniform pumping will produce temperature gradients in the rods, and lead to thermal lens-

*Project supported by the Knowledge Innovation Programme of the Chinese Academy of Sciences, the National High Technology Development Programme of China (Grant Nos 2002AA311120 and 2002AA311040), and the Council for Science and Technology of Beijing (Grant No H020420060060110).

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ing and thermal stress-induced birefringence, which may induce stress fracture.[11] Moreover, the transmitted and aberrated wave front from the rod causes diffraction loss in the resonator. Therefore, the power output with nonuniform pumping is limited. In addition, to achieve the effective bifocusing compensation, thermal-lensing uniformity within the cross section of the rod is also required.[6]

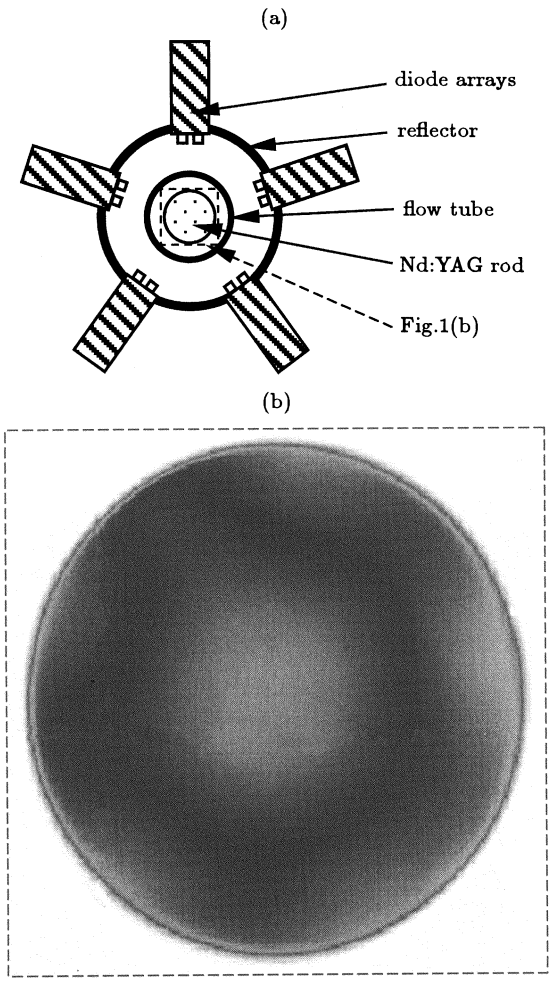


Fig.1. (a) Schematic front view and (b) Fluorescence distribution of the diode-side-pumped laser head.

Figure 1(a) shows the schematic front view of the diode-side-pumped laser head that meets a demand for uniform pumping. The laser head consists of five dual-line diode cw arrays and an Nd:YAG rod with a diameter of 7mm and a length of 180mm, and is surrounded by a flow tube and reflectors. The low Nd doping of 0.7 % in Nd:YAG is used to decrease thermal absorption. Five diode arrays are located evenly around the rod to produce a uniform pump-light distribution within the rod's cross-section. The combination of the uniform pump and the low thermal absorption is favourable for the production of a uniform gain distribution. Each array contains 110 diode bars with a wavelength of 808nm and a power output of 20W. To match the Nd:YAG absorption band at 808nm, all diode bars are selected carefully at a given drive current and a given cooling temperature to obtain a low spectral dispersion. The reflectors can reflect the pump radiation back to the Nd:YAG rod, which increases the absorption of pump light and the optical-to-optical conversion efficiency. In addition, by selecting an optimal distance between the rod and the diode bars and the curvature radius of the reflectors, the pump light is coupled into the Nd:YAG rod with high coupling efficiency while maintaining the uniformity of gain distribution. As shown in Fig.1(b), the fluorescence distribution of the laser head, measured at the rod end by a CCD, is uniform. By mounting one laser head within a short flat–flat cavity, a multimode cw power output of 570W at 1064nm is produced with a partial output coupler (transmittance, 30%), and optical-to-optical conversion efficiency is 27.3%.

Thermally induced spatial variation of the refractive index in the high-power-pumped Nd:YAG causes the rod to act as a lens with a variable focal length, which influences the zones of stable laser operation. Thermally induced stresses in the isotropic laser rod create birefringence, and the cavity mode is split into two components that are projected along the radial (r) and the tangential (ϕ) axes. The stable laser can be achieved only in the zones for the r- and the ϕ-polarization modes overlapped. Figure 2 shows a schematic of the experimental setup. Two identical Nd:YAG rods with a quartz 90° rotator between them are placed in the symmetrical flat–flat resonator. The quartz rotator produces a 90° rotation of every component of the electric field of the laser beam. Part of the mode that is radially polarized in the first rod is tangentially polarized in the second rod, and vice versa. Since each part of the beam passes through nearly identical regions of the two rods, the phase difference between the two parts will be removed. Therefore, the stable zones of different polarization modes overlap each other, which consequently can improve the power output. Taking the thermal lensing into account, the symmetrical flat–flat cavity acts as a thermally-near-unstable resonator, which can output beams with higher power and better beam quality.[10–13] The fundamental mode sizes in two Nd:YAG rods are the same, which enhances the efficient birefringence compensation. The total length of the flat–flat cavity is about 840mm, and the transmittance of the partial

output coupler is 30%.

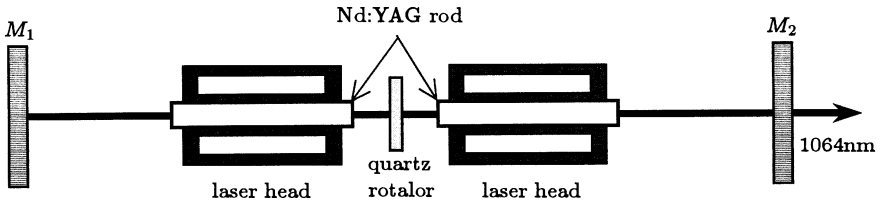


Fig.2. Schematic of the 1064nm cw laser: M_1: flat high reflector at 1064nm; M_2: flat partial output coupler at 1064nm.

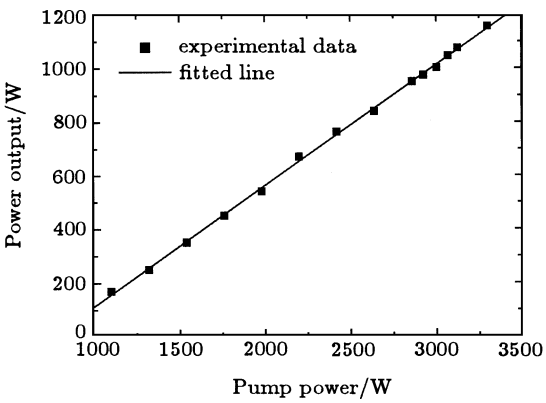


Fig.3. 1064nm power output as a function of pump power.

Figure 3 shows a plot of power output versus the pump power. When the diode pump power is 3300W at a driving current of 20A, the 1064nm cw power output is up to 1157W, corresponding to an optical-to-optical conversion efficiency of 35.1% and an electrical-to-optical conversion efficiency of 14.6%. The degree of linearity of the power output as a function of pump power is up to 99.95%. At the power output of 1157W, the instability of the laser operation remains less than 1.5% in two hours. By using a scanning-slit method, the waist width of the output beam is measured to be 4.2mm and the divergence is 12.5mrad, corresponding to the beam quality factor M^2 being estimated at about 39.

3. Conclusion

In conclusion, we have developed a high efficient laser head with five diode arrays for the side-pumped Nd:YAG rod. By employing a thermally-near-unstable symmetrical flat–flat cavity, a cw power output of 1157W at 1064nm cw has been generated with a beam quality factor of $M^2 \sim 39$. To our best knowledge, this is the highest power output at 1064nm for a side-diode-pumped two-rod Nd:YAG laser.

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