Rib waveguides fabricated by surface structuring with a femtosecond laser on (Yb,Nb):RTP/RTP epilayers

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***Abstract*- Channel waveguides in (Yb,Nb):RbTiOPO$_4$/RbTiOPO$_4$ epitaxial layers were fabricated by surface structuring with a femtosecond laser. The channel waveguide modes were successfully excited at 632 nm and simulations of the rib channel at the same wavelength show a high level of light confinement. The output near field pattern of the modes showed a Gaussian shape and the losses obtained were about 2.5 dB/cm. Type II second harmonic generation radiation at 1137 nm has been successfully obtained.**

Keywords: Nonlinear optical crystal, RbTiOPO$_4$, Liquid Phase Epitaxy, waveguides, laser ablation.

I. Introduction

Rubidium titanyl phosphate, RbTiOPO$_4$ (hereafter RTP) is an interesting nonlinear optical crystal due to its high nonlinear optical and electrooptical coefficients [1]. The doping of RTP with lanthanide ions has attracted the attention because it offers the possibility to merge the nonlinear optical properties of the crystal with the lanthanide emission to obtain a self-doubling material. Among the lanthanide elements, Yb^{3+} has special interest because of its emission at a wavelength close to 1 μm, its simple energy scheme, which consists of only two energy levels, its low quantum defect and high lifetime. The codoping of RTP with Nb^{5+} and Yb^{3+} allows us to obtain an Yb^{3+} concentration in the RTP structure, which is enough for lasing [2]. However, the presence of Nb^{5+} in the crystal structure contributes to decrease the growth rate and increases the stress in the crystal, which often causes defects in the bulk crystal. Due to these bulk crystal defects, as well as the interest to obtain large optical paths, the growth of (Yb,Nb):RTP/RTP epitaxial layers became an alternative [3]. Planar waveguides obtained using this method showed efficient type II Second Harmonic Generation (SHG) [4].

The aim of this work is to study and characterize the microstructuring of (Yb,Nb):RTP/RTP epitaxial layers by femtosecond laser ablation to obtain rib waveguides with high light confinement and low propagation losses.

II. Liquid Phase Epitaxial Growth

Epitaxial layers of (Yb,Nb):RTP were grown on **c** oriented RTP substrates by the Liquid Phase Epitaxy method (LPE), using self-flux solutions. The solution composition was Rb_2O-P_2O_5-TiO_2-Yb_2O_3-Nb_2O_5 = 40.8-27.2-29.76-1.92-0.32, in mol %. After accurately determining the saturation temperature, the substrate, previously cleaned as it is explained in reference [5], was dipped in the solution at a temperature 1 K above the saturation temperature to dissolve the outer part of the substrate. After dissolving for 5 minutes, the solution temperature was decreased up to 2 K below the saturation one to growth the epitaxial layer for several hours. During all the process, the rotation was maintained at about 40 rpm.
The chemical composition of the epitaxial layer was measured by Electron Probe Microanalysis (EPMA) and was $RbTi_{0.971}Yb_{0.015}Nb_{0.014}OPO_4$.

III. Femtosecond Laser Set-up and Experimental Conditions

The experimental set-up used to fabricate the channels is shown in Figure 1. A pulsed fs-laser amplification system, with 1 KHz repetition rate and pulse duration of 120 fs was used. The output energy was 1 mJ and the central wavelength was 799 nm. A SLM Hamamatsu X8267 spatial light modulator was used to control the beam wavefront, allowing us to design the intensity of the profile of the focused beam.

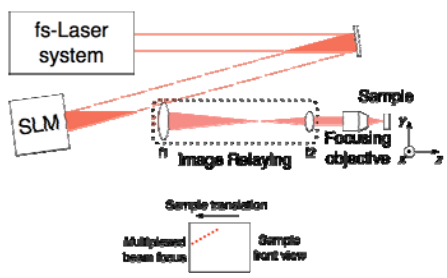

Figure 1. Experimental set-up used to inscribe the superficial channels for the fabrication of waveguides. The focused beam is multiplexed into seven spots, allowing to perform the approximation scanning technique in a single scan.

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To improve the quality of the micromachined channels, we used the approximation scanning method [6]. The SLM was used to multiplex the irradiation beam in seven spots arranged in a diagonal manner, as can be seen in Figure 1. Each spot rewrites the channel written by the previous one, but with a slight lateral displacement.

IV. WAVEGUIDING AND SECOND HARMONIC GENERATION CHARACTERIZATION

A Simulation of the light confinement at a wavelength of 632 nm using the MG Finite Difference method from OlympIOs package software was carried out. We used a trapezoidal channel rib of 13 µm at the top part, a base of 17 µm and 8 µm depth and took into account the refractive indices of the layer and the substrate (1.8956 and 1.8898 at 632 nm, respectively). The confinement obtained in this case was close to 90 %.

Previously to studying the channel waveguides modes and the Type II Phase Matching (PM) Second Harmonic Generation (SHG), the faces perpendicular to the channels direction were polished.

Using the rib waveguide of 13 µm at the top part, the channel waveguide modes were excited at 632 nm and the near field pattern obtained at this wavelength shows a Gaussian profile, as it is shown in Figure 2.

The transmission losses of the rib waveguide were obtained using the expression: Losses=(10/d).log(P_{out}/P_{in}), were d is the waveguide length and P_{out} and P_{in} are the corrected output and input powers. The corrections applied were the Fresnel losses, the objective microscope transmission losses and the mismatch between the spot after the input objective and the rib area. The losses obtained were around 2.5 dB/cm, which is lower than those previously obtained also by fs-laser surface structuring [7] and of the same order than those obtained by ultrafast laser inscription in the crystal bulk [8] in other materials.

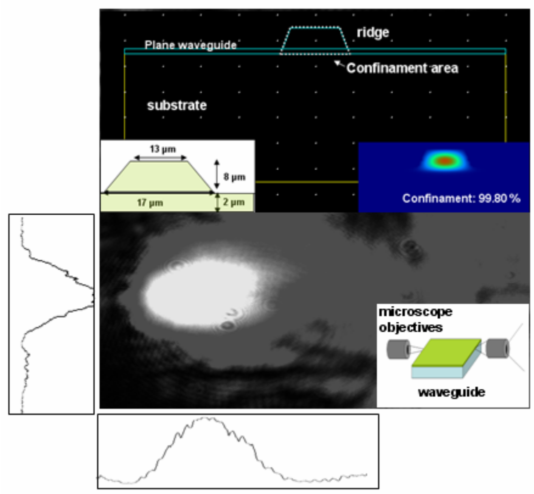

Figure 2. CCD picture of the near field pattern of the mode obtained at a wavelength of 632 nm and the profiles measured at centre of the mode.

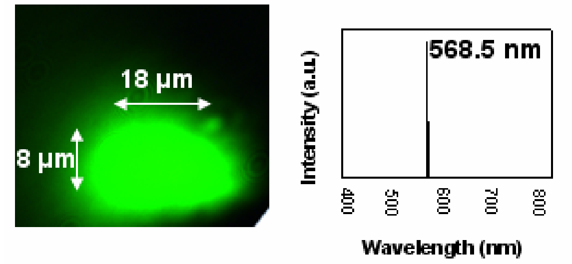

Figure 3. Type II SHG in a (Yb,Nb):RTP rib waveguide from a fundamental radiation of 1137 nm.

A tunable OPO was used to generate radiation with the wavelength required to obtain efficient SHG. The maximum second harmonic efficiency was obtained with a fundamental light of 1137 nm coupled to the channel waveguide parallel to ***a*** with a microscope objective. The second harmonic radiation, with a wavelength of 568.5 nm, was observed with a CCD camera and it is shown in Figure 3.

V. CONCLUSIONS

Femtosecond-laser micromachined rib waveguides were successfully fabricated on (Yb,Nb):RTP epitaxial layers grown on RTP substrates. Numerical simulations of the light confinement in the ribs show confinements close to 90 % at 632 nm. The channel waveguide modes were successfully excited at the same wavelength and the near field pattern obtained showed a Gaussian shape with high symmetry. The transmission losses were around 2.5 dB/cm. Finally, type II PM SHG was obtained from a fundamental radiation of 1137 nm.

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