Diode-pumped Yb:$Lu_2Si_2O_7$ laser with tunable and efficient output

Jinping He (何晋平)[1], Xiaoyan Liang (梁晓燕)[1*], Lihe Zheng (郑丽和)[2], Liangbi Su (苏良碧)[2], Jun Xu (徐　军)[2], and Zhizhan Xu (徐至展)[1]**

[1] *Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China*

[2] *Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai 200050, China*

[*] *E-mail: liangxy@mail.siom.ac.cn;* [**] *e-mail: zzxu@mail.shcnc.ac.cn*

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Diode-pumped laser action of a new crystal Yb^{3+}:$Lu_2Si_2O_7$ (LPS) is demonstrated for the first time to our knowledge. An output power of 2.22 W at 1070 nm and a slope efficiency of 34.7% were achieved with a 5 at.-% Yb: LPS sample. The tuning can cover the range form 1034 to 1080 nm.

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Recently, a variety of interesting results have been reported for continuous-wave (CW) or mode-locked operations based on the diode pumped Yb^{3+}-doped materials[1−9]. However, a drawback of current Yb^{3+} lasers is that Yb^{3+} can only be operated in a quasi three-level scheme. Thermal populating of the terminal laser level causes strong re-absorption at the emission wavelengths, resulting in high laser pumping threshold power. In order to limit thermal population of the terminal level, a relatively strong crystal-field is expected. Thus, a low-symmetry crystal structure and multi-type of substitution sites are essential for ytterbium-doped host materials.

Lutetium pyrosilicate crystal $Lu_2Si_2O_7$ (LPS) is a well known pyrosilicate that has been studied as a host for Ce^{3+} ion with applications as phosphors and excellent scintillators[10−12]. But to the best of our knowledge, up to now laser action and CW tunable laser performance have never been reported for Yb:LPS crystals.

Ytterbium-doped lutetium oxyorthosilicates Yb:Lu_2SiO_5 (Yb:LSO) single crystal is technologically important as a laser host material. More than 2.6-W average output with pulse durations of 260 fs at 1059 nm for Yb:LSO has been obtained[13]. Compared with Yb:LSO crystals, the advantages of Yb:LPS are the presence of effective low-symmetry monoclinic structure and its single crystallographic site, which are benefit for the low threshold and high output energy[14,15].

In this letter, we report, for the first time to our knowledge, the experimental investigation of laser diode (LD)-pumped CW and tunable Yb:LPS lasers. The output power reached 2.22 W at 1070 nm and the wavelength could be tuned from 1034 to 1080 nm.

The 5×5×3 (mm) 5 at.-% Yb:LPS sample, provided by the R&D Center for Laser and Opto-Electronic Materials of Shanghai Institute of Optics and Fine Mechanics (SIOM) was grown by the Czochralski method from an inductively heated iridium crucible. Pure SiO_2, Lu_2O_3, and Yb_2O_3 powders were mixed and pressed (200 MPa) into tablets. Nitrogen with purity of 5N was used as growth atmosphere. Finally, a colorless Yb:LPS crystal boule with a size up to 30 mm in length and diameter was obtained.

The room-temperature absorption and fluorescence spectrum of the Yb:LPS crystal is shown in Fig. 1. The orientation of the sample used for test is (0 0 1) plane and the Yb^{3+} concentration is 2.168×10^{20} atom/cm^3. We can observe that the absorption spectrum is mainly composed of three strong bands around 908, 976, and 1032 nm. Apparently, the absorption peak around 976 nm belongs to the zero-line transition between the lowest levels of $^2F_{7/2}$ and $^2F_{5/2}$ manifolds. The absorption coefficient of 976 nm is 4.59 cm^{-1} with absorption linewidth (full-wave at half-maximum) of 29 nm, which is larger than the absorption linewidth of Yb:LSO around 977 nm[16]. It is suitable for high efficiency diode-pumped operation.

As shown in Fig. 2, the fluorescence peaks are 977, 996, 1032, and 1069 nm, and the emission cross-sections are 0.18×10^{-20}, 0.31×10^{-20}, $0.34\times10-20$, and 0.20×10^{-20} cm^2, respectively. The fluorescence bands of 1032 and 1069 nm can serve as the possible laser output.

Although the emission cross-section of 1069 nm is smaller than that of 1032 nm, the re-absorption loss of the former is relatively low. As a result, the laser output around 1069 nm is more efficient. Although there is a weak re-absorption at 996 nm, it does not have too much effect on the laser output at this fluorescence band. In particular, the emission band at 1069 nm possesses a large emission cross-section for the smallest thermal populating of the terminal laser level of which brings about the smallest re-absorption losses. As a result, the

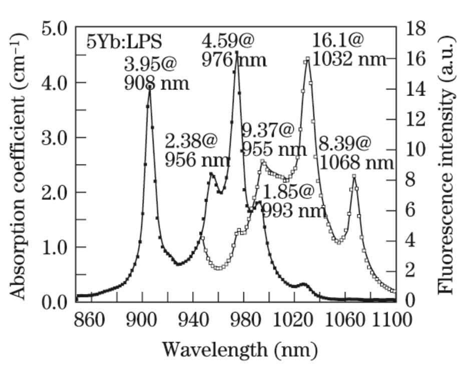

Fig. 1. Absorption and fluorescence spectrum of Yb:LPS crystal with (001) plane at room temperature.

laser output around 1069 nm becomes the most efficient one with easy population inversion and a low threshold value. It should be noted that the particularly broad emission bandwidth of the Yb:LPS crystal reaches about 62 nm, which can support pulses as short as ∼ 20 fs.

The pump source was a fiber-coupled diode laser with the core-diameter of 200 μm and numerical aperture (N.A.) of 0.22, emitting at the wavelength of 976 nm at room temperature. Pump beam was focused by a series of lens, and the pump spot on the crystal was about 180 μm. The 5×5×3 (mm) 5 at.-% Yb:LPS sample was wrapped with indium foil and mounted in a water-cooled copper block. The water temperature was maintained at 14 °C to prevent thermal fracture.

The laser experiments were performed with a stable three-mirror folded cavity, as illustrated in Fig. 3. The resonator consisted of a dichroic input coupler M_1 (high transmission at 976 nm and high reflection at 1030–1170 nm), a folding mirror M_2 (high reflection at 1030–1170 nm), and an output coupler (OC). M_1 and OC are both flat, and the curvature radius of M_2 is 300 mm. In order to realize the laser operation in TEM00 mode with high conversion efficiency, the length of two arms were configured to keep the mode matching in the crystal between the pump beam and the fundamental resonant mode. The wavelength tuning for Yb:LPS was fulfilled by inserting an SF10 dispersive prism in the collimated arm of the laser cavity.

In order to get the highest laser efficiency, we performed several experiments with various output coupler transmissions: 1.5%, 4%, 6%, and 9 % (at 1070±30 nm). The best performance was achieved with the 6% output coupler transmissions. And the dependence of the laser outputs on the absorbed pump power is illustrated in Fig. 4.

At the absorbed pump power of 7.9 W, the maximum laser output power of 2.22 W at 1070.9 nm was obtained

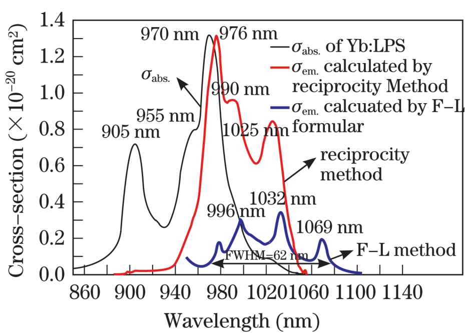

Fig. 2. Absorption cross-section $\sigma_{\rm abs}$ and the emission cross-section $\sigma_{\rm em}$ of Yb:LPS crystal

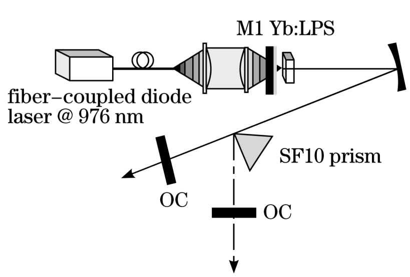

Fig. 3. Configuration of the CW Yb:LPS laser.

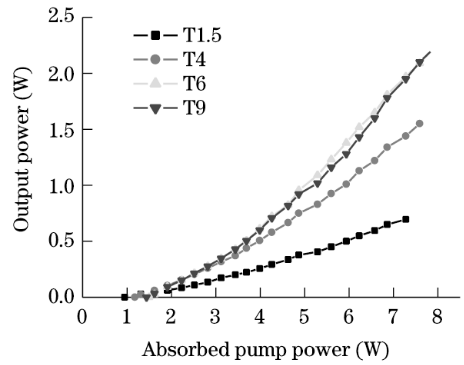

Fig. 4. Output power versus absorbed pump power with 5 at.-% Yb:LPS for different OCs at 1070 nm.

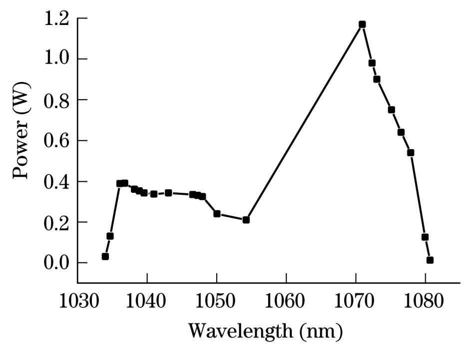

Fig. 5. Tuning curve of Yb:LPS with an SF10 dispersive prism and a 6% transmission OC.

with both 6% and 9% transmission DC, and the corresponding threshold was about 1.5W. Under lasing condition and at the maximum power, the uncoated crystal absorbed about 75% of the incident pump power, and the slope efficiency arrived at 34.7%. The efficiency was relatively low, and the efficiency could be higher if the crystal was coated with proper anti-reflection film, and a two-mirror short cavity was used as the laser cavity. Measured beam quality M^2 of less than 1.2 at all pump level was achieved. The laser threshold was approximately 0.94 W with a 1.5% OC transmission.

To tune the wavelength, we inserted a dispersive SF10 prism in the collimated arm of the cavity. In order to achieve efficient tuning output, the output coupler with 6% transmission was chosen. At about 7-W absorbed pump power, the Yb:LPS crystal supported a broad continuous range of 46 nm (from 1034 to 1080 nm). The wavelength tuning of Yb:LPS is illustrated in Fig. 5. Further tuning on shorter wavelength is limited by the coating of input coupler, which is difficult to maintain high reflection at this range and high antireflection around 976 nm.

In summary, with the 5 at.-% Yb:LPS sample, 2.22-W output (in TM00 mode) power at 1070 nm was achieved with a slope efficiency of 34.7%. And the tuning can cover the range from 1034 to 1080 nm. Its large emission cross section and wide emission spectra range confirm that this crystal is suitable for developing high efficiency all-solid-state femtosecond lasers. Our future work will focused on improving the laser crystal quality and getting its mode locked.

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