Growth and spectral characteristics of single crystal layer of KY(WO$_4$)$_2$ doped with Ho^{3+} ions

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ABSTRACT

We report on the growth and the characterization of Ho^{3+} doped KY(WO$_4$)$_2$ layers having high structural homogeneity and optical quality. The epitaxial layer of Ho(5.0 at.%):KGd$_{0.028}$Yb$_{0.047}$Y$_{0.875}$(WO$_4$)$_2$ with a thickness of 140 µm was fabricated by liquid phase epitaxy. The layer can be used as gain medium of planar waveguide lasers, emitting in the spectral range of about 2 µm.

1. INTRODUCTION

The infrared lasers operating in the eye-safe spectral range near 2 µm are used for free space applications, medical treatments, material processing, as well as a pump source for optical parametric oscillators [1-3]. Traditionally materials in this spectral region are Tm^{3+}- and Ho^{3+}-doped media. The absorption of Tm^{3+} at 800 nm makes possible an efficient pumping of its $^3H_6 \rightarrow ^3H_4$ transition by commercially available high power AlGaAs diode lasers. Cross-relaxation process ($^3H_6$, $^3H_4 \rightarrow ^3F_4$, $^3F_4$) leads to achieving a quantum efficiency well above unity [4]. Other attractions of Tm-doped lasers include its wide continuous wavelength tunable range [5]. Diode-pumped Tm lasers can be used for direct excitation of the upper laser level of Ho ions ($^5I_8 \rightarrow ^5I_7$). Such in-band pumping minimizes the quantum-defect-induced heat generation and reduces up-conversion processes probability.

In this work, we study a single-crystal layer of potassium tungstate having mixed chemical composition doped with trivalent holmium ions to use it as the gain medium for a waveguide laser under in-band laser pumping. Potassium double tungstate crystals, KRe(WO$_4$)$_2$ (Re = Gd, Y, Lu), serve as excellent hosts for trivalent rare-earth ions and are considered to be promising materials for waveguide lasers because of their high refractive indices [6]; large transition cross-sections [7]; long inter-ionic distance [8], allowing for large doping concentrations.

The gain medium of the waveguide planar lasers is a thin layer of active substance with a higher refractive index as compared to surrounding material. This makes it possible to localize the pump and generation radiation in a narrow spatial region with a size of several tens or hundreds of microns throughout the entire length of the waveguide, which leads to a high spatial consistency of the resonator and pump modes. That in turn provides high gains, low generation thresholds and greater resistance to thermal

effects. Active waveguide structures allow to create integrated high-performance optical systems for data processing.

2. EXPERIMENTAL

Growth of a single crystal layer of potassium-yttrium tungstate, co-doped with optically inert ions of gadolinium and ytterbium (under resonant pumping conditions) and an active holmium ion, was produced by liquid phase epitaxy on a substrate of $KY(WO_4)_2$ crystal, using a solution of $Ho(5at\%):KGd_{0.028}Yb_{0.047}Y_{0.875}(WO_4)_2$, in melted $K_2W_2O_7$, which had lateral dimensions of 10x10 mm and 2 mm thickness along b-axis. As the growth process was performed at quite low temperature (900-920°C) a viscosity of solution-melt was decreased via adjusting of a concentration of K_2O. The growth was performed in excess of K_2O estimated as 10-12 wt.% of the total mass of the solution-melt, thickness of the film was about 140 μm, concentration of Ho^{3+} ions ~5.0 at.%. The process of crystallization in the method of liquid-phase epitaxy is carried out due to the supersaturation of the solution-melt near the interface line in central near-surface area. The growth was carried out at a temperature of 900-920 °C, the substrate rotation speed was about 30-40 cycles per minute. The solution-melt was heated in a crucible above the saturation temperature by 30–50 °C and homogenized during 12 hours. Further, the temperature dropped by 1.5-2.5 °C below the saturation temperature and the substrate growth was performed to a planned thickness.

The obtained sample was cut along the axes of the optical indicatrix N_m and N_g and polished to a layer thickness of 140 μm (along b-axis). A photograph of the layer cross-section, obtained with a microscope Polam RP-1 (LOMO) using a CCD camera is shown in Figure 1. The grown layer is characterized by the absence of inhomogeneities, cracks and significant defects.

3. RESULTS AND DISCUSSION

X-ray structural analysis of the epitaxial layer, performed based on the data obtained with Bruker D2 diffractometer, has confirmed high structural quality of the layer. As the diffraction measurements were done on a bulk oriented sample, the diffraction spectrum contains only reflections from planes (0k0). The determined value of the b-parameter of the crystal lattice of the layer is 10.341 Å and the mismatch with the b-parameter of the substrate is 0.009%. This value is one order of magnitude smaller than the limit which determines a growing of the layers free of cracks [9].

The concentration of the rare-earth elements in the epitaxial layer was determined by energy-dispersive X-ray spectroscopy. The concentration of holmium ions Ho^{3+} was 5.0 at.%, and stoichiometric formula is $Ho_{0.05}:KGd_{0.028}Yb_{0.047}Y_{0.875}(WO_4)_2$.

Absorption spectrum of the sample was obtained using Fourier spectrometer (Vertex 70, Bruker) with a spectral resolution of 1 cm^{-1} in the spectral range of 1800-2200 nm for the radiation
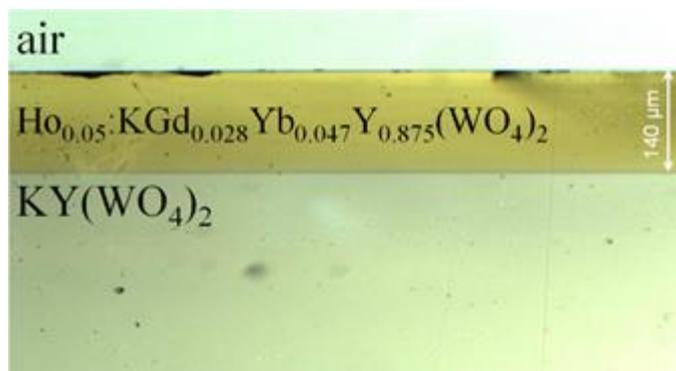
Figure 1. Photo of a single crystal layer activated by holmium ions grown on $KY(WO_4)_2$ crystal.

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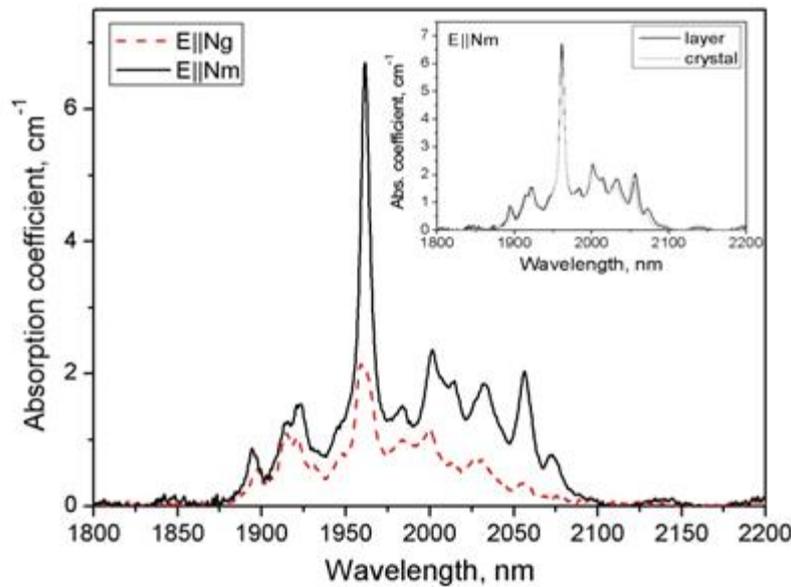
Figure 2. Absorption spectrum of a single crystal layer $Ho_{0.05}$:$KGd_{0.028}Yb_{0.047}Y_{0.875}(WO_4)_2$ in the range of 2 µm.

polarized along the axes of optical indicatrix N_m and N_g (Figure 2).

The absorption spectrum is characterized by significant anisotropy for the radiation with different polarizations and the spectrum is identical to the spectrum of a bulk crystal (Figure 2 on the inset).

The luminescence spectrum of the sample under InGaAs laser diode (975 nm) excitation was dispersed with MDR-23 monochromator and registrated with InGaAs PIN photodiode (G5853 Hamamatsu) connected to a lock-in amplifier (SR810 Stanford Research Systems). The measured spectrum is shown in Figure 3 with the similar spectrum of the bulk Ho:KYW crystal. The polarization of radiation is indicated in the Figure.
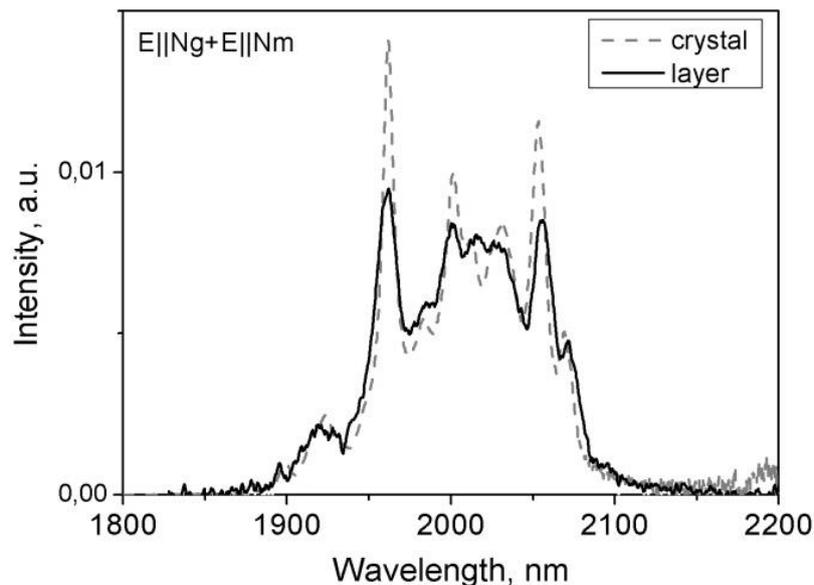
Figure 3. Luminescence spectra of the $Ho_{0.05}$:$KGd_{0.028}Yb_{0.047}Y_{0.875}(WO_4)_2$ layer and the bulk Ho:KYW crystal.

Some inconsistency between the indicated spectra is caused by insufficient resolution of the measured layer spectrum due to the weak luminescence signal. This is explained by a non-optimal excitation scheme through the energy transfer from the $^2F_{5/2}$ state of ytterbium ions to holmium ions.

4. CONCLUSIONS

Thus, high optical quality Ho(5at.%)-doped $KGd_{0.028}Yb_{0.047}Y_{0.875}(WO_4)_2$ epitaxial layer with 140 μm thickness along b-axis was obtained by liquid phase epitaxy technique. The sample is characterized by high optical and structural quality and can be used as a gain medium of planar waveguide lasers, emitting in the spectral range of about 2 μm.

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