Compact, high power CW ring laser resonator

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***Abstract*— We demonstrated the dynamically stable operation of a Nd:YAG ring laser with 51.8 W of linearly polarized, continuous output power. The laser was based on laser modules side-pumped by diode bars. The resonator, aimed at single-frequency operation, is a design improvement from a previous work with the resonator length 4.3 times smaller than the previous design, thus resulting in a larger free spectral range, favoring for operation at single-frequency.**

Keywords*— Ring resonator, dynamically stable resonators, Nd:YAG, solid-state laser.

I. Introduction

Ring lasers are particularly well-suited for single-frequency applications because they can eliminate the spatial hole-burning effect and stabilize their output with a narrow line width. One of the key advantages of ring lasers is their ability to create additional beam waists while exhibiting low sensitivity to misalignment in the ring plane and provide a higher output than linear resonators [1, 2].

In a previous work, we developed a high-power single-frequency DSR ring laser and simple equations were derived that relate the resonator geometry (mirror curvatures and distances) to the stability zone parameters (width and position in terms of dioptric power of the induced thermal lens) for the case of a symmetric resonator containing only a pair of curved mirrors [3-5]. These equations demonstrate that, for a given mirror curvature radius, the position and width of the stability zone and thus stationary beam waist size at rod can be adjusted by changing two distances in the resonator. Despite the resonator´s good performance, it had a large overall length, implying high sensitivity to misalignment and greater difficulty in achieving single-frequency operation due to its corresponding small free spectral range. By using the referred equations, it is easy to design a totally equivalent resonator in terms of stability zone while allowing for a 5 to 6 times smaller overall length [4]. In this work we show the results for the shorter resonator.

II. Experimental Setup

The laser used a commercial diode-pumped laser module that contained a 78 mm long 0.6 at. % Nd-doped YAG rod side pumped at 808 nm by 12 diode bars disposed in a three-fold geometry. Three flat mirrors at 45° HR at 1064 nm and a thin-film polarizer (TFP) were used to steer the beam, in order to create a rectangular ring resonator. By using two F = 29 mm lenses instead of curved mirrors, the resonator could assume a short length while avoiding high incidence angle on curved mirrors that would generate astigmatism. As it is shown in [6] this resonator could be further reduced by using positive lenses as small as possible or negative lenses

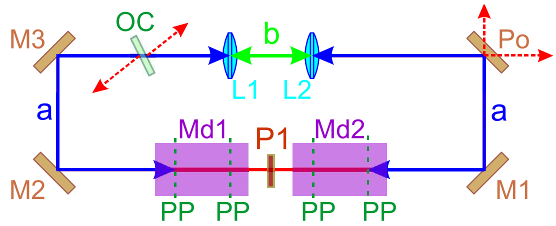

Fig. 1. Ring laser resonator Scheme. M1, M2, M3: flat mirrors; Po: polarizer; L1, L2: Resonator lenses; P1: half wave plate; Md1, Md2: Laser modules; PP: principal plane of the induced thermal lens; a and b: resonator distances.

with focusing distances about 75 mm, which would be the shortest possible resonator. However a 29 mm focusing length was chosen in order to create space between them for the insertion of a nonlinear crystal in the future.

Fig. 1 shows the experimental setup used, where Md1 and Md2 represent the modules, M1, M2 and M3 are the mirrors, Po is the TFP polarizer, Pl is a λ/2 plate used for birefringence compensation, L1 and L2 are the biconvex lenses and OC is the output coupler. The resonator distances *a* and *b* are also shown in the fig. 1. Specifically *a* is the distance between the principal plane PP of the induced thermal lens of the rod in Md1 to the lens L1 or from the principal plane of the rod in Md2 to the lens L2 and *b* is the distance between the lenses L1 and L2.

III. Results

First, the rod´s thermally induced lens was characterized. Fig 2 shows the thermal lens measurements performed on both modules for different input electric currents. The measurement of thermal focusing length was performed as described in [5-8] by passing a collimated laser through the rod while it was being pumped. A slit and a polarizer were inserted before the rod to select polarization components. The polarizer chose polarization in the vertical or horizontal directions, while the slit selected the regions of the rod corresponding to radial or tangential orientations. A screen was moved along the beam that emerged from the rod until the position at which it was focused, and the corresponding focal length was measured as being the distance from the screen to the principal plane of the laser rod.

The average focal lengths (average of the four measured components of polarization [7-11]) are plotted on fig 2, and a straight line was fitted to the data. The average focal distance obtained at the maximum current were 181.8 mm and 190.4 mm for modules 1 and 2, respectively. Measurements for module 1 were taken over a wider range of input currents while module 2 was measured only for current values near the operating point.

The ratio of tangential to radial focusing lengths f_t/f_r is 1.2 for Nd:YAG [12,13], however, when utilizing a non-

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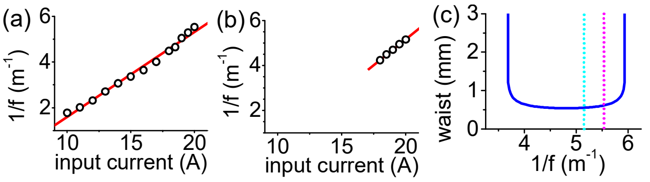

Fig. 2. Measured focal distance of modules 1 (a) and 2 (b) with a fitted straight line. (c) Calculated beam waist at rod for the resonator in the stability interval. Ciano and magenta vertical dotted lines in (c) represent the average thermal lenses at maximum pump power for the modules 1 and 2, respectively

uniformly pumped rod, as it is in the case of a module side pumped by diode bars, this ratio may assume lower or higher values depending on the chosen polarization direction. Therefore, by choosing the proper polarization orientation for a given module, it may be possible to obtain f_t/f_r closer to 1, allowing for better beam quality to be obtained [11,14]. The measured values of f_t/f_r are plotted in Fig.3. In fig. 3.a, as pump power increases, the ratio f_t/f_r becomes closer to 1.2 for horizontal polarization, leading to a worse performance. However, for vertical polarization it approaches values close to 1 thus allowing for a better performance. For module 2, f_t/f_r is close to 1 for both polarizations as it can be seen in Fig. 3.b. Based on these measurements, the best operation can be achieved with vertical polarization, and the proposed assembly shown in Fig. 1 can be utilized. The TFP with Rs > 99.8% and Rp < 1% can be used for selecting the vertical polarization component.

Next, the multimode output of the modules was measured by assembling a short flat-flat resonator using the two modules. The measured output power for different output couplers is shown in Fig. 3.c where 180 W of output was obtained with the T=40% output coupler

The laser then operated in the ring scheme as depicted in fig. 1, where distances *a* and *b* where 302 mm and 74 mm, respectively, resulting in an overall length of 820 mm, which represents a 4.3 times reduction in comparison with the original resonator. Fig. 2.c shows the beam waist inside the rod in the stability interval. A total output power of 51.8 W (sum of the clockwise and counterclockwise outputs) was obtained in the bidirectional operation, with 29% extraction efficiency relative to the multimode operation. Depolarization losses of 14.2 W were measured by the beam exit through the polarizers. The coatings of the lenses L1 and L2 are not optimized for 1064 nm with 0.8% reflection at each surface, resulting in a total loss of 3.2 %. The chosen output mirror was R=30%. Considering additional losses at the lenses, the total output could be 57.3 W, which is still smaller than the 91 W of polarized bidirectional output obtained in the longer resonator [3]. However, for this resonator the output coupling was 25% and we attribute the lower power to the difference in the output coupling efficiency. In the next step one of the mirrors with 45°incidence will be replaced by an optimized output coupler.

IV. Conclusions

The operation of a compact ring laser containing two Nd:YAG modules was demonstrated achieving 51.8 W of polarized, continuous output. Compared to the previous work [3], this shorter resonator exhibits reduced sensitivity to misalignment and has a 4.2 times larger free spectral range,

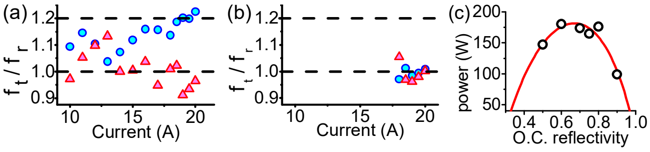

Fig. 3. Ratio between radially and tangentially polarized focusing lengths for horizontal (circles) and vertical (triangles) light polarization measured for module 1 (a) and 2 (b). (c) Measured multimode output power for the two modules operating at maximum pump power.

which improves the single-frequency operational stability when running unidirectional. The footprint of the laser was reduced by 5.8 times. An additional advantage of the developed laser is the use of commercial modules, significantly reducing its overall complexity and cost.

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