Optical Properties and Laser Operation of $Yb:Y_3Sc_2Al_3O_{12}$ Crystal

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Abstract: Optical properties of $Yb:Y_3Sc_2Al_3O_{12}$ crystal were investigated and compared with those from Yb:YAG crystals. Laser-diode pumped continuous-wave and passively Q-switched $Yb:Y_3Sc_2Al_3O_{12}$ lasers with Cr^{4+}:YAG crystal as saturable absorber has been demonstrated for the first time.

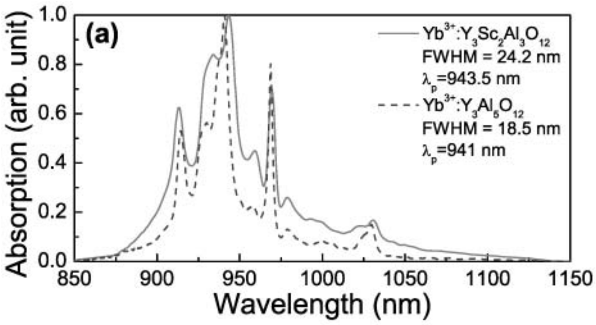
Keywords: $Yb:Y_3Sc_2Al_3O_{12}$, Optical properties, microchip laser, Q-switched operation

1. INTRODUCTION

Ytterbium doped laser materials have been intensely investigated for developing high power laser-diode pump solid-state lasers, and tunable lasers around 1 μm regions [1, 2]. Yb:YAG crystal and polycrystalline ceramics are one of the dominant laser gain media used for solid-state lasers owing to their excellent optical, thermal, chemical and mechanical properties [3]. There are several reports on the optical properties and laser performance of $Nd:Y_3Sc_2Al_3O_{12}$ (Nd:YSAG) crystals and ceramics [4, 5] owing to their good optical, themal-mechanical properties compared to YAG host. The distribution coefficient for Nd^{3+} in YSAG is roughly twice that of YAG [6], making it possible to increase the Nd^{3+} concentration in YSAG over that in YAG. Replacing Al^{3+} ions with larger Sc^{3+} ions increases the distance between dodecahedral lattice sites (substitutional sites for Nd^{3+} ions in the garnet structure). And the optical spectra of Nd:YSAG crystal become relative broader compared to those from Nd:YAG crystal. Here, we reported, for the first time to our knowledge, on the optical properties of Yb:YSAG crystal and continuous-wave and passively Q-switched microchip laser operation with Cr^{4+}:YAG as saturable absorber.

2. OPTICAL PROPERTIES OF YB:YSAG CRYSTAL

The Yb:YSAG crystal was grown by traditional Czochralski (CZ) method, the Yb^{3+}-ions doping concentration is 5 at.%. The absorption and emission spectra of Yb:YSAG crystal and Yb:YAG crystal were shown in Fig. 1. The absorption and emission characteristics of Yb:YSAG crystal are similar to those of Yb:YAG crystal. However, the peak absorption wavelength centered at 943.5 nm is about 2.5 nm red-shift comparing to that for Yb:YAG crystal. The bandwidth of Yb:YSAG crystal centered at 943.5 nm was measured to be 24.2 nm, which is about 6 nm wider than that for Yb:YAG crystal. Therefore, Yb:YSAG crystal is more suitable for laser-diode pumping owing to more broad band absorption features. Two main emission peaks are centred at 1031.4 nm and 1049 nm. The emission bandwidth centered at 1031.4 nm is about 5.2 nm wider than that from Yb:YAG crystal. The fluorescence lifetime was measured to be 1.1 ms owing to the radiative trapping effect in Yb doped materials.



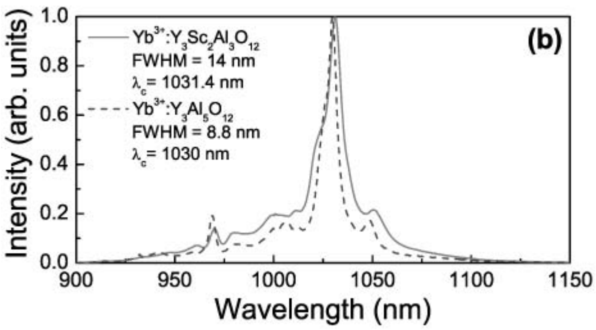


Fig. 1 Absorption and emission spectra of Yb:YSAG crystal doped with 5 at.% Yb^{3+}-ions at room temperature, the absorption and emission spectra of Yb:YAG was also plotted for comparison.

3. CW AND Q-SWITCHED LASER PERFORMANCE

Laser-diode end-pumped cw and Q-switched laser performance was conducted by adopting microchip laser configuration. A 2.5-mm-thick, plane-parallel coated Yb:YSAG crystal was used as gain medium. Plane-parallel output coupling mirrors with 5 and 10% transmission at 1030 nm was used as output coupler. One 0.5-mm-thick Cr^{4+}:YAG crystal with initial transmission of 95% was sandwiched between Yb:YSAG crystal and output coupler with 10% transmission for Q-switching operation. A high-power

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fiber-coupled 940 nm laser-diode with a core diameter of 100 μm and numerical aperture of 0.22 was used as the pump source. CW output power of Yb:YSAG microchip lasers as a function of the absorbed pump power for different output couplings was shown in Fig. 2. The absorbed pump power thresholds are 0.38, 0.56 W for T_{oc} = 5, and 10%. The output power increases linearly with the absorbed pump power. The output power decreases with increase of the transmission of output couplers. The sloped efficiencies were measured to be 35, and 21 % for T_{oc} = 5, and 10 %. Maximum output power of 1.12 W was measured with T_{oc} = 5% at absorbed pump power of 3.78 W, corresponding optical-to-optical efficiency was 30%. The slope efficiency was measured to be about 13% for Q-switched operation. Maximum average output power of 400 mW was achieved, that corresponds to optical-to-optical efficiency of 11%. There was no pump saturation, therefore, the output power can be scaled with high pump power.

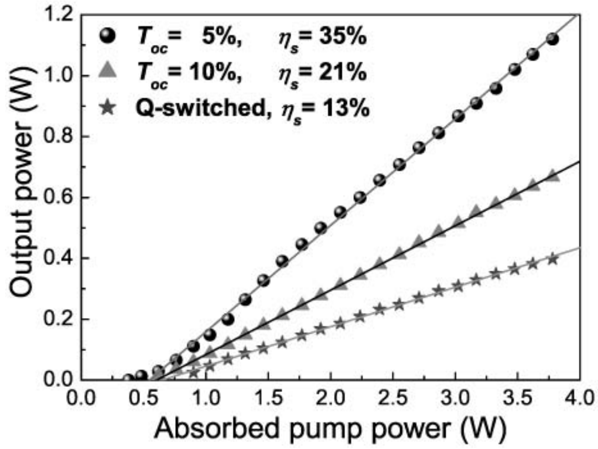

Fig. 2 Output power of cw and Q-switched Yb:YSAG microchip lasers as a function of absorbed pump power.

Repetition rate increases linearly with absorbed pump power. The pulse energy, pulse width and peak power are nearly independent on the pump power when the absorbed pump power is higher than 2 W. Peak power of over 12 kW stable laser pulses with the pulse width of 2.5 ns and pulse energy of 31 μJ were obtained at a repetition rate of 12.7 kHz. CW and passively Q-switched Yb:YSAG lasers operate at a TEM_{00} mode with multilongitudinal modes owing to the broad emission spectra of Yb:YSAG crystal. Fig. 3 shows the laser emitting spectra of CW and passively Q-switched Yb:YSAG microchip lasers under different pump power levels. The wide separation between each mode for Q-switched operation is attributed to Cr^{4+}:YAG plate acting as an intracavity titled etalon to select longitudinal modes.

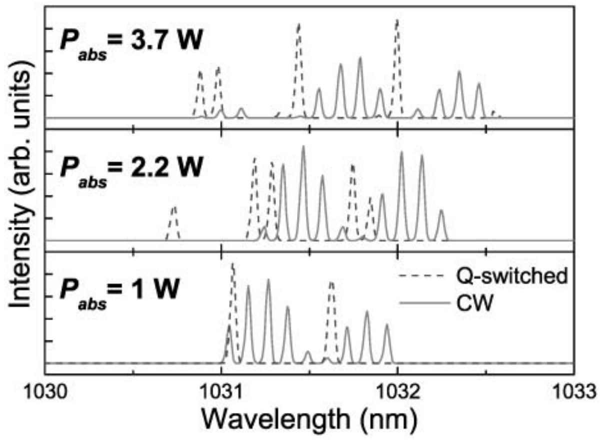

Fig. 3 Laser spectra of cw and Q-switched Yb:YSAG microchip lasers under different pump power levels.

4. CONCLUSIONS

In conclusion, the optical properties and laser performance (cw and passively Q-switched) of Yb:YSAG crystal were reported for the first time. The broad absorption and emission spectra of Yb:YSAG crystal compared to those from Yb:YAG crystal make Yb:YSAG crystal a potential candidate for high power solid-state lasers and tunable lasers.

REFERENCE

[1] W. F. Krupke, "Ytterbium solid-state lasers - The first decade," *IEEE J. Sel. Top. Quantum Electron.*, vol. 6, pp. 1287 - 1296, 2000.

[2] J. Dong, A. Shirakawa, K. Ueda, H. Yagi, T. Yanagitani, and A. A. Kaminskii, "Efficient Yb^{3+}:$Y_3Al_5O_{12}$ ceramic microchip lasers," *Appl. Phys. Lett.*, vol. 89, p. 091114, 2006.

[3] G. A. Bogomolova, D. N. Vylegzhanin, and A. A. Kaminskii, "Spectral and lasing investigations of garnets with Yb^{3+} ions," *Sov. Phys. JETP*, vol. 42, pp. 440 - 446, 1976.

[4] T. H. Allik, C. A. Morrison, J. B. Gruber, and M. R. Kokta, "Crystallography, spectroscopic analysis, and lasing properties of Nd^{3+}:$Y_3Sc_2Al_3O_{12}$," *Phys. Rev. B*, vol. 41, pp. 21 - 30, 1990.

[5] Y. Sato, T. Taira, and A. Ikesue, "Spectral parameters of Nd^{3+}-ion in the polycrystalline solid-solution composed of $Y_3Al_5O_{12}$ and $Y_3Sc_2Al_3O_{12}$," *Jpn. J. Appl. Phys.*, vol. 42, 5071 - 5074 2003.

[6] M. Kokta, "Solubility enhancement of Nd^{3+} in scandium-substituted rare earth-aluminum garnets," *J. Solid State Chem.*, vol. 8, pp. 39 -42, 1973.