Efficient and tunable laser operation of the disordered crystal $Yb:LiGd(MoO_4)_2$ near 1 µm

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Abstract: Output power of 470 mW, slope efficiency of 64.5% and tunability between 1016 and 1049 nm are achieved with the novel disordered uniaxial crystal $Yb:LiGd(MoO_4)_2$. Both possible polarizations are compared and diode-pumping is also demonstrated.

OCIS Codes: (140.5680) Rare earth and transition metal solid-state lasers; (140.3070) Infrared and far-infrared lasers; (140.3480) Lasers, diode-pumped; (160.5690) Rare earth doped materials

1. Introduction

Recently, an extensive crystal growth and characterization study has been conducted on single crystals of $LiYb(MoO_4)_2$ (LiYbMo) [1]. The high Yb density in this stoichiometric material (6.87×10^{21} cm^{-3}) results in large peak optical absorption coefficient (α >125 cm^{-1}) for both polarizations. Hence, very thin (of the order of 0.2 mm and less) and difficult to handle active elements will be necessary in order to control the reabsorption effects in the three-level operational scheme of the Yb^{3+} ion. In the present work we investigate the optically inert host $LiGd(MoO_4)_2$ (LiGdMo) and demonstrate for the first time to our knowledge laser operation with such type of disordered Yb-doped lithium double molybdate crystal. Lasing has been previously demonstrated with this host only for Nd-doping [2]. LiGdMo belongs to a more general class of tetragonal (uniaxial) double tungstates and molybdates with structural disorder for which stronger inhomogeneous broadening is expected to facility the generation of shorter pulses with mode-locked lasers. The first such host for which Yb-laser generation was obtained was $NaGd(WO_4)_2$ [3].

2. Crystal growth, structure, and spectroscopy

$LiGd_{1-x}Yb_xMo$ crystals were grown in air by the top seeded solution growth technique. The starting chemical products were Li_2CO_3, MoO_3, Yb_2O_3, Gd_2O_3 and the solvent was Li_2MoO_4. The growth mixture consisted of 50 mol % Li_2MoO_4 and 50 mol % $LiGd_{0.9}Yb_{0.1}Mo$. The Pt crucible with the charge was heated to 1030°C and the liquid was kept at this temperature for 4 days for homogenization. During the growth process, the crystal was slowly cooled at a rate of 1ºC/day and rotated at 4.5 rpm. Finally, it was pulled out from the melt and cooled down to room temperature at 15ºC/h. The Yb concentration in the grown boule was estimated by inductively coupled plasma emission. It corresponded to an actual crystal composition of $LiGd_{0.936}Yb_{0.064}Mo$ or Yb density of 4.06×10^{20} cm^{-3}. X-ray diffraction studies lead to refinement of the Yb:LiGdMo structure in the noncentrosymmetric space group $I\bar{4}$, the same as for LiYbMo [1], but different from the previously assumed centrosymmetric (scheelite) space group $I4_1/a$. $I\bar{4}$ has two nonequivalent 2*b* and 2*d* sites occupied by Li^+, Gd^{3+} or Yb^{3+} with specific occupancy factors. The occupancy factors obtained are (Gd+Yb)/Li: 0.49(4)/0.51(1) in 2*b* and (Gd+Yb)/Li: 0.53(4)/0.47(1) in 2*d*. Since they are very close to the statistical distribution over both sites, a high degree of disorder is expected giving rise to additional inhomogeneous broadening of the Yb^{3+} optical properties in comparison to the space group $I4_1/a$ assumption where a single 4*b* site for the Li^+, Gd^{3+} or Yb^{3+} cations exists.

The energy levels of the ground, $^2F_{7/2}$, and excited, $^2F_{5/2}$, multiplets of Yb^{3+} were assigned from low temperature (5 K) absorption and emission spectra. They were used together with the measured room temperature absorption cross sections to calculate the emission cross sections by the reciprocity method. The maximum absorption cross sections near 975 nm (suitable for diode pumping) amount to 1.64 and 1.17×10^{-20} cm^2 for the π- and σ-polarization, respectively. The maximum emission cross section is obtained for the π-polarization near 1000 nm: 3.5×10^{-20} cm^2. The fluorescence lifetime was measured using powder obtained from single crystals diluted in ethylene glycol. The result was τ_f = 250 µs (this value is 183 µs in LiYbMo).

3. Laser experiments

All laser experiments were conducted at room temperature without cooling using an uncoated 2.6-mm thick $LiGd_{0.936}Yb_{0.064}Mo$ plate with its ***c***-axis approximately 45° out of the surface. It was inserted under Brewster angle in a three-mirror, 74-cm long, astigmatically compensated laser cavity consisting of an end mirror with radius of curvature RC= –5 cm, a folding mirror with RC= –10 cm, through which the pump beam was focused by a f = 6.28 cm lens, and a plane output coupler of transmission T_{OC}. Single pass pumping was realized with polarization in the same plane as the plane fixed for the Yb-laser by the Brewster geometry. The Yb:LiGdMo sample was aligned in such a way that the electric field vector was at ≈20° and ≈70° to the ***c***-axis, which cases we designate here as π- and σ-polarizations.

The Ti:sapphire laser (975 nm) pump beam was focused to a spot of about 22 µm (waist) and the pump power incident onto the crystal was limited to 1.8 W. Strong absorption bleaching was observed but even for the highest T_{OC} used, the intracavity intensity was high enough to compensate this effect. Figure 1a shows the laser performance for the two polarization configurations. A maximum output power of 473 mW was obtained for the π-polarization with T_{OC}=10% at λ_L=1025.7 nm. In this case also the maximum slope efficiency (η=64.5%) was obtained and the laser threshold was about 520 mW. The overall laser performance was quite similar for the two polarizations with slightly longer wavelengths for the σ-polarization. The minimum thresholds for T_{OC}=1.2% were ≈300 mW.

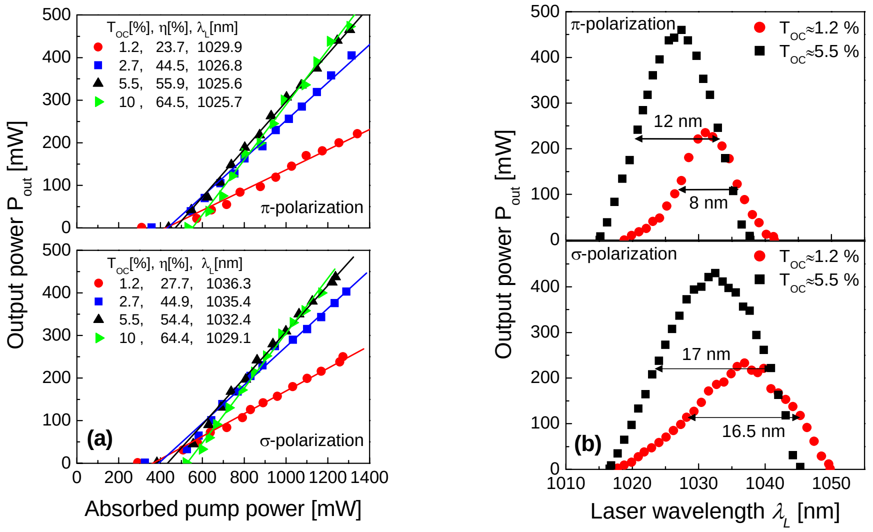

Fig. 1. Output power versus absorbed pump power at 975 nm for the cw Yb:LiGdMo laser under Ti:sapphire laser pumping with linear fits for the slope efficiencies η (a), and wavelength tunability for an incident pump power of 1.8 W (b).

The laser tunability was studied by inserting a two-plate Lyot filter close to the output coupler. Figure 1b shows the results achieved with two different output couplers. In both cases the tunability curves were limited on the short wave side by the spectral characteristics of the cavity mirrors and in particular by the output couplers used. The total tuning range obtained extends from 1016 to 1049 nm. Besides the longer lasing wavelengths, the tuning curves for σ-polarization are broader than those for π-polarization. The wavelength and polarization dependence could be explained by simple calculation of the threshold inversion using the cross section data.

Finally, a tapered diode laser (TDL) was used for demonstration of diode pumping. It had an output power of up to 1.25 W at an $M^2 < 3$ for the slow axis emission (linewidth of 1 nm near 975 nm). A collimated, polarized pump beam could be formed by relatively simple optics. Two output couplers, T_{OC}= 1.2%, and 2.7%, were used with the same set-up for the π-polarization. The absorption bleaching effect was relatively weak in this case. An output power of 77 mW at 1032.2 nm was obtained for T_{OC}=2.7% and the maximum slope efficiency with this output coupler was η=32.6%. For T_{OC} = 1.2%, the absorbed pump power at the laser threshold was 460 mW.

References

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