Appl Phys B (2009) 94: 81–84
DOI 10.1007/s00340-008-3303-0

Applied Physics B
Lasers and Optics

Diode-pumped single-frequency microchip CTH:YAG lasers using different pump spot diameters

Z. Lin · C. Gao · M. Gao · Y. Zhang · H. Weber

Received: 29 May 2008 / Revised version: 16 October 2008 / Published online: 26 November 2008

Abstract Single-frequency Cr,Tm,Ho:YAG (CTH:YAG) microchip lasers pumped by a 785 nm laser diode were reported. Three kinds of pump spot diameters (75, 100, and 120 μm) were investigated for 1 and 0.7 mm thick laser crystals. The maximum single-frequency output power was 32 mW at a crystal temperature of 10°C. The output power against the laser crystal temperature demonstrated the temperature sensitivity of the CTH:YAG laser. The frequency tuning by changing the temperature of the crystal was also investigated. A tuning coefficient of 1.4 GHz/°C was obtained.

PACS 42.55.Sa · 42.55.Xi

1 Introduction

Diode-pumped solid state lasers with wavelengths around 2 μm are useful in laser medicine, remote sensing, and Lidar [1–3]. In some applications single-frequency operation of the 2 μm lasers is required, such as the Coherent Doppler Lidar and Differential Absorption Lidar [4]. Several methods were used to obtain the single-frequency operation in the 2 μm region, such as an intra-cavity Fabry–Perot etalon [5], a microchip cavity [6, 7], a non-planar ring resonator [8–10], etc. Among them, the diode-pumped microchip laser has the advantages of compactness and simplicity. He and Killinger [6] reported the single-frequency operation of the diode-pumped Tm:YAG and Tm–Ho:YAG systems. The maximum single-frequency output was 5 mW, obtained with a Tm,Ho:YAG microchip laser at a temperature of -10°C. Single-frequency operation with other Tm, Ho co-doped crystal microchip laser such as Tm,Ho:YLF were also reported [7]. The maximum single frequency output power was limited to 11 mW.

In this paper, we present the experimental results of diode-pumped Cr,Tm,Ho:YAG (CTH:YAG) microchip lasers. The temperatures of the crystal were kept around 10°C by using a Thermal-Electric Cooler (TEC). Up to 32 mW single-frequency output power was obtained with a 1 mm microchip laser, which is the maximum output power from the 2 μm microchip lasers to our knowledge. The dependence of the output power on the temperature, and the thermal tuning coefficient of the laser frequency were also investigated.

2 Experimental setup

The CTH:YAG laser crystals used in our experiment were 4 mm in diameter and 1 mm (0.7 mm) in thickness, doped with 0.85 at% Cr^{3+}, 5.9 at% Tm^{3+}, and 0.36 at% Ho^{3+}. The input surface of the crystals has a coating with high transmission at 785 nm ($T > 99\%$) and high reflectivity at 2.09 μm ($R > 99.9\%$). The output surface of the crystals has a high reflectivity coating at 785 nm ($R \sim 93\%$) and 97.7% at 2.09 μm. The absorption coefficient α of the laser crystal at the pump wavelength of 785 nm was measured to be 4.3 cm^{-1}. Considering the reflectance of the output surface,

---

Z. Lin · C. Gao (✉) · M. Gao · Y. Zhang
Department of Opto-electric Engineering, School of Information Science and Technology, Beijing Institute of Technology, Beijing 100081, China
e-mail: gao@bit.edu.cn
Fax: +86-10-68913658

H. Weber
Institute of Optics, Technical University Berlin, 10623 Berlin, Germany

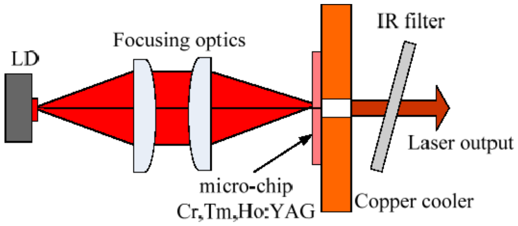

Fig. 1 The schematic setup of the CTH:YAG microchip laser

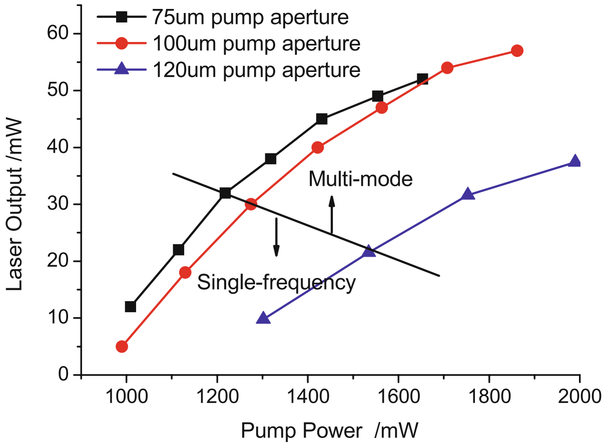

Fig. 2 The output powers of 1 mm CTH:YAG microchip laser as functions of the pump power for different pump spot diameters. The crystal temperature was kept at 10°C

the absorption of the 1 and 0.7 mm crystal for the pump beam are 56 and 44%, respectively.

The experimental setup is shown in Fig. 1. It consists of a diode laser, a focusing optical system, a microchip crystal, a copper cooler, and an infrared filter. Two kinds of 785 nm laser diodes were used for pumping CTH:YAG crystals. One pump source was a 100 μm fiber-coupled laser diode with a maximum output power of 1.9 W. The pump beam was focused by a 1:1 coupling optical system to a pump spot diameter of 100 μm. For comparison, we also used a 4:3 coupling optical system, and the minimum spot diameter of the pump beam was 75 μm. Another pump source was a commercial laser diode with an emitting area of 150 μm × 1 μm and an output power of 2 W. The pump beam was focused by two lenses with the focal lengths of 32 and 25 mm. In this case the minimum spot size of the pump beam was about 120 μm. The microchip was attached to a heat sink, which was cooled by a TEC. The temperature of the heat-sink can be controlled between 10–20°C. An infrared filter was used to block the non-absorbed pumping beam. The filter has a high absorption below 1 μm ($T < 1\%$) and a transmission of $T \sim 90\%$ at 2.09 μm. The output power was measured by a power meter behind the filter. A scanning confocal Fabry–Perot interferometer with a free spectral range of 2.5 GHz was used to observe the axial modes of the output beam.

3 Results and discussion

3.1 Laser output

First, the 1 mm thick CTH:YAG microchip laser was investigated. The pump spot sizes were 75, 100, and 120 μm, respectively. Figure 2 shows the output power as a function of the pump power for three pump spot sizes. The temperature of the CTH:YAG microchip was kept at 10°C in the three cases. By using the scanning confocal Fabry–Perot interferometer, we can find the single-frequency region and the multi-mode region. At 75 μm pump spot diameter, the maximum single-frequency output power was 32 mW. For 100 and 120 μm pump spots, the maximum single-frequency laser output powers were 30 and 21 mW, respectively. The slope efficiencies of single-frequency output powers respect to the pump powers were 9.5, 7.4, and 4.1% for three pump spot diameters, respectively. Since the absorption length of the microchip laser was only 1 mm, the efficiency of the microchip laser was lower than that of diode-pumped rod lasers which have longer absorption lengths. If the pump power absorbed by the microchips were used, the slope efficiencies were 17.0, 13.2 and 7.3%, respectively. It was shown that the microchip laser with smaller pump spot diameters had lower thresholds and higher slope efficiencies, since bigger pumping rates were obtained by using smaller pumping spots. The stability of resonator was achieved due to the thermal lens of the microchip crystal. However, the thermal lens has little effect on the mode size because the microchip laser has a very short cavity length. The thresholds and single-frequency efficiencies of the microchip CTH:YAG laser under different pump spots depend mostly on the pumping rates. Obviously smaller pump spots produce higher single-frequency efficiencies.

The 0.7 mm thick CTH:YAG microchip laser was operated by using the fiber-coupled pump-diode. Figure 3 shows the output powers versus the pump powers. The coupling systems and the crystal temperature were the same as in the former experiment. With the 75 μm pump spot, the maximum single-frequency output power was 33 mW, while for the 100 μm pump spot, it was 30 mW. The slope efficiencies of the single-frequency output powers with respect to the pump powers were 8.6 and 3.8%, respectively. If the pump powers absorbed by the microchips were used, the slope efficiencies were 19.5 and 8.6%, respectively.

The single-frequency operation region depends on the free spectral range (cavity length) and on the gain profile of the active material. In our experiment single-frequency operation can be obtained from the 1 and 0.7 mm thick microchip, but the efficiency is dependent on the pumping rate. The output coating can also influence the threshold and efficiency of the CTH:YAG microchip laser. By optimizing the

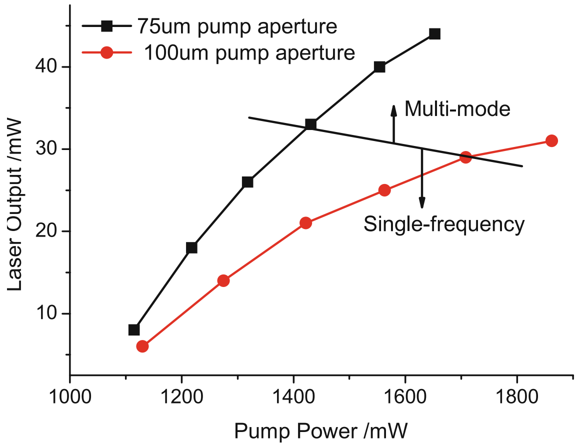

Fig. 3 The output power of the 0.7 mm CTH:YAG microchip laser versus the pump power for different pumping spots. The crystal temperature was kept at 10°C

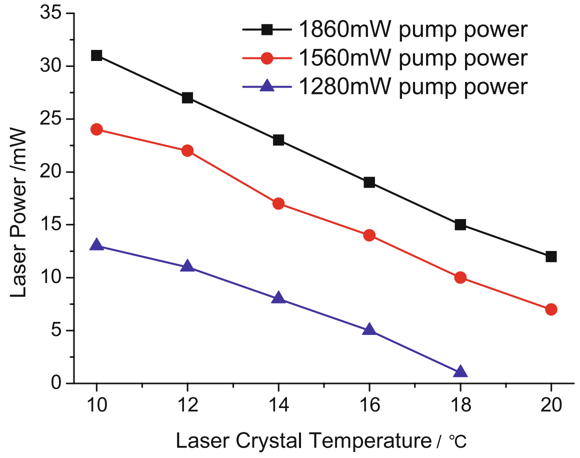

Fig. 4 The output power of the 0.7 mm CTH:YAG microchip laser versus the laser crystal temperature for different pumping powers

transmission of the output coating and decreasing the pump spot diameter, higher single-frequency output power can be achieved.

3.2 Tuning experiments

The dependence of the output power on the crystal temperature is shown in Fig. 4. For a constant pumping power of 1.86 W, the output power of the laser was 32 mW at 10°C and 12 mW at 20°C. With the incident pump power fixed at 1.28 W, the laser provided 13 mW at 10°C but was reduced to zero above 18°C. The CTH:YAG laser crystal is strongly temperature-sensitive.

The frequency tuning coefficient of laser is given by [8]

$$\frac{d\nu}{dT} = -\nu\left[\frac{1}{n}\frac{dn}{dT} + \alpha_T\right],$$

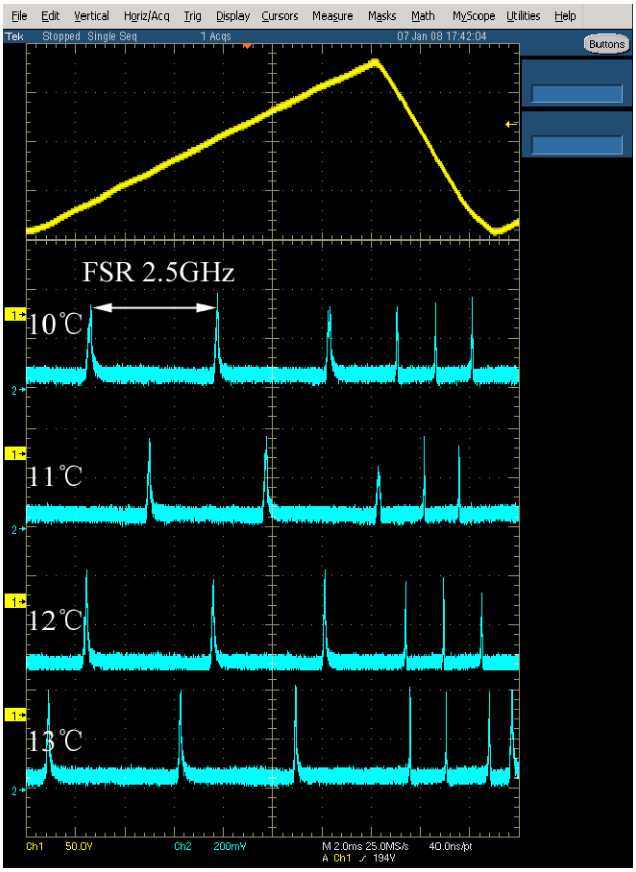

Fig. 5 Frequency tuning of the CTH:YAG microchip laser when the temperature varied from 10 to 13°C

where ν is the frequency of the laser, n is the index of refraction, $\frac{dn}{dT}$ is the temperature coefficient of the index of refraction, and α_T is the thermal expansion coefficient. For the CTH:YAG laser with a wavelength of 2.09 μm, the tuning coefficient is calculated to be 1.426 GHz/°C. Figure 5 shows the shift of the laser frequency when the crystal temperature turned from 10 to 13°C. The laser did not undergo a mode-hopping in this temperature range. From the ratio of frequency shift to the free spectral region (FSR) of the interferometer the tuning coefficient was obtained to be 1.4 GHz/°C, which agreed with the calculation.

4 Summary

We have investigated the single-frequency operation in diode-pumped CTH:YAG lasers by using different pump spot diameters. The CTH:YAG microchip lasers have excellent characteristics in single frequency operation. At 75, 100, and 120 μm pump spots, the maximum single-frequency output powers of the 1 mm thick CTH:YAG microchip laser was 32, 30, and 21 mW, respectively. 33 mW single-frequency output power was obtained from the 0.7 mm thick microchip CTH:YAG laser. The laser thresholds, output powers. and single-frequency output powers were influenced by the pumping spot diameters. The frequency tuning of the microchip CTH:YAG lasers were also investigated, and the tuning coefficient 1.4 GHz/°C was measured. The single frequency microchip CTH:YAG laser can be used as a seed laser for high-energy CTH:YAG lasers.

Acknowledgements This research was supported by the National Science Foundation of China (60478046, 60778002), the Program for New Century Excellent Talents in University (NCET-05-0178), and Sino–German Collaboration funded by DFG and NSFC.

References

1. L.E. Batay, A.A. Demidovich, A.N. Kuzmin, A.N. Titov, M. Mond, S. Kuck, Appl. Phys. B **75**, 457–461 (2002)
2. G. Galzerano, E. Sani, A. Toncelli, S. Taccheo, M. Tonelli, P. Laporta, Appl. Phys. B **78**, 733–736 (2004)
3. D. Gatti, G. Galzerano, A. Toncelli, M. Tonelli, P. Laporta, Appl. Phys. B **86**, 269–273 (2007)
4. C.P. Hale, J.W. Hobbs, P. Gatt, Proc. SPIE **5086**, 253–263 (2003)
5. P. Laporta, M. Marano, L. Pallaro, S. Taccheo, Opt. Lasers Eng. **37**, 447–457 (2002)
6. C. He, D.K. Killinger, Opt. Lett. **19**, 396–398 (1994)
7. C. Nagasawa, T. Suzuki, H. Nakajima, H. Hara, K. Mizutani, Opt. Commun. **200**, 315–319 (2001)
8. T.J. Kane, T.S. Kubo, Adv. Solid-State Lasers **6**, 136–139 (1991)
9. C. Svelto, I. Freitag, Electron. Lett. **35**, 152–153 (1999)
10. T.S. Kubo, T.J. Kane, IEEE J. Quantum Electron. **28**, 1033–1040 (1992)