Cylindrical Symmetry Optimal Solar Cavity for Solar-pumped laser using Cr/Nd:YAG

Tomomasa OHKUBO and Ei-ichi MATSUNAGA

School of Engineering, Tokyo University of Technology,
Hachioji, 192-0982, Tokyo, Japan

Thanh Hung DINH

Kansai Photon Science Institute, National Institutes for Quantum Science and Technology,
Kizugawa, 619-0215, Kyoto, Japan

Yuji SATO

Joining and Welding Research Institute, Osaka University,
Ibaraki, 567-0047, Osaka, Japan

Abstract

We developed a new optimization program to design a solar cavity for a solar-pumped laser. The software is based on ray tracing, and it calculates the optimal shape of the solar cavity to maximize total absorbed power into a laser medium. Results changing the co-doped density of Cr^{3+} in the laser medium of Cr/Nd:YAG ceramics are discussed. Although the maximum absorption efficiency of the laser medium is 0.65 when the traditional cone-shaped solar cavity and 1% of Nd^{3+} doped Nd:YAG is used, the optimized solar cavity with the same laser medium is expected to have 0.82 of absorption efficiency.

1 Introduction

Solar-pumped laser, which converts incoherent solar light into coherent laser directly, is expected as a promising technology for realizing a sustainable society. Although the first lasing of the solar-pumped laser was realized in 1965 by C.G. Young [1], its efficiency was low for a long time. In our previous studies, we developed a new solar-pumped laser that uses the Fresnel lens as the primary solar energy concentrator. We succeeded in increasing its output power and efficiency [2][3], and 120 W of laser output and 30 W/m^2 of total area performance was achieved using 4 m^2 of a Fresnel lens and cone-shaped pumping cavity [4]. However, Z. Cai recently realized 38.8 W/m^2 of total area performance in 2023 [5].

In this study, we discuss the density of co-doped Cr^{3+} in a Cr/Nd:YAG laser medium and the optimization of the shape of a pumping cavity to achieve higher absorption efficiency.

2 Calculated Results

At first, we calculated the absorption rate of a traditional cone-shaped cavity changing the density of Cr^{3+} in laser medium from 0 at % to 1 at % using our own developed ray tracer used in the previous studies. The calculated results are shown in Figure 1 (a). As shown in Figure 1 (a), when we use pure Nd:YAG laser medium (which means the density of Cr^{3+} is 0 at %), the total absorption rate is only 0.65, and it increases up to 0.73 when co-doped Cr^{3+} is even only 0.1 at %. Although the total absorption rate slightly increases as the density of Cr^{3+} increases, the difference between 0.5 at % and 1.0 at % is only 0.004. From this result, optimization only about the density of Cr^{3+} is not enough to realize a more effective solar-pumped laser.

Secondly, the optimal shape of the pumping cavity, which has maximum total absorbed power, is calculated when co-doped Cr^{3+} of 0 at % and 1.0 at % of Cr/Nd:YAG ceramics using our developed simulator used in the previous study [6]. The diameter of the calculated optimal cavity shape and the original cone shape, along with the optical axis, are shown in Figure 1 (b). Although the cone-shaped cavity has no peak, the optimal shape has two peaks. The optimal shape achieves more than 0.82 absorption efficiency using Cr^{3+} of 1.0 at % and Nd^{3+} of 1.0at % Cr/Nd:YAG ceramics as the laser medium.

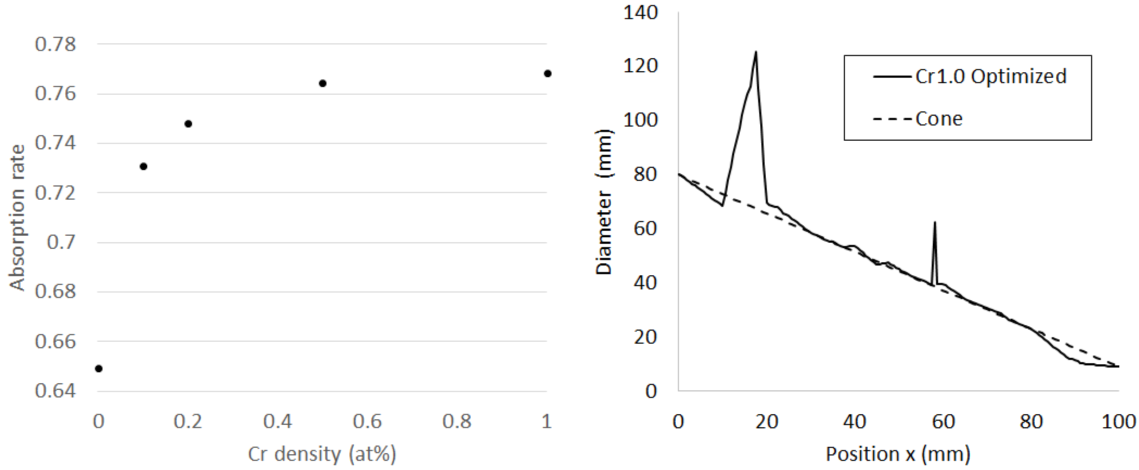

Figure 1: (a) Calculated absorption rate dependency on the density of Cr^{3+} when the traditional cone-shaped cavity is used, (b) Comparison of the optimized shape and the original shape.

3 Conclusion

We developed an optimization program to calculate the optimal shape of the pumping cavity for a solar-pumped laser considering the density of co-doped ions in the laser medium. With a traditional cone-shaped pumping cavity, increasing the density of co-doped Cr3+ from 0 at % to 1.0 at % in Cr/Nd:YAG ceramics of Nd3+ of 1.0 at % increases absorption efficiency from 0.65 to 0.77. Furthermore, the optimal shape calculated from this study realizes more than 0.82 absorption efficiency. With the optimal shape of the pumping cavity and Cr^{3+} of 1.0 at % and Nd^{3+} of 1.0at % Cr/Nd:YAG ceramics, more than 160W of the laser output is expected. Implementation and experiments based on this study are our future work.

Acknowledgments

This study was partially supported by JSPS KAKENHI (Grant number: 26870191, 22K04973).

References

[1] C. G. Young, A Sun-Pumped cw One-Watt Laser, Appl. Opt. vol. 5, Issue 6, pp.993-997, 1966.

[2] T. Yabe, T. Ohkubo, S. Uchida, K. Yoshida, M. Nakatsuka, T. Funatsu, A. Mabuti, A. Oyama, K. Nakagawa, T. Oishi, K. Daito, B. Bagheri, Y. Nakayama, M. Yoshida, S. Motokoshi, Y. Sato, and C. Baasandash, High-efficiency and economical solar-energy-pumped laser with Fresnel lens and chromium co-doped laser medium, Appl. Phys. Lett., Vol. 90, Issue 26, 261120, 2007

[3] T. Ohkubo, T. Yabe, K. Yoshida, S. Uchida, T. Funatsu, B. Bagheri, T. Oishi, K. Daito, M. Ishioka, Y. Nakayama, N. Yasunaga, K. Kido, Y. Sato, C. Baasandash, K. Kato, K. Yanagitani, and Y. Okamoto, Solar-pumped 80 W laser irradiated by a Fresnel lens, Opt. Lett., Vol. 34, Issue 2, pp.175-177, 2009

[4] T. H. Dinh, T. Ohkubo, T. Yabe, and H. Kuboyama, 120 watt continuous wave solar-pumped laser with a liquid light-guide lens and an Nd:YAG rod, Opt. Lett. Vol. 37, Issue 13, pp.2670-2672, 2012

[5] Z. Cai, C. Zhao, Z. Zhao, J. Zhang, Z. Zhang, and H. Zhang, Efficient 38.8 W/m2 solar pumped laser with a Ce:Nd:YAG crystal and a Fresnel lens, Opt. Express, Vol. 31, Issue2, pp. 1340-1353, 2023

[6] T. Ohkubo, E. Matsunaga, T. H. Dinh and Y. Sato, A Study of Cylindrical Symmetry Optimal Pumping Cavity for Solar-pumped laser, proc. ISPMAT 2022, 2022