(Er^{3+}, Yb^{3+}) doped K(Y,Gd,Lu)W waveguide fabrication

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***Abstract*—In this work the fabrication and characterization of (Er^{3+},Yb^{3+}) doped K(Y,Gd,Lu)W waveguides are presented. The KYW substrate is obtained by the Top-Seeded Solution Growth technique, and the active guiding layer is grown by Liquid Phase Epitaxy. While this process gives rise to planar waveguides, an ion milling structuring technique has been additionally used to provide lateral confinement to fabricate channel waveguides. The waveguide characterization includes refractive index measurements of the substrate and core regions, geometry of the ridge waveguides, and spectroscopy of the active ions around 1.55 µm. BPM has been used to obtain the modal intensity profiles to estimate the optical confinement of the guided modes.**

Keywords- KYW; Liquid Phase Epitaxy; channel waveguides; rare earth ions; integrated lasers

I. Introduction

KREW's are monoclinic crystals with three orthogonal optical directions N_g, N_m and N_p, where N_g and N_m are placed in the *a-c* crystallographic plane, and N_p is parallel to the *b* crystallographic axis. Each optical direction has a different refractive index n_g, n_m and n_p, where $n_g > n_m$ and $n_m > n_p$. The high refractive indices of KYW make this material a good candidate for developing integrated optical devices. Furthermore, the large absorption and emission cross sections for rare earth ions (~10^{-20} cm^2) offer low threshold laser operation, and the large ion separation enables high doping levels without quenching of luminescence. It has been demonstrated that it is possible to induce relevant refractive index modification by modifying the Y, Gd and Lu concentrations [1], and by adding active ions such as Er^{3+} Yb^{3+} or Tm^{3+} [1, 2]. As this work is focused on the 1.5 µm wavelength for communications applications, Er^{3+} ions have been chosen as active centers, and Yb^{3+} has also been added due to its efficient energy transfer to the $^4I_{3/2}$ multiplet of the Er^{3+} ion.

In this paper the fabrication and characterization of planar and channel waveguides of (Er^{3+},Yb^{3+}) doped K(Y,Gd,Lu)W on KYW substrates are presented. Details of the optical and spectroscopic properties of the guiding layers are given, with emphasis in the 1.5 µm spectral region. Modal characteristics of the channel waveguides has been also studied by numerical modeling using BPM techniques.

II. Experimental details

A. Planar waveguide fabrication

KYW crystals have been grown by the Top-Seeded Solution Growth slow-cooling method (TSSG). The fabrication is carried out in a vertical tubular furnace following the experimental setup described elsewhere [2].

Substrates are obtained from the KYW crystals, where they are polished These substrates are then used for the deposition of the active-guiding layer by Liquid Phase Epitaxy (LPE). (Er^{3+},Yb^{3+})doped K(Y,Gd,Lu)W layers were grown on the *-b* direction oriented substrates, as this direction allows polarizations parallel to N_m and N_p, where the absorption cross section at 980 nm is higher. LPE solution was prepared by a 7% mol solute on 93% KYW solvent, in order to control the supersaturation process [3]. Once T_s is achieved, the temperature of the solution is cooled 3 K to achieve the supersaturation of the solution, and the sample is immersed for 3 h in the solution. Finally the sample is removed from the solution, while the furnace is cooled at 15 K/h to prevent thermal shock cracking.

The guiding layer is grown to a thickness of 70 µm and polished to a roughness below 0.3 µm. The final layer is 12 µm thick with a length of 3.8 mm. The guiding layer stoichiometry is found to be $KY_{0.74}Gd_{0.18}Lu_{0.07}Er_{0.005}Yb_{0.005}(WO_4)_2$, which offers a theoretical lattice mismatch of 0.55×10^{-3}. This low value allows epitaxial growth free of internal cracks.

For a more symmetric distribution of the optical mode, a 50 µm thick KYW-cladding was added by LPE. This overcladding also serves to decrease propagation losses.

B. Channel waveguide fabrication

The growth of the substrate and the epilayer for channel waveguides were done following the same procedure as explained in the previous section. In addition to that, the

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substrate is micro-structured by ion milling in order to obtain ridge structures, where the guiding layer is grown.

Channels are structured by ion milling, and a 3% Er^{3+} doped K(Y,Gd,Lu)W epilayer is grown on the structured face of the substrate and then polished down to a 2 µm thickness over the non-structured surface. In this case the grown epilayer composition is found to be $KY_{0.58}Gd_{0.19}Lu_{0.20}Er_{0.03}(WO_4)_2$. This stoichiometry offers a negative lattice mismatch of -0.53×10^{-3} respect to the KYW substrate, which means low internal tension and hence fewer internal cracks. Finally a KYW cladding is deposited by LPE to improve the modal distribution.

The geometry of the fabricated channels is shown in figure 1. Type-I (Fig. 1a) has a triangular geometry, while type-II (Fig. 1b) has a trapezoidal shape. In both cases, a residual planar waveguide of 2 µm depth is left.

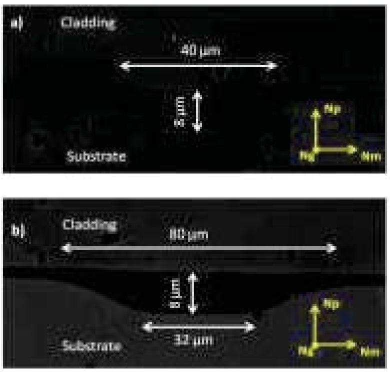

Figure 1. Type-I (a) and Type-II (b) channel waveguides.

III. Results and Discussion

A. Planar waveguide

The refractive indices of the planar waveguide were measured by the prism-coupler method. The fabricated waveguide shows increment in the refractive index of the guiding layer for all polarizations, from 2.1×10^{-3} for N_g polarization and up to 5.4×10^{-3} for N_p polarization, measured at 633 nm. Similar increments are obtained at 1.5 µm wavelength.

B. Channel waveguides

With a $KY_{0.58}Gd_{0.19}Lu_{0.20}Er_{0.03}(WO_4)_2$ guiding layer a higher refractive index increase has been measured for N_m and N_p polarizations. At 633 nm wavelength n_m increases 4.5×10^{-3}, while n_p increases 8.7×10^{-3}. As seen in the simulations (Fig. 2), this refractive index variation is enough for guiding at both pump and emission wavelengths. In Type I channel waveguides, BPM simulations give confinement factors of 0.914 for quasi TE polarization (parallel to N_m) at 1.55 µm wavelength, and 0.970 for a wavelength of 980 nm. For quasi TM polarization (parallel to N_p), the confinement factor increases to 0.930 at 1.55 µm wavelength and to 0.976 for a wavelength of 980 nm.

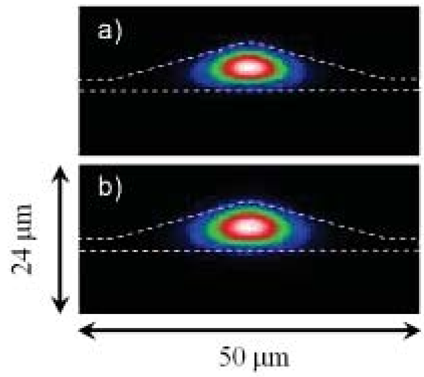

Figure 2. Fundamental quasi TE modes in Type I channel guides at 0.98 µm (a) and 1.55µm (b).

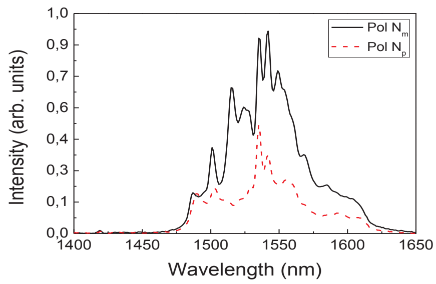

Figure 3. 1.55µm emission of $KY_{0.58}Gd_{0.19}Lu_{0.20}Er_{0.03}W$ / KYW Type II channel waveguide

The guided emission in the 1.55 µm range, due to pumping at 980 nm, was also studied, and is presented in figure 3. These emission spectra correspond to the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of the Er^{3+} ions for N_m and N_p polarizations, with the emission for N_m polarization being more intense than that for the N_p polarization. Identical results are obtained in the planar waveguide and in type I channel waveguides.

IV. Conclusions

Er^{3+} and Yb^{3+} doped K(Y,Gd,Lu)W planar and channel waveguides were successfully fabricated on KYW substrates with low lattice mismatch using the LPE technique. The measured refractive index increments in the guiding layer and the spectroscopic properties of the Er ions in the active region, indicate that these waveguides are promising optical elements for the development of lasers and amplifiers in a guided configuration operating in the 1.5 µm region.

V. References

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