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Compact, high-power, single-frequency, dynamically stable cw ring laser

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Abstract: We recently reported a single-frequency Nd:YAG ring laser with 55.6 W CW output. In this work our design equations are given in order to obtain compactness and increasing resonator free spectral range. © 2022 The Authors

1. Introduction

Single-frequency lasers are required in a number of applications such as in enhancement cavities for the highest conversion efficiencies in frequency doubling meanwhile presenting very small linewidth, several orders of magnitude lesser than the gain linewidth, which is required for applications such as high-resolution spectroscopy and laser decelerator. Ring lasers are necessary for single-frequency operation because their travelling wave nature can eliminate spatial hole burning allowing stable single frequency output with narrow linewidths. Among the characteristics of ring lasers are the fact that they can provide an order of magnitude higher output when compared to linear resonators [1], they have low sensitivity to misalignment in the ring plane and additional beam waists can be created where non-linear crystals and modulators may be placed [1,2]. When considering dynamically stable resonators (DSR), ring lasers have the advantages of having a one single stability interval with twice the width in relation to linear DSRs [3].

In previous works [4-6] we modeled symmetric ring DSRs with one pair of curved mirrors obtaining simple design equations which connect stability zone design parameters directly with the resonator's geometric parameters (distances between components and mirror radii of curvature). Among many characteristics of this ring resonator, it was shown that once the mirror curvature radii are chosen, the parameters of the stability zone (position and width) can be independently adjusted by changing two specific distances inside the resonator. By using these design equations we designed and constructed a ring resonator utilizing two diode side-pumped Nd:YAG modules [4]. A nonlinear crystal was utilized to suppress mode hops thus enabling 55.6 W of single frequency continuous output, to our knowledge the highest output power achieved for Nd:YAG single-frequency resonators without the use of amplifiers or seeding sources. The resonator had the benefit of utilizing commercially available laser pump modules thus allowing for low-cost laser components and ease of construction. The laser had the disadvantage of exhibiting a long resonator length which causes two concerns: first, resonator FSR is very small and longitudinal modes are very close to each other, causing some difficulty to avoid mode hops, and second, the long length of resonator created some long-term instability. Thus, a shorter design is desired for compactness and for increasing resonator FSR. In this work, these above-mentioned design equations are analyzed to study how the resonator length can assume shorter lengths.

2. Symmetric Ring DSRs with a pair of curved mirrors

The symmetric resonator scheme is displayed on Fig. 1 (a). The stability zone with corresponding parameters is shown in Fig. 1 (b). The parameters f_{max} (focusing length at the lower limit of the stability interval) and Δ_f (width of the stability interval in terms of rod focusing length) can be given in terms of distances *a*, *b* and mirror radius of curvature *R* [4]:

$$f_{max} = \frac{2a - R}{4} \quad \text{and} \quad \Delta_f = f_{max} - f_{min} = \frac{R^2}{4(b - R)}, \tag{1}$$

where f_{max} and f_{min} are both positive. The other parameters of the stability zone can be obtained from f_{max} and Δ_f (f_{min}, $\Delta(1/f)$ and stationary waist w_0 which is inversely proportional to $\Delta(1/f)$ [3]).

3. Resonator length reduction

Here we discuss the possible minimum values for the resonator parameters aiming to construct a shorter resonator in order to get to smaller resonator lengths while maintaining the same stability interval. By utilizing eq. 1 the distances *a* and *b* as a function of *R* were plotted in fig. 1. (c) together with resonator length L' =2a + b. The background is filled (pink) in the regions where *a* and *b* are positive. The smallest value of the resonator length *L*' will occur for negative radii of curvature, at $R = -4\Delta f$. For resonators with positive radius of curvature, the shortest length has the value $L' = 4f_{max}$ occurs for R→0. Therefore, for mirrors with negative radius of curvature, it is possible to construct a resonator with the shortest possible length and there is a limit to the longest length of $L'=4 f_{max} (f_{max} / \Delta f - 1)$ when $R = -4 f_{max}$. For positive radii of curvature, the shortest length of *L*' is $4 f_{max}$, which occurs for R→0 and the resonator can be as long as necessary for R→∞. We observe that resonators with negative radii of curvature are better for the construction of compact resonators. These resonators, however, only are operational for a small interval of mirror radii of curvature. For positive radii of curvature, on the other hand, the shortest length of the resonator will be still longer than for negative radii of curvature, and the construction of short-length resonators will always require mirrors with small radii of curvature. On the other hand, there will be total versatility in terms of radii of curvature of the mirrors, because for a given radius of curvature it is possible to build a resonator for any desired set of parameters of the stability zone. By choosing negative mirrors, the analysis shows that resonator length can be as low as 421 mm for R = -150 mm while for positive radius of curvature it the smallest resonator length is 610 mm for R = 25 mm which represents a great reduction compared to the current resonator with is longer than 3 m. Even though the ring resonators can reach smaller length with negative mirrors, positive mirrors are preferred because of the additional beam waist where nonlinear crystals can be inserted.

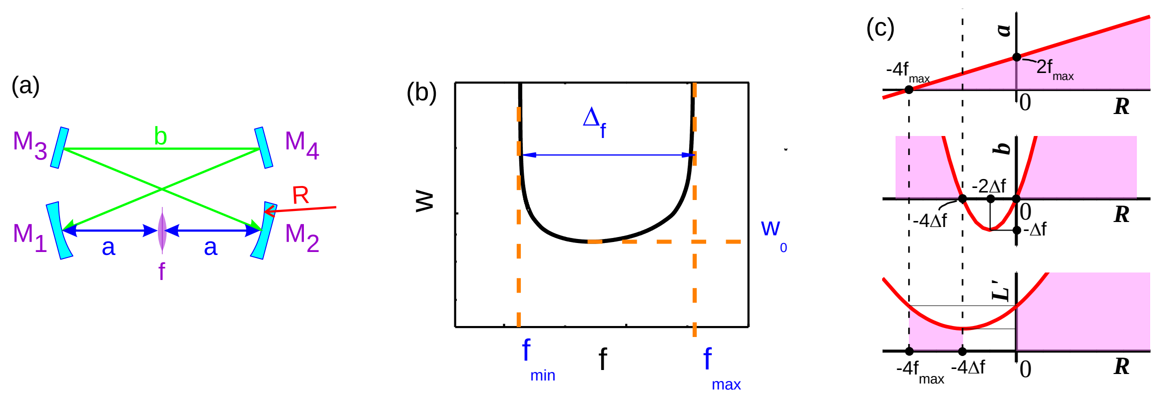

Fig. 1. (a) DSR ring resonator scheme showing geometrical parameters ***a*** and ***b***, stability zone parameters (b) and distances a, b and L´ as a function of R (c).

4. Conclusions

The use of a ring DSR resonators is suitable for producing very high-power, single-frequency lasers as demonstrated by our previous results. Aiming at developing more compact resonators with a wider FSR we showed by means of symmetric resonator modelling that by choosing a negative mirror curvature it is possible to reach the shortest resonators with, however, limited versatility of the stability range parameters. The results shows that the resonator length of our current ring resonator can be reduced by 8 and 5 times when considering negative and positive mirrors, respectively.

5. References

[1] T. A. King, "Ring Laser Resonators," in The Physics and Technology of Laser Resonators, D. R. Hall and P. E. Jackson, eds., 1st ed. (Adam Hilger, 1989), pp. 62–79.

[2] A. E. Siegman, "Unidirectiona ring-laser oscillators," in Lasers, University Science Books, ed., 1st ed. (1986).

[3] 1. S. De Silvestri, P. Laporta, and V. Magni, "Rod thermal lensing effects in solid-state laser ring resonators," Opt. Commun. 65, 373–376 (1988).

[4] A. Bereczki, A. A. Ferreira, and N. U. Wetter, "Dynamically stable single frequency ring resonator from diode pumped Nd:YAG modules with 55.6 W of output power," Opt. Express 29, 23167 (2021).

[5] A. Bereczki and N. U. Wetter, "Adaptive, dynamically stable, high-power ring resonator," in Laser Resonators, Microresonators, and Beam Control XXIV, A. M. Armani, A. V. Kudryashov, A. H. Paxton, V. S. Ilchenko, and J. V. Sheldakova, eds. (SPIE, 2022), Vol. 1198705, p. 17.

[6] 1. A. Bereczki, N. U. Wetter, and F. Caldas da Cruz, "Dynamically stable continuous single frequency green ring laser," in 2019 SBFoton International Optics and Photonics Conference (SBFoton IOPC) (IEEE, 2019), pp. 1–4.