学术期刊可以用微信做什么，快来看看！

微信自动应答服务平台
— 微时代 微革命 —

微服务
移动互联网时代的营销革命
简单快捷 • 高效互动 • 随时随地 • 广泛传播

微信扫一扫
开启智慧“微服务”
Diode-pumped efficient laser action of Yb$^{3+}$:LYSO crystal

Juan Du (杜 鹃)$^{1,3}$, Xiaoyan Liang (梁晓燕)$^1$, Yi Xu (许 轼)$^{1,3}$, Ruxin Li (李儒新)$^1$, Guangjun Zhao (赵广军)$^2$, Chengfeng Yan (严成锋)$^2$, Liangbi Su (苏良碧)$^2$, Jun Xu (徐 军)$^3$, and Zhizhan Xu (徐至展)$^1$

$^1$State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

$^2$Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

$^3$Graduate School of the Chinese Academy of Sciences, Beijing 100039

Received November 9, 2006

Effective diode-pumped continuous wave (CW) tunable laser action of a new alloyed crystal Yb$^{3+}$:LYSO is demonstrated. The alloyed LYSO crystal possesses the desirable physical and laser performance of La$_2$SiO$_5$ (LSO), as well as the favorable growth properties and costs of Y$_2$SiO$_5$ (YSO) in the same time. With a 5 at.-% Yb:LYSO sample, the output power of 2.84 W at 1085 nm and an optical-to-optical conversion efficiency of 54.5% are achieved. Its laser wavelength can be tuned over a broad range of 81 nm, from 1030 to 1111 nm.

OCIS codes: 140.3380, 140.3480, 140.5680.

Yb$^{3+}$-doped laser systems have received increasing attention since the rapid development of high power and high brightness laser diodes emitting at 900—980 nm in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in latter 1990s, and have been expected to be the most potential alternatives to the Nd$^{3+}$ in later...
typical transitions from the ground state of \( ^2F_7/2 \) longs to the zero-line transition between the lowest levels. Apparently, the absorption peak around 977 nm is mainly composed of one strong band around 977 nm, from it, we can see that the absorption spectrum curve UV/VIS/NIR spectrophotometer at room temperature. From it, we can see that the absorption spectrum curve is mainly composed of one strong band around 977 nm, and other two weak absorption bands around 899 and 923 nm. Apparently, the absorption peak around 977 nm belongs to the zero-line transition between the lowest levels of \( ^2F_7/2 \) and \( ^2F_{5/2} \) manifolds. Others correspond to the typical transitions from the ground state \( ^2F_{7/2} \) to other sublevels of \( ^2F_{5/2} \) of Yb\(^{3+}\) in LYSO host. The absorption peak at 977 nm is well matched with the emission wavelength of commercially available high-power InGaAs laser diodes. The IR fluorescent spectrum of Yb:LYSO excited under the InGaAs laser diode (LD) source with the wavelength of 940 nm at room temperature is also presented in Fig. 1. The fluorescence curve mainly includes four bands around 1005, 1033, 1058, and 1082 nm, corresponding to the transitions from the lowest level of \( ^2F_{5/2} \) to the other levels of \( ^2F_{7/2} \) manifold except the lowest one. The broad emission spectrum is favorable for the development of new broadly tunable laser sources, femtosecond oscillators and amplifiers. From the energy-level diagram, we can estimate the overall splitting of \( ^2F_{7/2} \) manifold reaches about 993 cm\(^{-1}\). Large fundamental manifold splitting promises low pump threshold laser operation, for reabsorption losses at emission wavelengths can be decreased due to low thermal population of the terminal laser level. Therefore, in Yb:LYSO laser, laser performance of low threshold is suggested because of its relatively large splitting.

The basic outline of the CW Yb:LYSO laser setup is shown in Fig. 2. The resonator consisted of one dichroic input coupler mirror \( M_1 \) (high-transmission at 976 nm and high-reflection at 1030—1170 nm), one folding mirror \( M_2 \) (high-transmission at 976 nm and high-reflection at 1030—1170 nm), and one output coupler (OC), and it was a stable three-mirror folded cavity supporting only TEM\(_{00}\) mode. The input mirror \( M_1 \) and output coupler were both flat, and the curvature radius of the folded mirror \( M_2 \) was 300 mm. The \( 5 \times 5 \times 3 \) (mm), 5 at.-\% Yb:LYSO sample was wrapped with indium foil and mounted in a water-cooled copper block, uncoated and polished with parallel end surfaces. The water temperature was maintained at 14 °C to prevent thermal fracture. In order to realize the laser operation in TEM\(_{00}\) mode and result in high conversion efficiency, the lengths of two arms were configured to keep the mode matching in crystal between the pump beam and the fundamental resonant mode, and the total cavity length was about 70 cm. A fiber-coupled diode laser, with a core-diameter of 200 \( \mu \)m, a numerical aperture of 0.22, and maximum output power of 10 W, emitting at the wavelength range of 975—978 nm was used as the pump source. To keep the maximum absorption, the operating wavelength was tuned by temperature of diode to match the peak absorption of the crystal. The pump beam was image-relayed to the crystal with a ratio of 1:1, and the pump radius in the crystal is \( \sim 100 \) \( \mu \)m.

For Yb:LYSO laser, we used output couplers with different transmissions to obtain the optimum output. Figure 3 shows the CW laser output power as a function of the absorbed pump power with different output couplers. For output transmissions of \( T = 1.5\% \), \( T = 4\% \), \( T = 5\% \) and \( T = 7\% \), corresponding laser thresholds are about 0.41, 0.56, 0.74, and 0.86 W, respectively. At absorbed pump power of 5.21 W, maximum laser output power of 2.84 W at 1085 nm without tuning was obtained with a 5\% transmission output coupler. Under lasing condition and at maximum power, the uncoated crystal absorbed about 70\% of the incident pump power, and the optical-to-optical conversion efficiency researched 54.5\% with respect to absorbed pump power. The fluorescence intensity of peaks decreases along the longer wavelength side in the emission spectrum. However, considering the corresponding terminal laser level of each band is decreasingly populated along the longer wavelength, laser actions around the peak of 1082 nm demonstrate low laser threshold and high conversion efficiency.

The wavelength tuning for Yb:LYSO laser fulfilled by inserting an SF 10 dispersive prism in the collimated arm
of the laser cavity is shown in Fig. 2. Output coupler with 4% transmission was chosen for efficient tuning output, instead of the optimum output coupler of 5% for no tuning cavity, because the insertion of the prism increased the intracavity losses. The wavelength tuning with horizontal polarization of Yb:LYSO is illustrated in Fig. 4. With absorbed pump power of 4.7 W, the Yb:LYSO crystal could support a broad continuous range of 81 nm, from 1030 to 1111 nm. To our knowledge, this is the broadest tunable range ever obtained from Yb:LSO laser, and it is broader than that of either Yb:LSO or Yb:YSO in Ref. [9]. We attribute the broader tunability of Yb:LYSO crystal to the merit of being a mixed crystal, which provides LYSO crystal more disordered structure than that of YSO or LSO, hence the excellent tunable capability. The wavelength tuning curve of Yb:LYSO is flatter and smoother with fewer fluctuations. And it sustains a range of 52 nm over 1.0 W, from 1040 to 1092 nm. And these results make more potential for the use of Yb:LYSO in the development of all-solid-state tunable CW and femtosecond lasers for shorter pulse duration. In our experiment, further tuning on shorter wavelength under 1030 nm is limited by the coating of our input coupler. Therefore, it always resonated at its vicinal emission peak of 1030 nm with worse beam quality when the laser was tuned to shorter wavelength. In addition, when combining our experiment results with the former one[15], in which the Yb:LYSO laser can be tuned to the shorter wavelength of 1014 nm, Yb:LYSO is promising to sustain a broad tunable range of about 100 nm if the dichroic coating of cavity mirrors is selected properly.

In conclusion, to maintain the excellent laser performance of Yb:LSO crystal, improve growth characteristics, and reduce costs, we grew Yb:LYSO crystal for an attractive substitute and investigated its laser action. Grown by Czochralski method, Yb:LYSO has attractive merits, such as reduced melting point, longer crucible lifetime, and lower cost of starting material. In a word, it retains excellent laser properties of LSO with reduced growth cost, as well as the favorable growth properties of YSO. With the 5 at.-% Yb:LYSO sample, 2.84-W output power at 1085 nm was achieved with an optical-to-optical conversion efficiency of 54.5%. The laser wavelength could be tuned from 1030 to 1111 nm continuously, which is the broadest range ever achieved from Yb:LYSO laser. Owing to its broadly flat wavelength tuning range, it is also favorable to be used for a mode locked laser operation. In consequence, Yb:LYSO offers an promising alternative for efficient, low-cost, broadly tunable diode-pumped lasers, although researches on it are still elementary. Currently we are working on the growth of a series of Yb:Lu$_2$SiO$_5$ $(x = 0 \sim 1)$ crystals and their laser performances. We believe that, by choosing the most appropriate value of $x$, more interesting results will be demonstrated, and Yb:Lu$_2$SiO$_5$ could be one of the most excellent laser crystals for achieving high-power diode-pumped broadly tunable CW or mode locked lasers.

This work was supported by the National Natural Science Foundation of China under Grant No. 60578052 and 60544003. X. Liang and Z. Xu are authors to whom the correspondences should be addressed, their e-mail addresses are liangxy@mail.siom.ac.cn and zzxu@mail.shcnc.ac.cn.

References