Efficient tunable diode-pumped CW Yb:LSO laser

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We demonstrate an efficient tunable diode-end-pumped continuous wave (CW) Yb^{3+}:Lu_2SiO_5 (Yb:LSO) laser. With a 5 at.-% Yb^{3+}-doped sample, we obtained 3.24-W output at 1080 nm for 7.3 W of absorbed pump power, the corresponding slope efficiency was 55%. And the laser wavelength could be tuned from 1017 to 1084 nm.

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In the past few years, there has been growing interest in ytterbium-doped materials as attractive laser gain media for efficient, simple, and compact directly diode-pumped solid-state lasers near 1 μm. Compared with Nd^{3+}-doped materials, Yb^{3+}-doped ones have broader absorption and emission spectra owing to the strong electron-phonon coupling, the strong zero-line absorption bands are well matched to the high-power InGaAs laser diodes of approximately 980 nm, and broadband emission transitions are between 1010−1090 nm, typically with high emission cross sections between 1020−1060 nm. In addition, the only two electronic multiplets of Yb^{3+} (the ground state $^2F_{7/2}$ and the excited state $^2F_{5/2}$) give rise to a simple electronic-level scheme, and contribute to a low intrinsic quantum defect, a weak thermal load, an absence of luminescence quenching, and an enhanced laser action; Also, the longer radiative lifetimes of the upper laser manifolds of Yb^{3+}-doped materials, i.e., increased energy-storage property, are favorable to enhancing the economic utilization of the diode pumps and hence the development of high-energy diode pumped sources. Therefore, Yb^{3+}-doped laser systems have been expected to be the most potential alternatives to the Nd^{3+}-doped ones in the near-IR spectral range.

A variety of interesting results have been reported for continuous wave (CW) or mode-locked operations based on the diode pump with Yb^{3+}-doped materials during the past decade[1−8]. And recently a new developed crystal Yb:LSO, with 8 at.-% Yb-doping concentration, has been demonstrated for efficient CW and mode-locked laser operation[9,10]. With the combination of easy growth, good thermal conductivity, high absorption cross-sections, and large emission spectra, this new crystal shows great advantages for the development of high-efficiency, tunable, diode-pumped lasers. And in this paper we present the results obtained with a 5 at.-% doped Yb:LSO sample.

The Yb:LSO single crystal used in our study was grown by the Czochralski method. The 4×5×3 (mm) Yb:LSO crystal (polished with parallel end faces, uncoated) was wrapped with indium foil and mounted in a water-cooled copper block, and the water temperature was maintained at 14 °C.

The crystal was end-pumped by a fiber-coupled laser diode with the emission wavelength around 976 nm controlled by a temperature regulation. The diameter and numerical aperture of the fiber core are 200 μm and 0.22, respectively. The pump laser beam is focused by two 60-mm focal-length doublets with a pump spot about 100 μm of radius inside the Yb:LSO crystal. The experiment setup is shown in Fig. 1. The resonator was a stable three-mirror (output couplers, $T = 2.5\%, 5\%, 9\%$) fold cavity. It consisted of one plane dichroic input mirror M1 (highly transmissive at 976 nm and highly reflective at 1060−1120 nm), one folding mirror M2 (highly transmissive at 976 nm and highly reflective at 1060−1120 nm, curvature radius of 300 mm), and one output coupler (OC). The cavity was designed to support only TEM_{00} oscillation and focus the mode to a beam radius of approximate 100 μm inside the crystal.

For Yb:LSO laser, as expected, the efficient laser action of Yb:LSO crystal was operated at 1080 nm under direct diode-pumping at 976 nm. The emission spectrum of the 5 at.-% Yb:LSO was similar to the 8 at.-% Yb:LSO crystal. As described in Ref. [9], laser action may occur around the strong emission bands of 1000, 1050 and 1080 nm. Since the band around 1080 nm exhibits a terminal laser level very few populated, so it makes low threshold and efficient laser systems, even if emission cross-sections are generally small. The output power of the laser at 1080 nm under different output transmissions (2.5% , 5%, and 9%) was investigated, the corresponding laser thresholds were about 1.02, 1.2 and 1.41 W. Under lasing condition and at maximum power, the uncoated crystal absorbed about 70% of the incident pump power. The best performance was obtained with a 9% transmission. At absorbed pump power of 7.3 W, maximum laser output of 3.3 W was obtained, corresponding to a slope efficiency of 55% .The dependence of the laser outputs on the incident

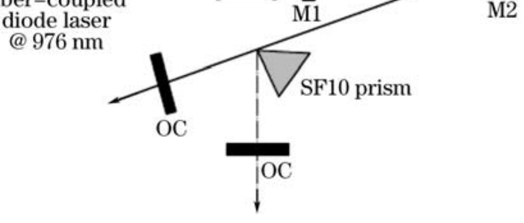

Fig. 1. Configuration of the CW Yb:LSO laser.

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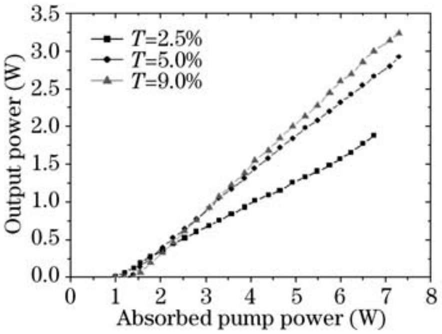

Fig. 2. Output power versus absorbed pump power with 5 at.-% Yb:LSO for different output couplers at 1080 nm.

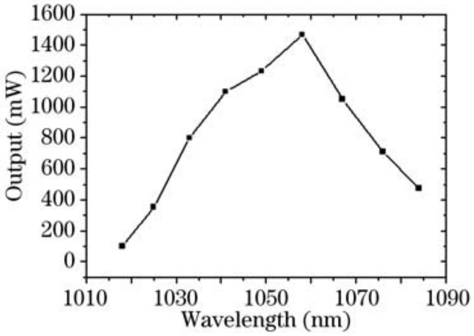

Fig. 3. Tuning curve of Yb:LSO with a 5% transmission output coupler.

pump power is illustrated in Fig. 2.

To investigate its wavelength tuning, we used another three coating mirrors (M1, plane dichroic mirror, HT 976 nm, HR 1020−1090 nm; M2, concave mirror, $R = 300$ mm, HR 1020−1090 nm; OC, plane output mirror, $T = 5\%$). Because the insertion of the prism increased the intracavity losses, we chose the output coupler with 5% transmission to achieve efficient tuning output, rather than the optimum output transmission without tuning of 9%. At absorbed pump power of 4.7 W, the crystal provided laser action at a range of 67 nm, from 1017 to 1084 nm, with a maximum output power of 1.72 W near 1058 nm. The further wavelength tuning was restricted by the coating of our mirrors. The wavelength tuning of Yb:LSO is illustrated in Fig. 3.

In conclusion, we have demonstrated that the 5 at.-% doped Yb:LSO crystal is suitable for the development of high-power diode-pumped lasers. With 5 at.-% Yb:LSO sample, 3.24-W output power at 1080 nm was achieved with a slope efficiency of 55%. The laser wavelength of the Yb:LSO crystal could be tuned from 1017 to 1084 nm.These results show that 5 at.-% doped Yb:LSO crystal possesses the same merits as the 8 at.-% doped one. Also we can conclude that Yb-doping concentration do not influence the laser performance of Yb:LSO crystal to some extent.

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