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Highly efficient diode-end-pumped Nd:YAG composite rod laser

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An end-pumped laser scheme using diode-laser stack and additive shaping optics has been implemented. The improvement of laser output power and efficiency of high power diode-end-pumped laser using composite YAG/Nd:YAG/YAG rod instead of simple Nd:YAG rod has been investigated experimentally. Compared to the simple rod laser, the output power and efficiency of the composite rod laser were increased more than 80% and 21.5% respectively, with a more homogenized beam profile. Also the laser threshold was decreased 90% in the composite rod. These results are due to the decrease of thermal effects.

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1. Introduction

One of the main problems in design of high power solid state lasers is managing the destructive effects of heat generation inside the laser medium, during the pumping process [1]. The thermal management of end-pumped lasers can be greatly improved by use of composite rods. Laser crystals such as Nd:YAG, Nd:YVO4, and Yb:YAG have become available with sections of undoped host material on one or both ends. These end caps are diffusion bonded to the doped laser crystal. Composite rods are proven to provide a very effective way to reduce temperature and stresses at the face of end-pumped lasers.

The diffusion bond provides uninhibited heat flow from the doped to undoped region. A large temperature reduction is achieved for the composite rod, where a significant part of heat flow occurs into the undoped end cap. The undoped end cap prevents the doped pump face from expanding along its axis; therefore no surface deformation takes place at this interface. This leads to strong compressive stresses instead of tensile stresses as was the case for the unrestrained surface [2-5].

It has been shown that using composite rods could increase the output power up to 100% and reduce the thermal lensing effect by 30% [6-7]. A composite laser rod in a diode-end-pumped geometry was first demonstrated by Hanson [8].

In end-pumped solid-state lasers with homogeneous dopant distribution, the exponential decay of the pump light distribution causes high temperature gradients. As a result for a given rod length, mechanical stresses put practical limitation on the maximum incident pump power and slope efficiency [9].

In this paper, for decreasing the thermo-optical effects, the composite YAG/Nd:YAG/YAG laser rod, which was constructed with diffused bonding technique, has been used in end-pumped geometry with high power diode laser stack. Advantages of using composite rod have been discussed in terms of threshold pump rate, efficiency and beam profile.

2. Experimental setup

Design of laser configuration, which controls the pumping, cooling and energy extraction, plays a critical role in average power scaling of laser, when a good quality laser beam is required. An efficient optical pumping scheme is one of the key elements of the laser design.

In this research for evaluating thermal effects in simple and composite laser rods, a diode end-pumped configuration was implemented using various optical elements. To improve the laser pumping efficiency, we should measure the intensity, power, and wavelength of laser diode with and without the laser rod.

Pumping configuration (including the diode stack bars), optical components, an active laser medium, and measurement instruments have been illustrated in Fig. 1. The divergences of laser diode bars along the fast and slow axes are 35 and 10 degrees, respectively. However, microlenses of multi-bars nearly collimate the output power in the fast axis of diodes (0.25 degree). The diode laser beam passes through five optical components consisting of three spherical flat-convex lenses, one flat-concave lens, and one cylindrical flat-convex lens for focusing and enhancing the intensity of pumping light beam.

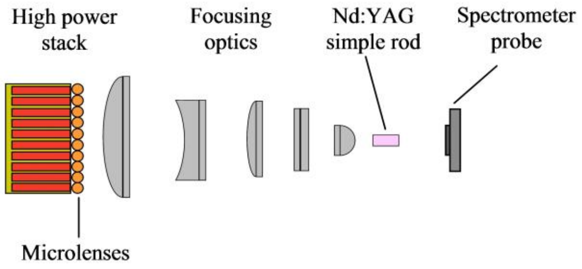

Fig. 1. Schematic setup for measurement of wavelength and intensity.

The laser diode output power after focusing through the optical components was measured as a function of diode current at 27, 32, and 35 ^{o}C cooling temperatures. As shown in Fig. 2, by increasing the temperature of cooling system, the output power of laser diode is decreased.

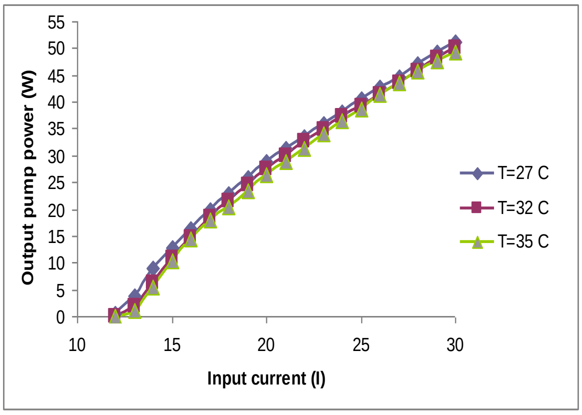

Fig. 2. Output pump power versus input current in different temperatures.

On the other hand, the peak wavelength of the laser diode is dependent on the diode temperature. Thus, for obtaining the most suitable wavelength of the diode laser, the variations of peak wavelength as a function of diode temperature, which are shown in Fig. 3, were measured. The optical spectrum of diode laser with FWHM of 2.5 nm was measured with a resolution of 0.5 nm. As illustrated in Fig. 3, by increasing the diode temperature until 36 ^{o}C for a given input current, the peak wavelength is shifted to 808 nm by the rate of 0.3 nm/^{o}C, which is well fitted by Nd:YAG absorption band.

The pump power/intensity with and without the Nd:YAG simple rod have been also shown in Fig. 3. The simple rod has 20 mm length, 5 mm diameter and 1% Nd ions concentration without coating on its end faces. It should be noted that for comparing the power/intensity of pump laser with and without the laser rod, the amount of power/intensity of pump before incident the laser rod was scaled down with a fraction of 1/100.

It can be seen in Fig. 3, when the pumping wavelength becomes close to 808 nm, due to increasing of the absorption inside the rod, the pump intensity/power after passing the rod is decreased. Thus, the optimum temperature of diode laser that provides the highest possible absorption was found.

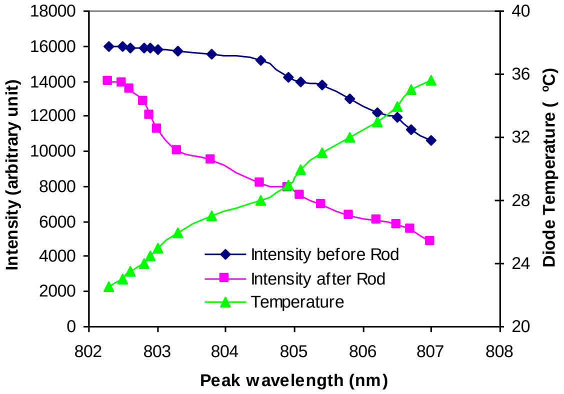

Fig. 3. Variation of pumping wavelength of diode laser versus temperature and its intensity versus peak wavelength with and without laser rod.

In this research, for decreasing the thermal effects in the laser rod and power scaling of end-pumped laser, the diffused bonded composite YAG crystal was constructed. The composite laser rod consists of two caps of 10 mm length and 5 mm diameter of undoped YAG which diffused bonded to a 1% doped Nd:YAG laser rod with 20 mm long and 5 mm diameter. The total length of composite rod is 40 mm.

The performances of composite YAG/Nd:YAG/YAG laser rod compared to the simple 20 mm Nd:YAG laser rod of 1% Nd dopant. Both simple and composite rods are antireflection coated for the pump wavelength of 808 nm and highly reflective (HR) for laser wavelength of 1064 nm, such that the backsides of rods act as resonator mirrors. The opposite sides are antireflection coated for the laser wavelength and highly reflective coated at 808 nm. Therefore, the double pass of input pump light increases the absorption in the rod which in turn will increase the output power. A water coolant has been used for cooling of lateral surfaces of both laser rods in which, flow rate, pressure and the temperature are set to be 3 l/min, 2 bar and 8 ^{o}C, respectively.

The experimental setup of the resonator is shown in Fig. 4. The resonator is linear with 53 mm length. Simple and composite laser rods are pumped longitudinally by a high power CW laser diode stack at 808 nm. An optimum plane mirror of transmission of 20% at 1064 nm was used as the output coupler of the resonator.

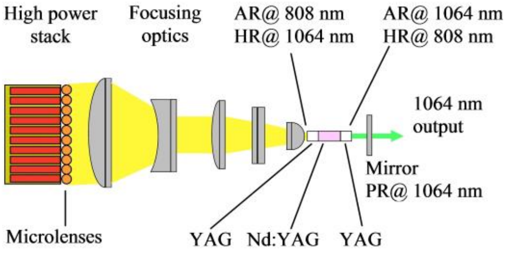

Fig. 4. Optical setup for diode-end-pumped composite rod laser.

In order to obtain maximum mode volume in end-pumped scheme, the focal point of pumping beam should be located at the center of laser rod in both simple and composite rods. However, in our experiments the optimum focusing position is practically dependent on the absorption coefficient of laser rod, such that by increasing the absorption coefficient the focusing position is shifted to the entrance face of the Nd:YAG laser rod [10-12].

3. Results and discussion

In order to evaluate the specifications of the simple and composite laser rods, the CW multimode laser output powers were measured. The laser output powers for simple and composite rods versus different input pumping powers are illustrated in Fig. 5. The threshold input powers for the simple and composite laser rods were measured to be 6.5 and 3.5 W, respectively. Maximum output powers at 39.5 W input pump power were obtained 10 W and 18.6 W for simple and composite laser rods, respectively. According to the result of Fig. 5, by increasing the input pump power, the laser output power of the simple rod is saturated and by more increasing the input pump power, the coating of the entrance face of the rod was damaged and the laser power fell down. In this condition, the increasing of the laser output power of the composite rod was observed, so that 25 W laser output power was obtained at 51.3 W input pump power.

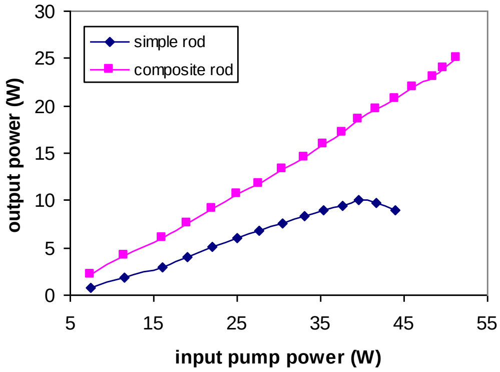

Fig. 5. Laser output power versus input pump power for simple and composite rods.

The point efficiency of simple and composite laser rods are shown in Fig. 6. At 39.5 W input power, which is the maximum input power for the simple rod, the 25.3% point efficiency, and 16% slope efficiency with simple rod, and 47% point efficiency and 27.5% slope efficiency with composite rod were achieved.

Also, 48.7% point efficiency and 27.6% slope efficiency were obtained for composite laser rod at 51.3 W input pump power.

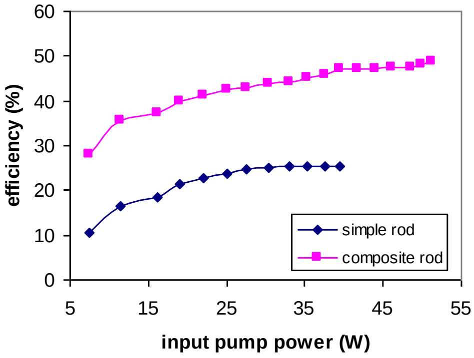

Fig. 6. Efficiency versus input pump power for simple and composite laser rods.

The beam profile of 10 W laser output power for both simple and composite rods were measured by CCD-camera and shown in Fig. 7. The better uniformity in the composite rod with respect to the simple rod is observed, which shows the decrease of thermal effects and uniformity of temperature distribution in the composite laser rod.

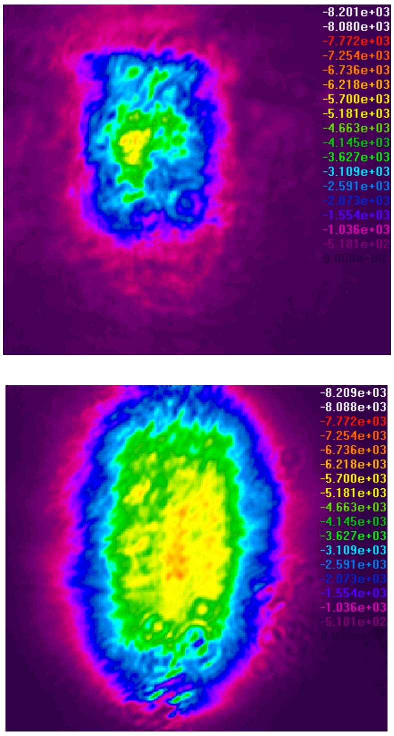

Fig. 7. Comparison of 10 W 1064 nm laser output beam profile for simple rod (up) and composite rod (down).

4. Conclusion

In this paper, the performances of composite YAG/Nd:YAG/YAG laser rod are comprehensively compared to simple Nd:YAG laser rod.

In comparison with simple laser rod, the output power and efficiency of composite laser rod have been increased more than 80% and 21.5%, respectively and its beam profile has been more homogeneous, because of the decrease of thermal gradient and mechanical stress due to undoped caps in the end faces of composite laser rod.

Finally, a highly efficient laser using Nd:YAG composite laser rod in an end-pumped configuration by a high power diode laser stack was presented. The laser threshold was observed to be 3.5 W and the output power of 25 W was obtained at 51.3 W input power.

Acknowledgments

It should be noted that making of Nd:YAG rod and composite rod by diffused bonding technique and the coating of optical components are home made. We thank the Crystal Growth, the Optical, and the Mechanical Groups of Laser and Optics Research School for manufacturing of simple and composite rods and their coatings and other optical and mechanical components that we used in this project.

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