Polarization switching in the 2-µm Tm:KLu(WO_2)$_4$ laser

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Abstract: We report on polarization switching in the Tm:KLu(WO_4)$_2$ laser between the N_m and N_p states oscillating at different wavelengths. This switching strongly depends on the thermal management of the active medium.

OCIS codes: (140.3580) Lasers, solid-state; (140.3480) Lasers, diode-pumped; (140.3295) Laser beam characterization

1. Introduction

The monoclinic potassium double tungstate crystals, KRE(WO_4)$_2$ (RE = Y, Gd and Lu), doped with lanthanide ions, are established as promising solid-state laser materials providing very high laser efficiencies. In particular, the KLu(WO_4)$_2$ (KLuW) crystal is very suitable as host for Yb and Tm ions [1]. In this class of biaxial crystals, the emission bandwidths are relatively broad and the transition cross-sections (absorption and emission) are very high for selected polarizations. In the case of Tm:KLuW, at room-temperature, the absorption cross-section at 802 nm amounts to 5.95×10^{-20} cm^2 for E//N_m, and 1.76×10^{-20} cm^2 for E//N_p, and the emission cross-section at 1950 nm is 1.20×10^{-20} cm^2 for E//N_m and 0.57×10^{-20} cm^2 for E//N_p. In the three-level Tm-system these values and the calculated gain cross-section change with temperature. It may happen that at a certain temperature the gain cross-section is similar for two polarizations at different wavelengths and simultaneous laser oscillation of two perpendicular polarizations at different wavelengths may occur. Similar phenomenon was previously observed in some other laser crystals, for example in Yb-doped vanadates as reported in [2]. In this work, we report on the switching of two polarization states, N_m and N_p, in a diode-pumped Tm:KLuW laser operating in continuous-wave (CW) regime. We are not aware of the existence of such polarization switching in other Tm-doped crystals.

2. Experimental laser cavity

The active elements were 3 at.% Tm:KLuW crystals grown by means of the Top-Seeded Solution Growth Slow Cooling (TSSG-SC) method. This doping level presented optimum laser performances in our previous work in CW regime with Ti:sapphire laser pumping [3]. The crystals were cut for propagation along N_g optical axis with 3 mm thickness and 1.5×3 mm^2 aperture along the N_p and N_m principal optical directions, respectively. The faces of the crystals normal to N_g were AR coated for the pump and laser wavelengths. A fiber-coupled AlGaAs laser diode emitting in the 805-807 nm range and delivering 20 W of maximum power was used as pump source. The pump beam was focused onto the crystal with a spot size of 200 µm. The two mirror cavity consisted of a flat input mirror with AR coating for the 770 – 1050 nm range and HR coating for the 1800 – 2075 nm range, and a concave output coupler with transmission (T_{oc}) of 1.5%, 3% and 5% for 1820 – 2050 nm range and radii of curvature (R_{oc}) of 25, 50 and 75 mm. The active elements were actively cooled using two different Cu holders. The first one enabled contact with two lateral surfaces of the crystal and the second one was in contact with all four lateral surfaces. Indium foil was used for better thermal contact between crystal and holder.

3. Polarization switching of N_g-cut Tm:KLuW laser

At low pump powers and for all output couplers used in this experiment, the laser polarization that naturally oscillates at threshold is that with E//N_m because of the larger gain cross-section. By increasing the pump power, the crystal experiences an increase in temperature and at a certain point, the gain cross-section of the N_m and N_p polarizations becomes equal at two different wavelengths leading to competition between these two laser states and consequently the laser output consists of two components with perpendicular polarization and different wavelength. The use of different radius of curvature of the output coupler modifies the overlap between the pump and laser modes leading to different heat management and consequently to different temperature in the crystal. This is shown in Fig. 1a and b for the case when only two lateral surfaces of the active element are in contact with the crystal holder. In Fig. 1a, a R_{oc} = 50 mm output coupler was used and the competition of the two polarization states occurred in the 10-12 W range for the incident pump power. At an incident pump power of 10 W, the N_m polarized output of the Tm-laser, having reached 2 W, started decreasing (red symbols in the figure) while the N_p–polarized component (blue symbols in the figure) appeared. This coexistence extended up to ~12 W of incident pump power. Above this power, the N_p-polarization dominated. Interestingly, the total output power dependence remained unchanged as a function of the incident pump power. In Fig. 1b, a R_{oc} = 25 mm output coupler was used. In this case, the mode matching was much better increasing the incident pump power (~18 W) for which competition of the two polarizations occurred. This happened at an output power level of 3.5 W.

The above results can be compared with cooling all four crystal lateral surfaces which is shown in Fig. 1c for all other parameters as in Fig. 1b. In this case, no competition of the two polarizations in the range of available incident pump power (up to ~20 W) is observed, independent of the output coupler used. In these conditions, the laser reached 4 W of output power operating at 1946 nm (T_{oc} = 3%), linearly polarized along N_m principal optical axis. The quality of the beam, directly observed on a visualization card, was improved for the whole range of incident powers, while in the case of coexistence of two polarizations it was good only in the vicinity of the coexistence region.

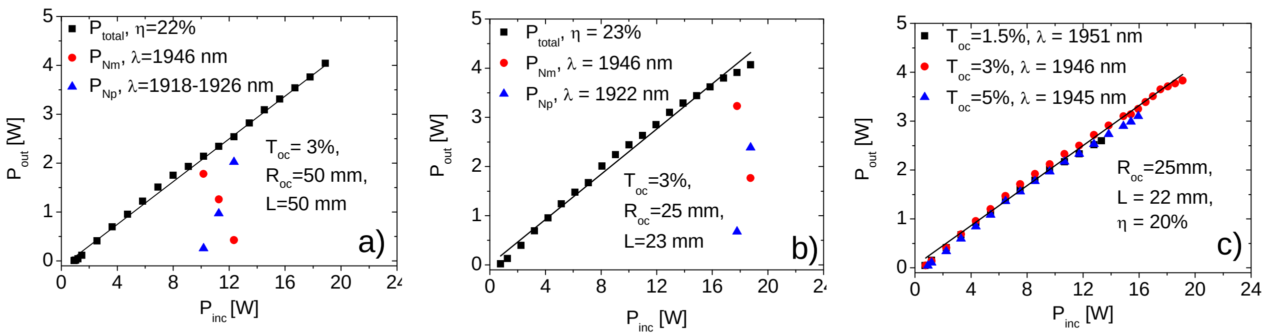

Fig. 1. Polarization switching in the operation of the Tm:KLuW laser, (a) cooling of two crystal surfaces and using R_{oc}=50 mm output coupler, (b) the same with R_{oc} =25 mm output coupler, and (c) cooling all four crystal surfaces and using R_{oc}=25 mm output coupler. The total output power in the coexistence region is the sum of the powers of both polarization states. L is the cavity physical length and η is the slope efficiency.

We also compared the results with another geometry of the active medium using a cube of 3×3×3 mm^3. From this experiment, with four crystal faces in contact with the cooling holder, there is clear evidence that shorter crystal dimension along N_p helps significantly to eliminate the polarization switching. However, further reduction of the dimension along N_p (1 mm) produced a high thermal gradient between the beam focus (high temperature) and the face in contact with the cooling holder (low temperature) which was detrimental for the beam quality, apparently affected by pronounced thermal lensing.

4. Summary

We observed and characterized polarization switching in the laser operation of a 3% Tm:KLuW crystal. We established, that there is a competition of two polarizations, N_m and N_p oscillating at different wavelengths, and that this can be eliminated by modified design of the laser cavity and better cooling of the active medium.

5. References

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