International Journal of Latest Research in Science and Technology **ISSN (Online):2278-5299**
Vol.1,Issue 4 :Page No.314-316 ,November-December 2012
https://www.mnkpublication.com/journal/ijlrst/index.php

LASER DIODE PUMPED CONTINUOUS WAVE Yb$_3$Al$_5$O$_{12}$ LASER

[1]H. Hitotsuya, [1]Y. Kondo, [1]S. Matsubara, [1]K. Otani, [1]T. Ueda, [1]M. Inoue, [1]Y. Sasatani, [1]N. Shimojo, and [1-3]S. Kawato
[1]Graduate School of Engineering, University of Fukui, Fukui, 910-8507, Japan, E-mail: hiro0904@u-fukui.ac.jp
[2]Japan Synchrotron Radiation Research Institute (JASRI), Sayo, 679-5148, Japan, E-mail: kawato@u-fukui.ac.jp
[3]Research and Education Program for Life Science, University of Fukui, Fukui, 910-8507, Japan

---

***Abstract* : Continuous wave (CW) laser oscillation of a stoichiometric microchip Yb$_3$Al$_5$O$_{12}$ (YbAG) crystal was realized at room temperature (RT) with laser diode (LD) pumping. For single-emitter LD pumping, the maximum output power was 70 mW at an oscillation wavelength of 1079 nm. The maximum slope efficiency and the maximum optical-to-optical efficiency were 13% and 10% for the absorbed pump power, respectively. It is a first result of CW operation by LD pumping in stoichiometric material lasers.**

Keywords *– Stoichiometric Yb material, YbAG crystal, Quasi-three-level, LD pumped, CW laser oscillation, Room temperature*

I. INTRODUCTION

In recent years, the ytterbium (Yb)-ion doped materials have been recognized having attractive potential for laser diode pumped solid state lasers [1]–[11]. Their absorption spectrum around 900 nm wavelength is suited for pumping by reliable InGaAs high-power laser diodes. They offer several advantages over the Nd-doped materials due to their simple electronic structure. The Yb-doped materials have no excited state absorption (ESA) and cross relaxation by existing only two manifolds. The main advantage with respect to high power and high efficiency lasing is caused by their small quantum defect due to their small Stokes shift between absorption and emission. Moreover, Yb-doped materials have a long emission lifetime around 1 ms to increase the storage pulse energy. Broad emission spectra enable to generate ultrashort pulses. Yb-doped materials are especially suited as gain media for high power ultrashort pulse lasers and amplifiers with high efficiency.

One of the features of the Yb-doped materials is that it can incorporate very high concentrations of the Yb ions without concentration quenching. Highly doped Yb:YAG lasers have been realized previously [3]–[11] and highly efficient oscillation was demonstrated close to the laser quantum limited efficiency around 90% in the Yb:YAG crystal of 20 at.% concentration by high intensity pumping around 200 kW/cm^2 [4], [5]. The high laser ion-doped materials with short absorption length permit the use of thin gain media with high absorption efficiency. The thin media are useful for high efficiency oscillation by high intensity pumping. Laser diodes with low beam quality can be used as pump sources with high mode-matching efficiency between the laser beam and the pump beam.

The Yb-doped materials have the disadvantage of the absorption at the laser wavelength as the reabsorption loss by the thermal population of the lower laser level. Therefore, the stoichiometric Yb laser materials, which have the highest ion concentration, have some problems of thermal distortions and an increase in the reabsorption loss caused by high heat generation density. Techniques to compensate the thermal distortions and to reduce the reabsorption loss are necessary for efficient laser oscillation of the highly doped Yb materials, especially of the stoichiometric Yb laser materials.

Until now, laser oscillations of only two stoichiometric Yb materials have been reported with 100% Yb concentration [4]–[11]. They are YbAG and KYbW crystals. On the KYbW, which is one of the stoichiometric materials, CW oscillation was obtained at 1068 nm wavelength by pumping from a Ti:sapphire laser at 1025 nm wavelength to reduce the heat generation density [9]. For pumping between 900 nm and 1000 nm wavelengths, which are suitable for LD pumping, the KYbW laser was only reported by pulsed pumping [8], [9].

On the YbAG, which is another stoichiometric material, it has several advantages over the KYbW. The thermal conductivity of the YbAG is 7 W/(m K) [7] which is more than two times larger than the KYbW [8]. The fractional thermal population at the lower laser level of the YbAG is smaller than that of the KYbW because of higher energy separation of the lower laser level from the ground state. The YAG is optically isotropic, stable, and robust compared with the Yb-doped host materials. In previous studies, we have achieved CW YbAG laser oscillation by using the microchip crystal to minimize the reabsorption loss by optimum thickness and to realize high intensity pumping [10], [11]. Although the pump source was a Ti:sapphire laser, the pump wavelength was 937 nm which is suitable for LD pumping. In this paper, we report the first CW YbAG laser oscillation at RT with LD pumping, to our knowledge.

II. EXPERIMENT AND RESULTS

The structure of the microchip YbAG laser was shown in Fig. 1. We used the YbAG crystal (Scientific Material Corp.) which was used in the previous experiment [10], [11]. To optimize the pump absorption efficiency, the crystal thickness was chosen to be 200 μm. The (100) cut crystal was

Publication History
Manuscript Received : 22 December 2012
Manuscript Accepted : 25 December 2012
Revision Received : 28 December 2012
Manuscript Published : 31 December 2012

used to realize intrinsic reduction of the thermal-birefringence induced depolarization in the crystals [12], [13]. The peak absorption wavelength of the crystal is 937 nm. The pump surface of the crystal, was used as an end mirror of the laser resonator, was coated for high reflection between 1020 and 1080 nm wavelength and anti-reflection coated at 937 nm wavelength. The other surface was coated for broadband anti-reflection. The crystal was adhered to a copper heat-sink to cooling. The heat-sink temperature was controlled around 20°C by a thermo-electric cooler.

The pump source was a multi-mode single emitter LD (OSRAM) with an emitter area of 1 μm × 200 μm. The maximum output power was 720 mW with a wavelength of 940 nm. The LD beam was focused in the laser crystal with a spot area of 30 μm × 150 μm. The pump absorption efficiency was 94%. The maximum pump intensity in the laser crystal was obtained around 19 kW/cm^2 for the absorbed pump power.

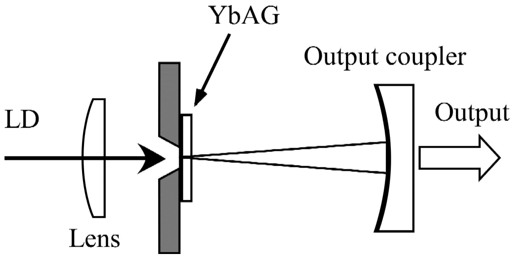

Fig. 1 Schematic of the CW YbAG laser.

In this setup, LD pumped CW laser oscillation of the stoichiometric YbAG crystal was achieved. The lasing spectrum is shown in Fig. 2, and the peak wavelength was 1079 nm which is a similar result in the previous experiment [10], [11].

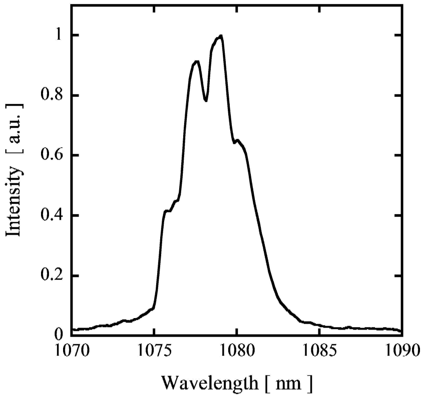

Fig. 2 The lasing spectrum of a CW YbAG laser with multi-mode LD pumping.

Figure 3 shows the output power of the YbAG laser by multi-mode LD pumping and Ti:sapphire laser pumping as a function of the incident pump power. With an output coupler of a transmittance $T = 0.1\%$, the lasing threshold was around 140 mW and the maximum output power was 70 mW. The lasing threshold intensity for the absorbed power was around 4 kW/cm^2. The optical-to-optical efficiency was 9.7% for the incident pump power and 10% for the absorbed pump power. The slope efficiency was 12% for the incident pump power and 13% for the absorbed pump power. These efficiencies are low compared to those of the Ti:sapphire pumped laser due to low mode-matching efficiency and high lasing threshold. The low mode-matching efficiency was caused by the difference in shape between an elliptical spot of the LD beam and a nearly circular spot of the laser beam in the crystal. The high lasing threshold was caused by a large spot area of the LD beam compared to that of the Ti:sapphire laser beam. The mode-matching efficiency will be increased, if the spot shape of the laser beam and the pump beam are almost same in the YbAG crystal. The optical-to-optical and slope efficiencies will be increased by multi path pumping schemes which are usually used in thin-disk lasers.

For Ti:sapphire laser pumping in the previous experiment [10], [11], the YbAG did not lase with higher pump power above 400 mW. Here, we obtained laser operation up to 700 mW pump power. The reason which limits the lasing pump power is considered to be thermal distortion such as thermal lensing.

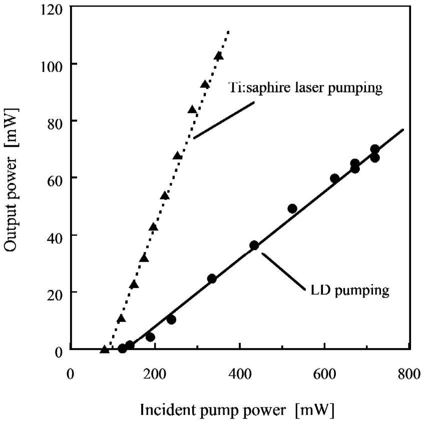

Fig. 3 The output power of CW YbAG laser as a function of the incident pump power. The pump sources were the multi-mode LD and the Ti:sapphire laser.

III. CONCLUSIONS

In conclusion, we obtained a CW YbAG laser oscillation with LD pumping. It is the first report for the CW stoichiometric Yb laser oscillation with LD pumping, in our knowledge. The maximum output power was 70 mW with a laser wavelength of 1079 nm. The maximum slope efficiency and the maximum optical-to-optical efficiency were 13% and 10% for the absorbed pump power, respectively. These results were obtained using the microchip gain materials. The efficiencies can be increased by precise compensation of thermo-optic effects.

REFERENCES

[1] A. Giesen, H. Hugel, A. Voss, K. Wittig, U. Brauch, and H. Opower, "Scalable Concept for Diode-Pumped High-Power Solid-State Lasers," *Appl. Phys. B*, vol. 58, pp. 365–372, May 1994.

[2] P. Lacovara, H. K. Choi, C. A. Wang, R. L. Aggarwal, and T. Y. Fan, "Room-temperature diode-pumped Yb:YAG laser," *Opt. Lett.*, vol. 16, pp. 1089–1091, Jul. 1991.

[3] T. Taira, J. Saikawa, T. Kobayashi, and R. L. Byer, "Diode-Pumped Tunable Yb:YAG Miniature Lasers at Room Temperature: Modeling and Experiment," *IEEE J. Sel. Top. Quantum Electron.*, vol. 3 pp. 100–104, Feb. 1997.

[4] S. Matsubara, T. Ueda, T. Takamido, S. Kawato, and T. Kobayashi, “Nearly quantum-efficiency limited oscillation of Yb:YAG laser at room temperature,” in *Proc. Advanced Solid-State Photonics*, 2005, paper TuB38.

[5] S. Matsubara, T. Ueda, S. Kawato, and T. Kobayashi, “Highly Efficient Continuous-Wave Laser Oscillation in Microchip Yb:YAG Laser at Room Temperature,” *Jpn. J. Appl. Phys.*, vol. 46, pp. L132–L134, Feb. 2007.

[6] F. D. Patel, E. C. Honea, J. Speth, S. A. Payne, R. Hutcheson, and R. Equall, “Laser Demonstration of $Yb_3Al_5O_{12}$ (YbAG) and Materials Properties of Highly Doped Yb:YAG,” *IEEE J. Quantum Electron.*, vol. 37, pp. 135–144, Jan. 2001.

[7] P. Klopp, U. Griebner, V. Petrov, X. Mateos, M. A. Bursukova, M. C. Pujol, R. Sole, J. Gavalda, M. Aguilo, F. Guell, J. Massons, T. Kirilov, and F. Diaz, “Laser operation of the new stoichiometric crystal $KYb(WO_4)_2$,” *Appl. Phys. B*, vol. 74, pp. 185–189, Feb. 2002.

[8] M. C. Pujol, M. A. Bursukova, F. Guell, X. Mateos, R. Sole, J. Gavalda, M. Aguilo, J. Massons, and F. Diaz, “Growth, optical characterization, and laser operation of a stoichiometric crystal $KYb(WO_4)_2$,” *Phys. Rev. B*, vol. 65, 165121, pp. 1–11, Apr. 2002.

[9] P. Klopp, V. Petrov, U. Griebner, V. Nesterenko, V. Nikolov, M. Marinov, M. A. Bursukova, and M. Galan, “Continuous-wave lasing of a stoichiometric Yb laser material: $KYb(WO_4)_2$,” *Opt. Lett.*, vol. 28, pp. 322–325, Mar. 2003.

[10] S. Matsubara, M. Inoue, S. Kawato, and T. Kobayashi, “Continuous Wave Laser Oscillation of Stoichiometric YbAG Crystal,” in *Proc. CLEOE-IQEC*, 2007, paper CA-8-1 WED.

[11] S. Matsubara, M. Inoue, S. Kawato, and T. Kobayashi, “Continuous Wave Laser Oscillation of Stoichiometric YbAG Crystal,” *Jpn. J. Appl. Phys.*, vol. 46, pp. L61–L63, Jan. 2007.

[12] I. Shoji and T. Taira, “Intrinsic reduction of the depolarization loss in solid-state lasers by use of a (110)-cut $Y_3Al_5O_{12}$ crystal,” *Appl. Phys. Lett.*, vol. 80, pp. 3048–3050, Apr. 2002.

[13] I. Shoji, Y. Sato, S. Kurimura, V. Lupei, T. Taira, A. Ikesue, and K. Yoshida, “Thermal-birefringence-induced depolarization in Nd:YAG ceramics,” *Opt. Lett.*, vol. 27, pp. 234–236, Feb. 2002.