# Femtosecond writing Double line appraoch Waveguides in Er-Yb doped Niobium Borate glasses

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*Abstract*— **In this paper we present waveguides made in Niobium Borate glasses doped with $Er^{3+}$ and $Yb^{3+}$ ions. These buried waveguides were fabricated by using femtosecond laser writing under double line approach. Propagation performance and index refractive profiles were studied in this work. Finally, simulated guiding structures by using commercial software RSOft were performed in order to test these guiding structures as potential amplifiers systems for optical communication purpose.**

***Keywords-component; waveguides, femtosecond laser writing, Optics communication, niobium borate glasses, Er-Yb***

## I. INTRODUCTION

Nowadays, femtosecond (fs) laser writing represents a well established technique to achieve optical circuits in a large number of materials either by using passive or active samples. This fast, low cost, and easy method can be applied on a large number of materials such as crystals and glasses. This is possible by adjusting the experimental parameters (writing speed and pulse energy), and also performing different writing strategies [1,2]. In this work we have fabricated the buried waveguides by the so called method "double line approach" this means the laser-matter interaction region is achieved at intensities above the optical breakdown threshold inside the materials by several non linear processes so after that the interaction regions keep a residual stress surrounding the optical breakdown tracks (OBT). Besides at the OBT larger expansion takes places therefore a lower density walls also support the confined light in these guiding structures [3,4].

In this sense, this type of optical waveguides guarantee high power confinement as well as the possibility to tailor several closed region to guide the light but the most advantages is 3D fabrication optical circuits. A variety of good performance photonic applications generated with this technology have been reported as: emitters, lasers, sensors, modulators, etc. [5, 6].

In this paper we explore the possibility to achieve this kind of guiding structures in Niobium Borate Glasses doped with $Er^{3+}$ and $Yb^{3+}$ optically active ions. With respect to the host, as it is well known that the borate glasses enriched with Niobium ions has higher optical transparency from UV to Visible spectral range. Also, the $Er^{3+}$ ions doping this glass improve the luminescence features since the quenching effect is reduced [7]. The $Yb^{3+}$ added in optical materials as it is well known, acts as sensitizer for $Er^{3+}$ ions through energy transfer mechanism that allows increasing the Erbium content in the material [8]. This goal is motivated for optical communication purpose such as integrated optical amplifier based in Er-Yb co-doped samples.

In this work, we will show the propagation characteristics and perform guiding simulations by using RSoft commercial software for optical waveguides obtained.

## II. EXPERIMENTAL PROCEDURE

The waveguides were conducted following the well-established technique of laser direct writing under double line approach [2], this means these guiding structures were made by focusing a CPA Ti:Sapphire (Spectra Physics Mai Tai-Spitfire) laser beam lasing at 800 nm into a rectangular piece of 10x 12 mm2 and 2 mm thickness. The CPA system has a repetition rate of 1 KHz with about 120 fs pulse width. The laser beam was focusing 250 μm below sample surface by using a microscope objective 10 X. The waveguides were fabricated by setting the energies per pulse, by using a polarizer and a half plate , at 30 μJ and the writing velocity at 25 μm/s by using a motorized translation stage in a micromachining station which is detailed in [4]. For generate the double tracks structure we have fabricated the waveguides between consecutive straight lines separated 20 μm.

## III. RESULTS AND DISCUSSION

### *A. Waveguides optical performance*

To explore the light propagation into the resulted buried waveguides, we have used a standard end-fire coupling system as it is described in reference [4]. By means of this system, it is launched laser light coming from 532 nm compact solid state system. Under this procedure, we focus the laser with a 10x objective in one of the polished faces of the sample. At the output, a similar 10X microscope objective was used to collect the near field which is directly focusing onto a beam profile analyzer (BPA). From these pictures and by taking into account the CCD size and the optical magnification, the real size of modal distribution can be determined. The propagation losses were estimated by means of measurement the scattered light from the top of the waveguides; by averaging registered pictures for the same waveguide we obtain a value of 2dB/cm.

### *B. Simulations: refractive index profile*

By using commercial simulation software RSoft, it was able to simulate a double track waveguide fabricated inside Niobium Borate glasses. To do that, we have to build a function that can describe the refractive index profile after laser interaction. To perform the overall profile, we have considered this function as a sum of Gaussians functions. For each of them, the variation of the modified refractive index profile consists of a central Gaussian, located on the OBT, which spans from a decreasing of 1.35 x $10^{-2}$ up to an increment of $1x10^{-3}$ with respect to unmodified material. The distance between the lateral Gaussian functions was set at 20 µm, similar to those used for the fabricated the waveguides.

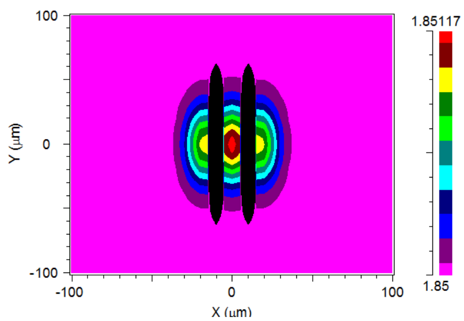


Figure 1. Refractive index profile obtained from RSoft after matching modal distribution.

To find the resultant refractive index profile, we have compared the propagated modes with those simulated by using the above function in the RSoft software. By means of an iterative procedure the simulated modes found coincide with the experimental mode taken by the BPA.

The adjusted refractive index profile by running the above method is shown in Figure 1. A wavelength of 532 nm was used to perform the simulation, this wavelength is the same used for the optical experiments. Figure 2 (top) shows two modes, one corresponding to the experiments (a) and simulations (b), respectively. Finally, in order to know the waveguide's characteristic for optical communication purpose we also performed a simulation for a wavelength of 1550 nm. The propagated mode at this wavelength is also shown in the Figure 2 (c) (bottom). As it can be seen, the mode is almost confined within the waveguide region which is delimited by an open black box. This result suggests that these integrated systems could have good performance for optical communications applications.

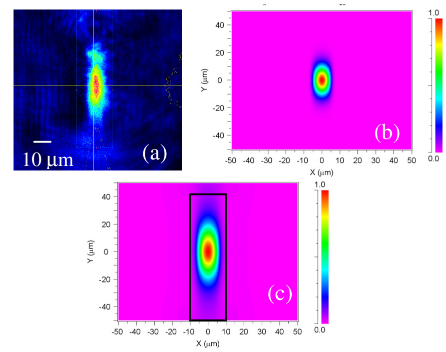


Figure 2. (a) Experimental and (b) simulated mode propagated at 532 nm in the waveguides presented in this paper. (c) Simulated mode at 1550 nm.

## IV. CONCLUSIONS

In this paper we present buried waveguides obtained by femtosecond laser writing in Niobium Borate Glasses co-doped with Er-Yb ions for potential application in optics communication. The double tracks approach have shown a refractive index increment between the OBT of 1 x $10^{-3}$ and a decreasing of refractive index on OBT of 1.35 x $10^{-2}$. These values were retrieved by using commercial software RSoft and are similar to those reported for waveguides fabricated by using this experimental procedure. These waveguides can be good candidates to perform optical amplifiers for optical communications systems.


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