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Influence of Yb concentration on Yb:KYW laser properties

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Abstract

CW and Q-switched $KY(WO_4)_2$:Yb^{3+} with ytterbium concentration of 5%, 10%, and 20% laser operation under LD pumped have been investigated and the main characteristics of the $KY(WO_4)_2$:Yb^{3+} laser are presented here. A maximum slope efficiency of 66% was achieved for this active medium.

Keywords: Ytterbium concentration; Laser

1. Introduction

The ytterbium containing active media are attractive for application in all solid-state diode pumped lasers emitting at ~1 μm because of their favourable spectroscopic properties leading to small quantum gap and therefore to low thermal loading [1–4]. Another feature of Yb lasers is the possibility of broadband laser generation and therefore of building tunable or ultrashort pulse laser systems [5]. On the other hand the neodymium-doped double potassium tungstates were shown to be an effective laser media with high emission cross section [6,7] and are easy to grow. CW laser performance of Yb in KGW and KYW host crystals was studied by Kuleshov et al. [8]. Unfortunately the slope efficiency for diode pumping achieved by authors was very low ($\eta \approx 10\%$) because of the inappropriate wavelength of the pump source and the relatively long laser crystal used in the experiments. Also there is no information about optimum concentration of ytterbium in these laser materials.

In this article we present the results of experimental investigation of the laser properties of $KY(WO_4)_2$:Yb^{3+} (or Yb:KYW) active media. We present, for the first time to our knowledge, comparative data for the laser performance of Yb:KYW with Yb concentration varying in a wide range (1, 5, 10, and 20 at%). The results indicate that this material has very good potential as an active medium for efficient all solid-state diode pumped lasers.

2. Crystal growth

Potassium yttrium tungstate has a monoclinic C_{2h}^6–C2/c structure [9]. The parameters of the crystal unit cell are $a = 8.05$ Å, $b = 10.35$ Å, $c = 7.54$ Å, $\beta = 94°$. Material density is 6.5 g/cm^3 [9].

The Yb:KYW crystals were grown by the modified Czohralski technique from solution in $K_2W_2O_7$ melt. The crystal growth was carried out in several steps. Firstly, synthesis of charge in platinum crucible by caking the mechanical mix of WO_3, K_2CO_3 and Y_2O_3 (Yb_2O_3) at temperature within the 600–900°C interval with thorough intermixing carried out for every 100°C. Then, the synthesised charge and solvent components were loaded inside the furnace into the platinum crucible. For meeting the growth condition it was necessary to dissolve completely the synthesised charge in $K_2W_2O_7$ solvent at a temperature close to the growth one. The crystal growth was carried out at a temperature less than that of the crystal phase

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transition (900–1000°C) using an oriented crystal seed and followed by a slow cooling condition. To obtain KYW crystals of 70–80 mm length, the growth process was continued for about 400 h. The temperature of the solution-melt medium during this time was decreased by 20–30°C. High optical quality of the crystals was achieved by a precise temperature stabilisation of the growth process.

3. Absorption and lifetime measurements

The absorption spectra of Yb:KYW for different Yb concentrations measured at room temperature are plotted in Fig. 1. Maximum absorption in the 900–1050 nm wavelength range is observed at λ=981 nm where commercial laser diodes are available.

The main disadvantage of Yb:KYW as a quasi-four level system is re-absorption loss due to significant population of the lower laser level at room temperature. For such systems the effect of radiation trapping by single centres or pairs takes place and can lead to a considerable increase in the measured fluorescence lifetime [10]. This is very important because, according to the Fuchtbauer–Ladenburg formula, the effective emission cross section value is inversely proportional to the radiative lifetime. In our fluorescence lifetime measurements special measures were taken in order to eliminate this effect. The measured samples were thin plates with ground facet; aperture was placed at the Yb:KYW sample to limit transverse sample area seen by the detector. Unfortunately, as is seen in Fig. 2, the lifetime rise with increase of activator concentration is observed. Most likely it takes place because of a re-absorption effect. Nevertheless, because the radiation trapping becomes weaker with decrease of Yb concentration, we can suppose that the fluorescence lifetime value for Yb:KYW is about 0.3 ms. This value is the lifetime

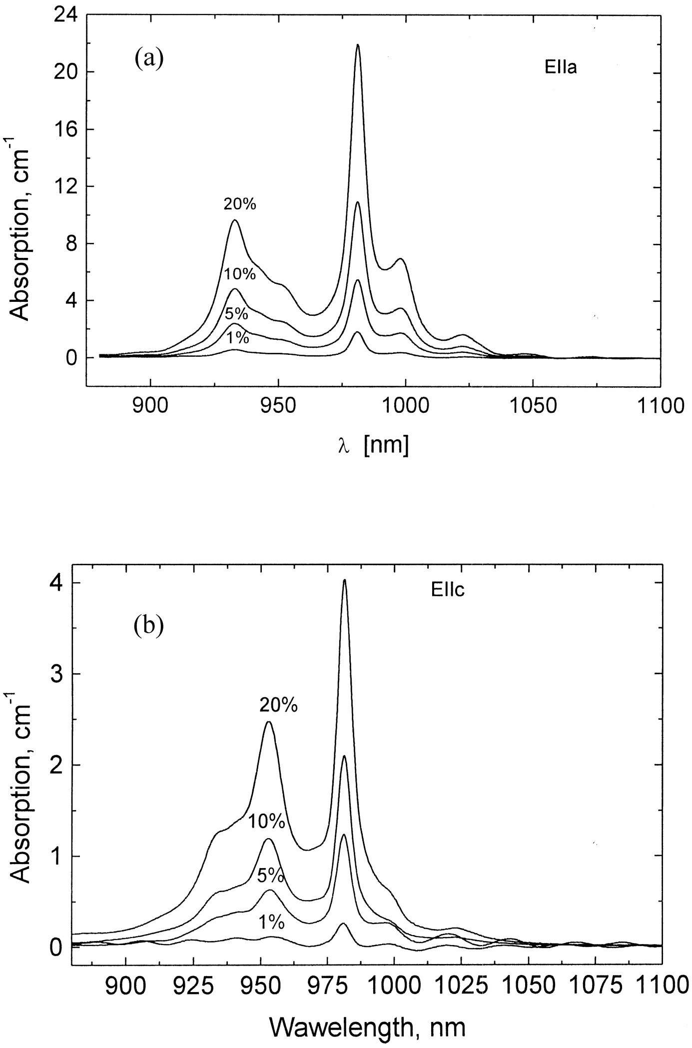

Fig. 1. Absorption spectra of Yb:KYW with different Yb concentrations (a-E||a, b-E||c).

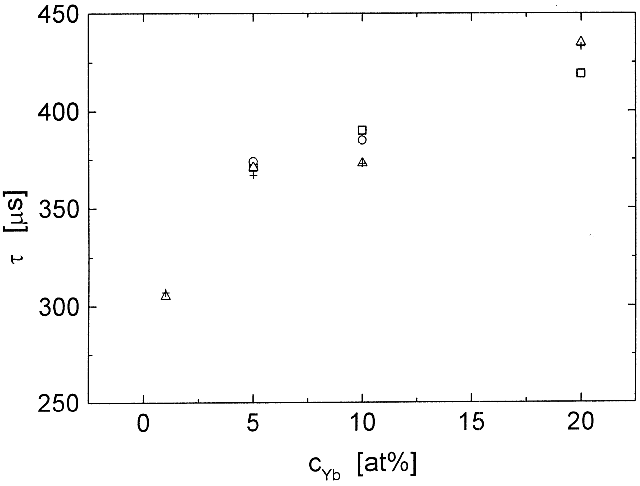

Fig. 2. Fluorescence lifetime τ of Yb:KYW measured for samples with different Yb concentration C_{Yb}.

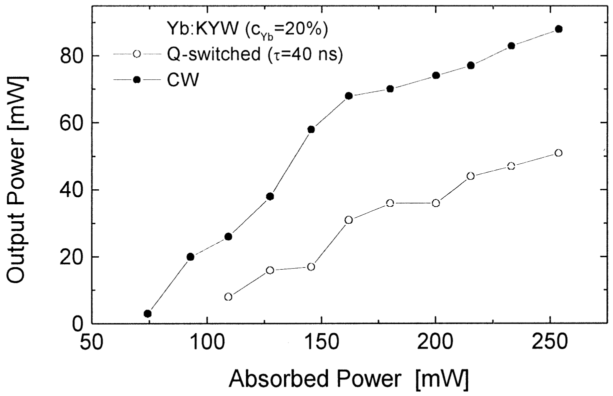

Fig. 4. Comparison of output power characteristics of Yb:KYW (C_{Yb}= 20%) laser for CW and Q-switched (average power) regimes.

which was measured for Yb:KYW with 1% of concentration of ytterbium. It is more than 2.5 times less than that given by Kuleshov et al. [8].

4. Laser performance

In the diode pumping experiments a nearly hemispherical cavity configuration was used. It consisted of the Yb:KYW chip with dimensions of ∅3×1 mm^3 cut out along the *b* axis, and a 98% reflectivity spherical (40 mm radius of curvature) output mirror placed 38 mm apart from the pumped facet of laser crystal. The facets of the crystal chips were coated for high reflectivity on the outer side and anti-reflected on the inner side at the lasing wavelength. An AR coated 200 μm thick Cr^{4+}:YAG plate with an initial transmission of 97% was also used to obtain passive Q-switching.

The pump source was a multimode laser diode (LD) with an output power of 1 W at 980 nm mounted on a thermoelectric cooler. The optical system for focusing the pump beam into the laser crystal consisted of a triplet collimator (NA=0.5), $4^{\times}$ cylindrical telescope and focusing lens (f=10 mm). The LD beam was focused by this optical system into a spot of about 80 μm diameter.

The Yb:KYW laser output power as a function of absorbed pump power for CW regime of operation is shown in Fig. 3. Because the HR input mirror on the crystals was not optimised for pump wavelength, laser performances were evaluated by using the absorbed power in crystals. All attempts to get lasing in the sample with 1% of Yb were unsuccessful. Thresholds for the 5%, 10% and 20% Yb samples were estimated to be 37 mW, 46 mW, and 79 mW respectively. The best slope efficiency η=0.66 was achieved for 5% and 10% samples. For samples with 20% Yb slope efficiency was 10% less. The maximum CW output power obtained was 93 mW at 240 mW absorbed pump power.

We also compared the output power characteristics for CW and Q-switching operation regimes of the Yb:KYW laser. As is shown in Fig. 4 the average output power for

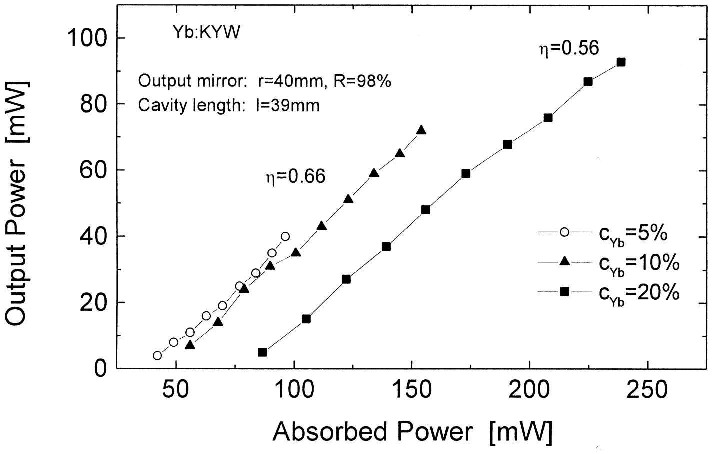

Fig. 3. Output characteristics of Yb:KYW laser with different Yb concentration of active medium.

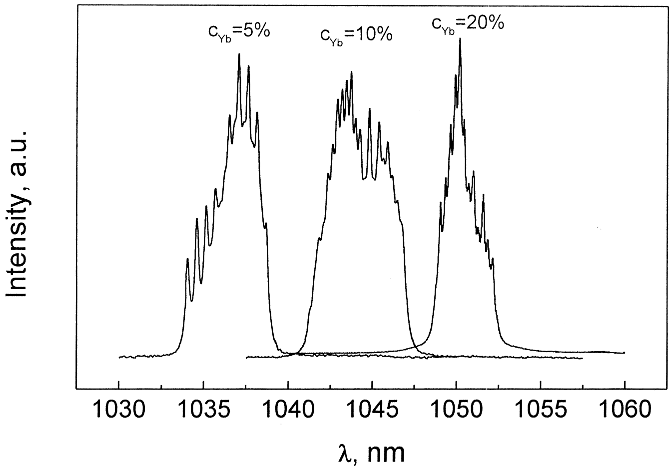

Fig. 5. Yb:KYW CW lasing spectra.

20% Yb samples in the Q-switching regime was about two times less than in the CW regime of operation under the same cavity conditions.

For fixed Yb concentration the Yb:KYW the CW laser emission spectrum almost does not depend on the pump power, but with increase of Yb concentration it exhibits a red shift (see Fig. 5). This behaviour can be attributed to the fact that the passive losses in quasi-four-level systems depend on the activator concentration. With increase of Yb concentration the laser resonator passive losses rise and therefore the emission wavelength shifts towards longer wavelength. The laser emission spectrum half-width for all samples with different concentration of ytterbium lies in the range 3.5–4.0 nm.

5. Conclusion

CW and Q-switched laser operation of LD pumped Yb-doped potassium yttrium tungstate with ytterbium concentration of 5%, 10%, and 20% has been investigated and the main characteristics of the $KY(WO_4)_2:Yb^{3+}$ laser are presented here. A maximum slope efficiency of 66% was achieved for this active medium. The fluorescence lifetime of Yb:KYW has been estimated to be 0.3 ms.

Possible application areas for this kind of lasers include tunable and ultra-short pulse laser systems with low average output power.

Acknowledgements

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