Optical Channel Waveguides in $KY(WO_4)_2:Yb^{3+}$

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Abstract: First channel waveguide emission from Yb-doped $KY(WO_4)_2$ has been demonstrated. Two different methods have been used to fabricate micron-size active-guiding structures, namely reactive ion etching and ion implantation.

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1. Introduction

Fabrication of passive and active channel waveguide structures is highly desirable in order to meet the requirements of compactness and low pump threshold. Confinement of pump and signal radiation in both vertical and horizontal directions results in improved overlap between the two beams as well as higher pump intensity and potentially leads to lower lasing thresholds and higher slope efficiencies. We fabricated, for the first time to our knowledge, active channel waveguides in epitaxial thin films of Yb-doped $KY(WO_4)_2$ (hereafter KYW), using two methods: reactive ion etching and ion implantation. Recently, we reported on the liquid-phase epitaxy of Yb-doped $KY(WO_4)_2$ layers on undoped KYW (010) substrates. Given the good quality of the grown active layers with less than 3% Yb doping concentration, planar waveguide lasers with a maximum slope efficiency of 80.4% were obtained [1]. In this report, we continue our efforts in the direction of laser miniaturization by creating micron-size waveguide channels within the planar layers.

2. Fabrication methods

Reactive Ion Etching (RIE) is a well-established method for producing high-quality µm-size structures with low roughness in optical materials, as was previously demonstrated, e.g., for Ti:sapphire [2] thin films. We employed a similar approach for obtaining micro-structured ribs in Yb-doped KYW epilayers. The 10-µm thick film had a 1.7% Yb doping level. Aluminum thin films were employed as transfer masks using standard photolithographic techniques and RIE in fluorine atmosphere. High-resolution defined rib-like structures with height of 1.75 µm were obtained and roughness values of 13 nm and 6 nm were measured for the unetched and etched regions, respectively. The smallest etched features obtained are shown in Fig. 1. Both the AFM image (a) and the profilometer scan (b) show that RIE can produce high-quality rib structures with smooth surfaces and sharp edges.

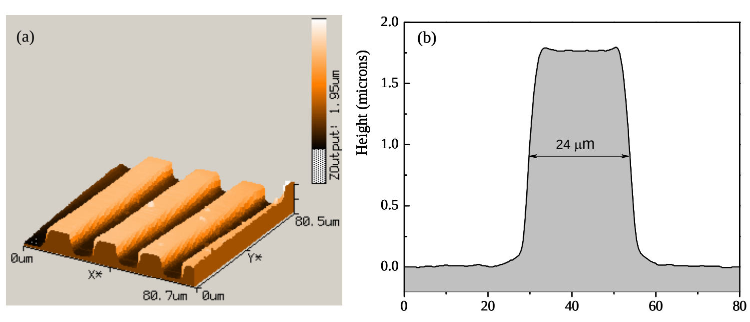

Fig. 1. (a) AFM contact-mode image of several RIE-structured 1.75-µm high by 8-µm wide ribs in a 10-µm thick KYW:Yb planar waveguide. (b) Profilometer scan of a 1.75-µm high by 24-µm wide rib on the same epilayer.

Channel mode profiles were investigated by launching 980.8-nm pump light into the ridge waveguide through a 6.3x microscope objective. The pump and fluorescence emission from the rear end of the waveguide were collimated by a 40x microscope objective and imaged onto a CCD camera. Figure 2 shows the experimentally recorded channel-waveguide beam profile (left panel) emitted from a 24-µm wide channel. Good agreement is obtained between the experimental beam profile and simulated (right panel) fundamental-mode intensity profile at 980.8 nm. The simulation was performed using the Fimwave software. Due to the small refractive-index contrast with respect to the substrate ($\Delta n = 6\times10^{-4}$), the dimension of the mode is rather large and the best confinement is provided by the 24-µm wide ribs.

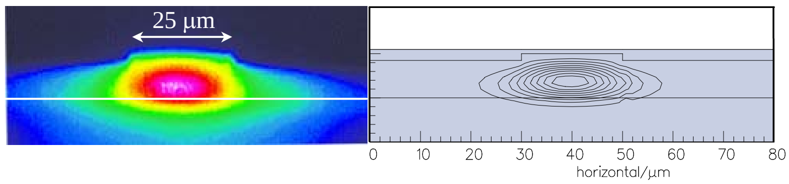

Fig. 2. Experimentally recorded channel-waveguide beam profile (left panel) and simulated fundamental-mode intensity profile (right panel).

The second technique used to obtain waveguide channels based on our KYW:Yb thin films was ion implantation [3]. A damaged area with decreased refractive index is created at the end of the ions' tracks. Lateral optical barriers are produced by implantation through a slit. The result is shown schematically in Fig. 3(a).

A KYW:Yb (1.7%) epilayer with a 4-µm thickness was irradiated through a slit at four different incident angles of implantation, using He^+ ions with fixed energy of 1.5 MeV and doses of $2\text{x}10^{16}$ ions/cm^2 for each angle. The refractive-index change was of the order of $\Delta n = -1\%$ with respect to the non-irradiated medium. The channel waveguide was formed between two such implanted sidewalls, 8 µm apart from each other. The near-field image of the out-coupled beam intensity profile is shown in Fig. 3(b).

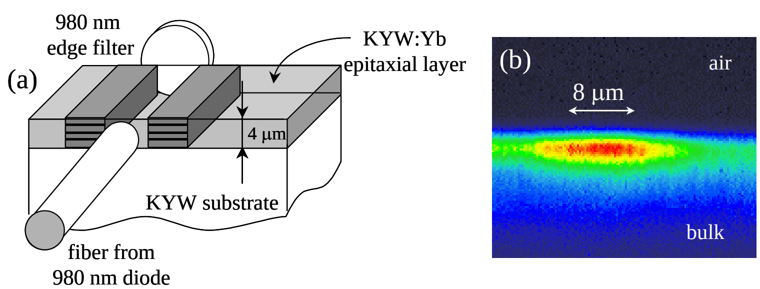

Fig. 3. (a) Schematic representation of the He^+ barriers implanted into the 4-µm thick KYW:Yb layer, which form a channel wavguide between the implantations, and the coupling scheme used to couple the 980-nm light. (b) Experimentally recorded beam intensity profile containing both the fluorescence intensity centered at 1025 nm and the residual unabsorbed 2% of the coupled 980.8-nm pump light.

The comparison of the channel mode profiles obtained from the two techniques shows that RIE is more suitable for producing well confined guiding modes underneath the low-roughness ribs. The propagation losses in the planar epilayers measured under lasing conditions were as low as 0.08 dB/cm [1]. The propagation losses in both types of channels are currently under investigation. Results will be reported at the conference.

3. Summary

The first channel waveguide emission from KYW:Yb has been demonstrated using guiding structures obtained by reactive ion etching or He^+-ion implantation. These results represent an important step towards the realization of miniaturized lasers with strong pump confinement, improved mode overlap, and increased interaction lengths.

4. References

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