Er - doped $KY_{1-x-y}Gd_xLu_y(WO_4)_2$ surface channel waveguides

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Abstract— **Channel waveguides on $KY_{1-x-y}Gd_xLu_y(WO_4)_2$ epitaxial films doped with Er^{3+} were obtained by ion beam milling and guided modes at wavelengths near 1.5 µm confirmed single mode behaviour. Absorption and emission spectra of these waveguides agree with those of bulk crystals of the same family, showing potential for a planar waveguide laser.**

Keywords- tungsten compounds; epitaxial growth; dielectric films; optical strip waveguides; etching.

I. Introduction

Novel materials for integrated optics applications are under intense investigation. The interest in using the rare earth potassium double tungstates, $KRE(WO_4)_2$ (or KREW, for short, where RE = Y, Gd and Lu), is mainly because they: (i) exhibit large values of absorption and emission cross sections for the active lanthanide ions, allowing high gain to be obtained and hence laser generation; (ii) possess large ion to ion distance, which allows high doping levels of the active ions without the quenching of fluorescence; and (iii) have high refractive index values of about 2.0, which makes them suitable for the fabrication of compact integrated optical devices. Planar waveguide lasers using KREW have already been reported [1-2], however, Er-doped KREW planar waveguide lasers have not been yet reported and in this work we explore the possibility to obtain these planar waveguide lasers. Through a systematic study [3], we determined the optimum composition of a $KY_{1-x-y}Gd_xLu_y(WO_4)_2$ film which exhibits both low lattice mismatch and high refractive index contrast with the $KY(WO_4)_2$ substrate. This composition, corresponding to a $KY_{0.59}Gd_{0.19}Lu_{0.22}(WO_4)_2$ layer was successfully grown by liquid phase epitaxy on a **b** oriented $KY(WO_4)_2$ substrate without cracking and with a refractive index contrast with the substrate of the order of 2×10^{-3} at λ = 632.8 nm, allowing the demonstration of passive waveguiding; with scattering losses ~ 1 dB/cm. More recently we have doped our lattice matched layer with 1 at% Er^{3+} and 1 at% Tm^{3+}, maintaining the high structural quality and the refractive index contrast [4]. These layers had the following chemical compositions: $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ and $KY_{0.59}Gd_{0.18}Lu_{0.22}Tm_{0.01}(WO_4)_2$. We are interested in exploiting the 1.5 µm transition from Er^{3+} which matches the third telecommunications window very well. Surface and buried channel waveguides fabricated from monoclinic double tungstates have only been reported by Borca et al [5-6] using femtosecond laser writing and reactive ion etching (RIE), respectively. In this work we report on the fabrication and characterization of surface channel waveguides on $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ epitaxial layers grown on $KY(WO_4)_2$ substrates, structured by Ar ion beam milling using standard UV photolithography for the mask deposition.

II. Experiment and Results

$KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ layers were grown on $KY(WO_4)_2$ substrates by Liquid Phase Epitaxy, (LPE). The refractive indices n_g and n_m were measured by ellipsometry in the range 300 nm – 1600 nm. From these measurements and using the approximation reported in [7], we determined the dimensions of the channels which would provide for single mode operation 1.5 µm. A channel design of 8 µm width and 7 µm height was chosen.

The epitaxial layers were polished to a thickness of 7 µm and cut with their edges perpendicular to the N_g and N_m optical directions and the four edges were also polished to laser quality [3]. Our early experiments using RIE with CHF_3 and SF_6 gases on $KY(WO_4)_2$ substrates were not satisfactory because we obtained an etch rate of 200 nm/h, too low for our purposes. We then explored the Ar ion beam milling technique. A 4 µm thick S1828 photoresist (PR) film was spun onto a $KY(WO_4)_2$ substrate. The system (PR + substrate) was exposed to the Ar ion beam for different etching times. In this way we determined an etch rate of 1.134 µm/h for the substrate and 1.014 µm/h for the photoresist. We therefore selected this method due to its improved etch rate and acceptable selectivity for structuring the KREW's.

After spinning photoresist of about 8 µm thickness in two stages on the $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ / $KY(WO_4)_2$ slab waveguide, straight channels were patterned using standard UV photolithography. The slab waveguide patterned with

This work was supported by the Spanish government under projects MAT 2008-06729-C02-02/NAN and PI09/90527 and the Catalan government under project 2009SGR235 and the fellowship (W. Bolaños) 2009FI_B 00626 and 2009 BE1000481.

photoresist was exposed to dry etching for 6 hours after which, we found that the etch rate of the epitaxial guiding layer (1.333

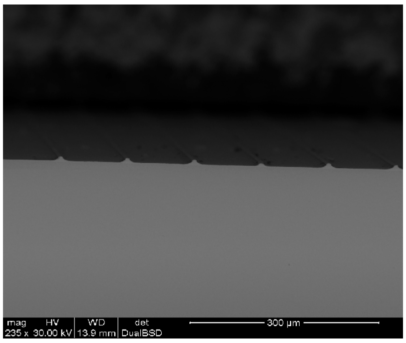

Figure 1. Cross-sectional image of the surface channels patterned on a $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$/ $KY(WO_4)_2$ slab waveguide.

µm/h) was slightly higher than that of the substrate. Figure 1 shows a cross-sectional view of some of the channels obtained by Ar ion beam milling on the $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$/ $KY(WO_4)_2$ slab waveguide.

Instead of a rectangular channel cross-section, a trapezoidal shape was obtained; nonetheless at wavelengths near 1.5 µm the light was well confined in the channels, as can be seen in figure 2, and monomode operation was obtained, confirming the prediction made using [7].

We determined the photoluminescence spectra of the $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$/ $KY(WO_4)_2$ waveguides, at room temperature, in the wavelength region of the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition upon excitation at 974 nm. Figure 3 shows the emission spectrum which is similar to those reported for this active ion in other crystals of the same family [8]. The maximum emission intensity was found at 1533 nm; no broadening of the peaks due to the presence of multiple ions (Y, Gd and Lu) occupying the same structural site was observed.

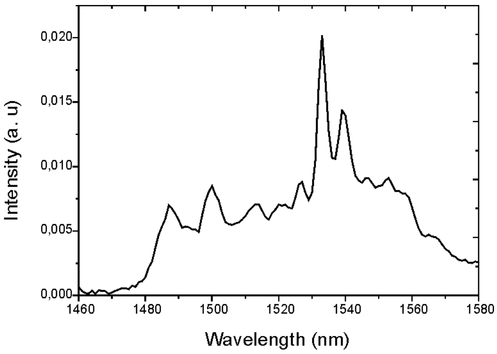

Figure 3. Emission spectra measured at room temperature corresponding to the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} in $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$/ $KY(WO_4)_2$ slab waveguide.

III. Conclusions

Surface channel waveguides were fabricated from $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$/ $KY(WO_4)_2$ slab waveguides using the Ar ion beam milling. The slab waveguide was characterized in terms of refractive indices and allowed the measurement of the photoluminescence spectra whilst the

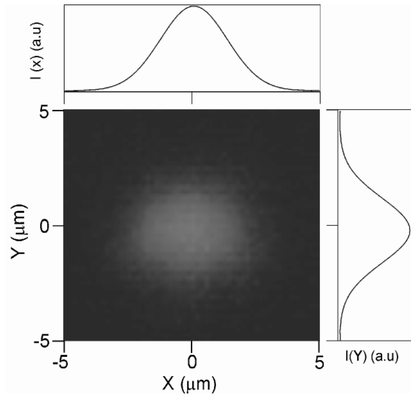

Figure 2. Near field intensity at 1.5 µm corresponding to a 8 µm width $KY_{0.60}Gd_{0.18}Lu_{0.21}Er_{0.01}(WO_4)_2$ channel.

channel waveguides were characterized in terms of guided modes. Experiments to realise a waveguide laser for wavelengths near 1530 nm are ongoing

Acknowledgment

The authors like to express their gratitude to David Sager and Neil Sessions for their support in the clean room.

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