Continuous-Wave and Passively Q-Switched Nd:LYSO Lasers

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Abstract—Continuous-wave (CW) and passively Q-switched performance of a Nd-doped oxyorthosilicate mixing crystal, (Nd\textsubscript{0.005}Lu\textsubscript{0.4975}Y\textsubscript{0.4975})\textsubscript{2}SiO\textsubscript{5} (Nd:LYSO), were reported. As a result, new dual-wavelength all-solid-state lasers at 1075 and 1079 nm were achieved. When the absorbed pump power was 3.87 W, the CW laser produced 1.1 W output, corresponding to an optical conversion efficiency of 28.4% and a slope efficiency of 32.4%. By using a Cr\textsuperscript{4+}:YAG wafer as the saturable absorber, we achieved Q-switching operation of Nd:LYSO crystal. The maximal average output power, shortest pulse width, largest pulse energy and highest peak power were measured to be 294 mW, 27.5 ns, 34.3 µJ and 1.18 kW, respectively. By difference frequency, these dual-wavelength lasers have potential applications for the generation of a broadband coherent radiation from 0.7–1.3 THz.

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1. INTRODUCTION

Generally, oxyorthosilicates allow large activator concentration and possess high mechanical, chemical, and thermal durability [1]. Among them, YSO (Y\textsubscript{2}SiO\textsubscript{5}) and LSO (Lu\textsubscript{2}SiO\textsubscript{5}) have been researched as host materials for many laser rare-earth ions, including Nd\textsuperscript{3+}, Yb\textsuperscript{3+}, Er\textsuperscript{3+}, Ho\textsuperscript{3+}, and Tm\textsuperscript{3+} [1–18]. Both YSO and LSO have low symmetry crystal structure of positive monoclinic C\textsubscript{2}/c space group and two non-equivalent crystallographic sites [19] which can be substituted by rare-earth dopants. As an example, Nd:YSO has attracted much interest due to its favorable growth properties, strong nature birefringence, wide absorption and emission lines, large absorption cross section, etc. [4, 5]. Whereas LSO provide better thermal properties: the thermal conductivity of undoped YSO and LSO are 4.4 and 5.3 Wm\textsuperscript{-1}K\textsuperscript{-1}, respectively [8]; In the case of Nd doped, the mass discrepancy between Lu and Nd is much smaller than that between Y and Nd, which may contribute to keep a high thermal conductivity.

Previous research has discovered that due to the inhomogeneous broadening of spectrum, mixed crystals often present some novel laser performances, such as enhancement of pulse energy in Q-switching [20] and much shorter pulse width in mode-locking [21], compared with single ones. Fortunately, substituting Y for Lu will not change the structure intensively because the radii difference between Lu\textsuperscript{3+} and Y\textsuperscript{3+} was only 5% [22]. Overall, the mixed oxyorthosilicate crystal LYSO has the same crystal structure with YSO or LSO and combines the advantages of them. Since its first growth on 1997 [22], researches about LYSO have been focused on scintillator applications [22–24] and Yb-doped lasers [25–28]. Reference [25] demonstrated that Yb:LYSO possess large ground-state splitting and broad spectra with inhomogeneously terminal laser sublevels, and achieved efficient tunable laser operation. Subsequent work explored passively Q-switched Yb:LYSO laser [26], and recently self-mode locked Yb:LYSO laser was reported [28]. Those indicated that the LYSO is an excellent host material. Considering the properties of Nd\textsuperscript{3+} ions, it can be believed that the Nd doped LYSO should also be an excellent laser material. In a previous work, we have demonstrated a preliminary laser experiment on Nd:LYSO crystal [29]. In this paper, we present advanced results in CW operation for Nd:LYSO and new results concerning passively Q-switched operation.

The maximum CW output power was 1.1 W, corresponding to an optical conversion efficiency of 28.4% and a slope efficiency of 32.4%, respectively. Using Cr\textsuperscript{4+}:YAG as the saturable absorber, the shortest pulse width of 27.5 ns, the maximal average output power of 294 mW, the largest pulse energy of 34.3 µJ, and the highest peak power of 1.18 kW were obtained.
2. LASER SETUP

Figure 1 is the schematic diagram of the laser setup. The pump source is a fiber-coupled LD with a central wavelength around 808 nm. Its output beam was delivered into the laser crystal with a pump spot radius of 0.256 mm through a focusing system (N.A. = 0.22). The cavity comprised a flat input mirror M₁ coated for high transmission at the pump wavelength and high reflectivity at 1075 nm, and a flat output coupler M₂ with a certain transmission at 1075 nm. The Nd:LYSO crystal (3 × 3 × 7 mm³, cut along the b axis) has Nd³⁺ doping concentration of 0.5 at %. Its end faces were polished and antireflection coated at 808 and 1075 nm. With a Cr⁴⁺:YAG wafer (89.5 × 0.285 mm²) used as the saturable absorber, the passively Q-switched performance was achieved. Its initial transmission T₀ at 1064 nm is 97.5%. The laser crystal was wrapped with indium foil and mounted in a water-cooled copper block, and the temperature of the water was controlled to be 15°C. The Cr⁴⁺:YAG crystal was attached on a copper block without cooling water. The total length of the cavity was about 2 cm. The laser output was measured by a power meter (EPM 2000, Molectron Inc.), the spectrum was detected by a spectrometer (HR4000 CG-UV-NIR, Ocean Optics Inc.), and the pulse profile was recorded by a DPO7104 digital oscilloscope (1GHz bandwidth and 20.0 G/s sampling rate, Tektronix Inc.).

3. CW OPERATION

Using six flat mirrors with different transmittance (1.6, 5, 8, 10, 13, and 16% at 1075nm) as the output coupler (OC), we measured the CW laser performance of Nd:LYSO. Figure 2 shows the output power as a function of the absorbed pump power. Table 1 gives the output properties with different output couplers. With the 1.6% output mirror a maximum output power of 1.1 W was obtained at the absorbed pump power of 3.87 W, corresponding to an optical conversion efficiency of 28.4% and a slope efficiency of 32.4%. High transmittance of the output mirror will increase the optical loss in the cavity and therefore increase the laser threshold, so the lowest threshold of 0.5 W was also obtained by the 1.6% output mirror. Based on the analysis of [30] on the influence of inhomogeneous broadening of spectra on the laser performance, it can be believed that with the increase transmittance of output couplers, the intracavity power decreased and less ions on the upper energy level participated the laser operations. Therefore it can be found that viewed as a whole, the output power and slope efficiencies decreased with the increase of the transmission of output couplers.

The room-temperature absorption spectrum of Nd:LYSO crystal indicated that it’s absorption peak was at 811 nm, corresponding an absorption cross-section of 6.14 × 10⁻²⁰ cm² [29]. For 808 nm, the prac-

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<th>Transmittance of OC, %</th>
<th>Pump threshold, W</th>
<th>Maximum laser output, mW</th>
<th>Optical-optical efficiency, %</th>
<th>Slope efficiency, %</th>
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