45W CW TEM_{00} mode diode-side-pumped Nd:YAG rod laser with linearly polarized beam

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Abstract: Using a commercial, diode-side pumped Nd:YAG rod laser module, we obtain more than 53% extraction efficiency in fundamental mode with respect to multimode operation in a fully polarized beam.
OCIS codes: (140.3580) Lasers, solid-state; (140.4780) Optical resonators

1. Introduction

Many industrial and scientific applications require laser beam sources with high output power and high beam quality. The output power scaling of TEM_{00} mode beam sources with well-defined polarization are of primary importance.

In order to obtain stable operation in fundamental mode with high output power, it is necessary to make the TEM_{00} mode spot size inside the rod (w_{30}) as large as possible, but not too large, in order to avoid diffraction effects at the border of the rod. Generally, the mode spot size inside the rod of radius r is chosen such that r/w_{30} is of the order of 1.5 to 2.2. Nevertheless, the heat load induced by the high pump power generates birefringence in the gain medium degrading the beam quality and imposing a limit to the output power of polarized laser beams due to depolarization losses. The thermally induced birefringence causes a separation of the original linearly polarized mode into tangential and radial components that suffer different path length and thermal focal lengths inside the rod. Different methods have been proposed over the years for birefringence compensation [1,2]. However, it is very difficult to obtain high output power in a linearly polarized TEM_{00} mode from a diode-side-pumped module. Generally, good birefringence compensation is achieved using two rods with a half-wave plate in between them, imaging one polarization component exiting the first rod into the exact same radial and tangential location of the second rod, but with opposite polarization [3]. For a single module, the method suggested by Clarkson et al [4], using a quarter wave-plate in conjunction with a cavity end-mirror, stands out because of its simplicity and efficiency, especially in the case of TEM_{00} mode operation [5]. The highest extraction efficiency in polarized fundamental mode operation reported so far for a single side pumped rod is 50% with respect to multimode [6].

In this work, we report a stable and efficient TEM_{00} operation with 45W output power in a linearly polarized beam. In addition we demonstrate 50W with a 92% polarized beam using only a quarter wave plate inside the cavity. Associating mode filling and birefringence compensation makes it possible to obtain polarized beams at high output powers. The simplicity of this set-up makes the resonator easily reproducible using commercial Nd:YAG modules.

2. Mode Filling

To achieve maximum stability in fundamental mode operation, the resonator is optimized to operate with joint stability zones. This means that the resonator will have a continuous range of stability without any separation into the two distinct stability zones [7]. Thus, the resonator can maintain the dynamically stable operation over a wider range of pump powers. The mode spot size minimum w_0 is related to the width of the stability interval by [8]:

$$w_0^2 = 2\lambda/\pi\,\Delta\left(\frac{1}{f}\right) \tag{1}$$

The thermally induced birefringence due to the pumping process generates two distinct values of focal length for a beam with radial or tangential polarization. As a result we find different stability intervals for each polarization [8,9]. However, stable laser operation requires a minimum amount of overlap between the radial and tangential stability intervals. The maximum mode spot size that still maintains overlap between the radial and tangential stability zones can be determined by [9]:

$$\frac{2\lambda}{\pi \cdot w_{30}^2} > 0.18k \cdot P_{in} \tag{2}$$

The constant k is easily obtained by the ratio $1/f = k \cdot Pin$, where Pin is the pump power and f is the focal length of the thermal lens. Thus, a value of w_0 is obtained that maintains the resonator dynamically stable for both polarizations at the maximum pump power.

3. Results

The laser module used in the experiment consisted of a commercially available module (HTOE, Model DPL-1064-S1-0075) based on a 78mm long, 3mm diameter, 0.8 at% Nd-doped rod, positioned in a water flow tube for cooling. The two end faces of the crystal are anti-reflection coated for the 1064 nm wavelength and pumping occurs from the side by 12 diode bars, operating at 808nm, resulting in a total pump power of 207W. The maximum extractable energy was obtained by using a short flat-flat cavity in multimode operation which generated 81.2W with 39% optical to optical efficiency. Mode-filling was tested using 12 different cavity set-ups until we achieved more than 60% extraction efficiency in fundamental mode. In order to polarize the laser output, a quarter-wave plate (QWP) was employed before the DPSSL module. When one of the axes of the QWP was aligned with the vertical axis of the DPSSL module, the laser already showed 92% horizontally polarized beam with 50W output power. For more than 99% polarized fundamental-mode output, a Brewster window was inserted in the horizontal direction which decreased the output power by 11% to 45 W. Figure 1 shows the optimized convex-convex resonator with birefringence compensation.

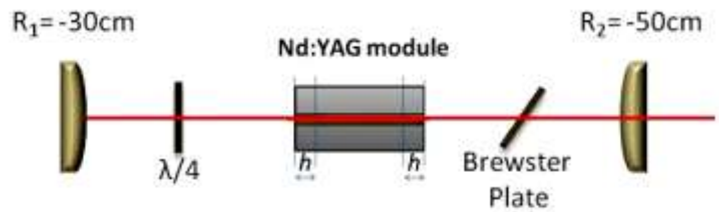

Fig. 1. Laser resonator using a 30% transmission convex output coupler of 50 cm radius of curvature.

With this simple scheme 45W fundamental mode output was achieved with full polarized output and 53% extraction efficiency with regard to multimode operation. To our knowledge this is the highest extraction efficiency obtained for a linearly polarized Nd:YAG single rod laser in TEM_{00} mode operation.

4. References

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