Diode-Pumped Nd:YAG Laser Using Reflective Pump Optics

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Abstract. We have examined the performance of a diode-laser side-pumped Nd:YAG laser using elliptical mirrors to focus the output of 6×10 W laser-diode arrays into the Nd:YAG rod. The multimode cw output power was 14 W with an optical to optical efficiency of 29%. With a resonator designed for TEM00 mode operation 12 W of output was achieved.

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The availability of high power laser diodes in the near infrared has led to the rapid development of diode-laser pumped solid-state lasers as compact, efficient sources. Both transverse (side) and longitudinal (end) diode-laser pumping configurations are widely used. In general, end-pumped lasers have higher efficiency than side-pumped lasers, especially for TEM00 operation, because of the improved overlap of the gain profile and the laser mode. However, side-pumped lasers are more readily scaled to higher powers because of the large volume of the gain medium available for pumping [1]. This differentiation has gradually diminished as end-pumped systems have reached 90 W output [2] and as the efficiency of side-pumped systems has increased to 30% [3-5] but side-pumping continues to be the most straightforward configuration to scale. We have investigated an efficient side-pumping scheme for a Nd:YAG laser using reflective pump optics with 63 W of laser-diode power.

The coupling of laser-diode pump light into the gain medium, in particular the method of focusing the highly divergent spatial mode of the diode array, is extremely important. Two common side-pumping schemes either require a glass-rod lens to focus the pump light [3] or use direct coupling of the diode-laser beam without any pump optics [4-7]. A glass rod of suitably small diameter placed in front of the diode array will focus the divergent diode-laser beam into the gain medium. This allows for a simple arrangement of laser-diode arrays around a laser rod. The required proximity of the rod lens to the facet of the laser diode and to the surface of the gain medium imposes certain practical constraints. Besides endangering the unprotected facet of a laser-diode array, the small distances make it more difficult to engineer adequate heat removal from the laser rod. Furthermore, the curvature of the small rod lens and the large divergence of the laser-diode array combine to produce both image distortion due to large (spherical) aberration and additional reflective losses due to large incident angles. In contrast, direct coupling places the laser-diode array very close to the gain medium and uses no focusing optics except possibly for the lensing action of the laser rod itself. This has the advantage of minimizing reflection losses and aberrations of pump optics but reduces overlap between the gain profile and the fundamental laser mode and creates similar working distance constraints.

To get a reasonable overlap between the pump-light distribution and the laser volume often a zigzag path of the laser mode in the slab is chosen.

Our laser consists of a 1.1% doped, 2 mm diameter, 40 mm long, Anti-Reflection (AR) coated Nd: YAG rod pumped by 6×10 W linear laser-diode arrays (Siemens/Heimann OPUS 3237) in a 25 cm long planoconcave resonator. The output beams of the laser-diodes are focused into the center of the rod by three elliptical copper mirrors with a protective SiO2 coating arranged symmetrically around the rod (Fig. 1). The diode arrays are at one focus of the ellipse and the axis of the Nd:YAG rod at the second focus. The distance from the mirror to the diode facet is several millimeters while the distance from the mirror to the Nd:YAG rod is approximately 1 cm. The elliptical mirrors have the advantage of producing a primarily aberration-free image of the laser-diode at the center of the rod while maintaining adequate spacing between all components. To ensure correct positioning of the laser-diode array, the mirrors and laser-diodes are moved relative to one another with two small translation stages. The laser-diode arrays are temperature regulated by means of controlled water cooling of the copper heat sink. The pumping ar-
Fig. 1. Cross section of the pump configuration showing the geometry of the Laser-Diode arrays (LD) and the Elliptical mirrors (ER) with respect to the Nd:YAG Laser Rod (LR). The Copper heat sink (C) and the Flow Tube (FT) are used to cool the laser diodes and the laser rod, respectively.

Fig. 2. Measured fluorescence profile in the 2 mm diameter Nd: YAG rod at a pump power of 63 W. The profile reflects the symmetry of the pump configuration.

Fig. 3. Multimode output power vs pump power incident on the flow-tube for a plano-concave resonator with a radius of curvature of the HR mirror of 5 m and a length of 25 cm for 11%, 7.5%, and 2.3% output couplers. The slope efficiencies calculated with the absorbed pump power are 38%, 39%, and 27%, respectively.

Fig. 4. TEM$_{00}$ output power vs pump power incident on the flow tube for a 7.5% output coupler and the same resonator configuration as in Fig. 3 but with an inserted aperture. The slope efficiency calculated for the absorbed pump power is 24%.

Thermal lensing is a major concern in high power solid-state lasers [8,9]. A flow tube insures efficient cooling of the Nd:YAG rod. On the side opposite the elliptical mirrors, the flow tube was gold coated to reflect any pump light not absorbed on the first pass through the Nd:YAG rod. The flow tube does introduce additional reflection losses, approximately 7% for the sum of the different air-glass, glass-water, water-Nd:YAG interfaces but these could be reduced to 3% if AR coating were used. Of the unreflected light, 82% is absorbed in the two passes through the Nd:YAG rod resulting in approximately 76% absorption of the incident pump light. Interferograms of the pumped laser rod show circular interference fringes due to the thermal lens; the three-fold symmetry of the pump geometry was not apparent and at maximum pump power the focal length of the thermal lens was measured to be 28 cm. The double-pass thermally induced depolarization within the Nd:YAG rod was measured to be less than 1.5%.

Several resonator configurations were tested with the best results obtained for the 25 cm long plano-concave resonator formed by a 5 m radius of curvature, concave High Reflector (HR) and a flat output coupler. This resonator proved stable at all levels of available pump power despite thermal lensing. Since the laser output power is a function of the output coupling three different output couplers were tested with transmissions of 11%, 7.5%, and 2.3% (Fig. 3). The maximum cw laser output power was 14 W multimode using a 7.5% output coupler at a pump power of 63 W incident on the flow tube. Using the absorbed power (48 W) as a measure for the efficiency, the optical to optical efficiency is 29% and the slope efficiency was 39%. It shows no decrease at high