Polymer channel waveguide: prospects of production and characterization

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***Abstract*— This work shows the production of optical channel waveguides in polymethyl methacrylate slabs. A writing technique employing an Argon laser at 488 nm was used. Parameters in the writing step were adjusted to obtain waveguides with different characteristics. Writing scanning speeds of 5 mm/s, 3 mm/s and 1 mm/s resulted in waveguides widths of 0.4 mm, 0.5 mm and 0.8 mm, respectively. Transversal profiles of refractive index of waveguides were measured by means of Optical Coherence Tomography. Guiding capability was determined by the near field pattern diffraction.**

***Keywords*— channel waveguide, refractometric sensor, waveguide production .**

I. Introduction

In the field of photonics, optical waveguides have found many applications as devices for communication systems, as well as evanescent field sensors. Search for advances in the quality of optical communication, by developing high speed and low cost devices, have contributed to the development of technology of optical waveguides. Besides, sensors based on waveguide evanescent field are interesting for applications where high sensitivity is required. Although silica-based waveguides are the standard devices, polymer waveguides have also been employed due to their unique characteristics. Different techniques were proposed to produce optical waveguides and specifically for polymer waveguides, new fabrication methods were used [1-3]. Among the production techniques, the illumination with a focused laser beam is a straightforward procedure employed to produce optical waveguides. In this technique, the laser beam is focused inside the sample, changing the material refractive index below the sample surface. The sample is moved with a constant speed perpendicular to the laser beam, producing a single-line writing waveguide. This so-called Type-I waveguide, with positive refractive index changes in the illuminated region, acts as the guiding region or channel waveguide. In Type-II waveguides, two adjacent and closely spaced regions are modified to develop negative refractive index changes, the guiding region being the space between these double-line written waveguide [4]. Some design parameters can be controlled to provide a device with desired characteristics. Among them are the laser wavelength and power, the sample dimensions and displacement speed, as well as the focal length and numerical aperture of the lens used to focus the laser light. Using this technique and different lasers, waveguides were produced in materials as silica, borate and fluorozirconate [5-7].

This work describes the production of channel waveguides in a polymethyl methacrylate - PMMA by the illumination with an Argon ion visible laser. An increase in the polymer refractive index is produced by the illumination with the laser light. Refractive index profile of the waveguide was determined by optical coherence tomography imaging. To demonstrate the guiding capability, near field diffraction profiles of guided light were measured.

II. Methodology

In a first step, to determine the magnitude of the refractive index changes produced in PMMA by the laser beam, a polished sample of transparent PMMA was illuminated by the expanded beam of an Argon ion laser (Innova 70-2, Coherent) at 488 nm. A red PMMA (when observed under transmission) sample 6 mm thick, 10 mm width and 12 mm length was used in this experiment. A beam expander composed of two lenses with focal lengths of 6 cm and 15 cm provided a uniform illumination of the sample (50 mW at 488 nm) during 35 minutes in 3 consecutive stages. After each stage, refractive index of sample was measured 3 times under repeatability conditions with an Abbe refractometer (Atago DR-A1, Sodium D line @589 nm, ± 0.0001 resolution) at 21 °C.

In a second step, optical waveguides were produced by illuminating a polished sample of PMMA (3.0 mm thick, 17.3 mm width, 21.4 mm length) with the focalized light of the Argon ion laser at 488 nm. An objective lens (Leitz 10x, NA= 0.25) focused the light 3 mm below the PMMA sample surface (approximately half of its thickness). A controlled stepping motor (Newport M-UTM50PP.1 and MM3000) provided the displacement of the sample, in order to write a waveguide along the whole length of the sample. Displacement speeds of 5 mm/s, 3 mm/s and 1 mm/s were employed, resulting in different time illuminations to the writing beam and

This work is supported by CAPES, CNPq, FINEP, ANP and Fundação Araucária.

leading to channel waveguides with different transverse cross-sections.

The refractive index profile of the waveguides was determined by means of OCT (Optical Coherence Tomography) operating at 1300 nm, with axial (depth) and transversal (lateral) resolutions of approximately 20 µm and 35 µm, respectively [8].

Guided light profile was determined by the near field diffraction pattern of a semiconductor laser (Opnext-HL6320G, fibre-coupled (Thorlabs CFS2-532-FC0) operating at ~635 nm (@20°C). The laser beam was focused on the input surface of the waveguide by an objective lens (Newport M10 10x, NA= 0.25) and the guided light was collected by a similar lens at the output surface. The diffraction pattern was measured with a profile meter (Thorlabs BP104UV).

III. Results and Discussions

Fig. 1 shows the temporal non-linear increase in the PMMA average refractive index from 1.4874 to 1.4887 resulting from the laser (Argon) illumination during 105 minutes. The error bars are the combined uncertainty for type A (statistical) and type B (instrumental) uncertainties. The total increase in the refractive index of $\Delta n \cong 0.0011$ obtained in the experiment indicates that the guiding effect can be obtained in PMMA with an adequate pattern of illumination.

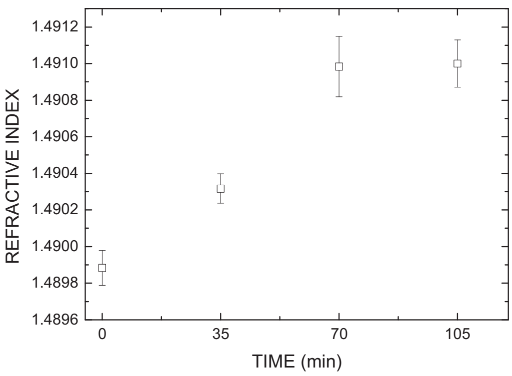

Fig. 1. Temporal photo-induced changes in the refractive index of PMMA under Argon laser (@488 nm) illumination. Line connecting the points is just a visual aid.

Fig. 2 shows refractive index profiles of the waveguides provide by the OCT images. Waveguides were produced by moving the sample during the writing process. The writing speed v and width w of the region where the refractive index was modified were: Fig. 2(a) v = 5 mm/s, w = 0.4 mm; Fig. 2(b) v = 3 mm/s, w = 0.5 mm; Fig. 2(c) v = 1 mm/s, w = 0.8 mm. The reflectivity of the interfaces with different refractive indexes inside the material is depicted by the color scale from red (higher reflectivity) to violet (lower reflectivity). Although the writing beam had been focused 3 mm below the upper surface, changes in the polymer refractive index were observed just below this surface. It might be a combined effect resulting from the high optical absorption of the material at 488 nm, together the reduction of the focal length of the writing objective lens inside the polymer. Besides the photo-induced increase in the refractive index inside the material, the long illumination time also led to damage on the PMMA surface.

This effect is better observed in Fig. 2(c), where there is a reduction in the reflectivity of the upper air-polymer interface.

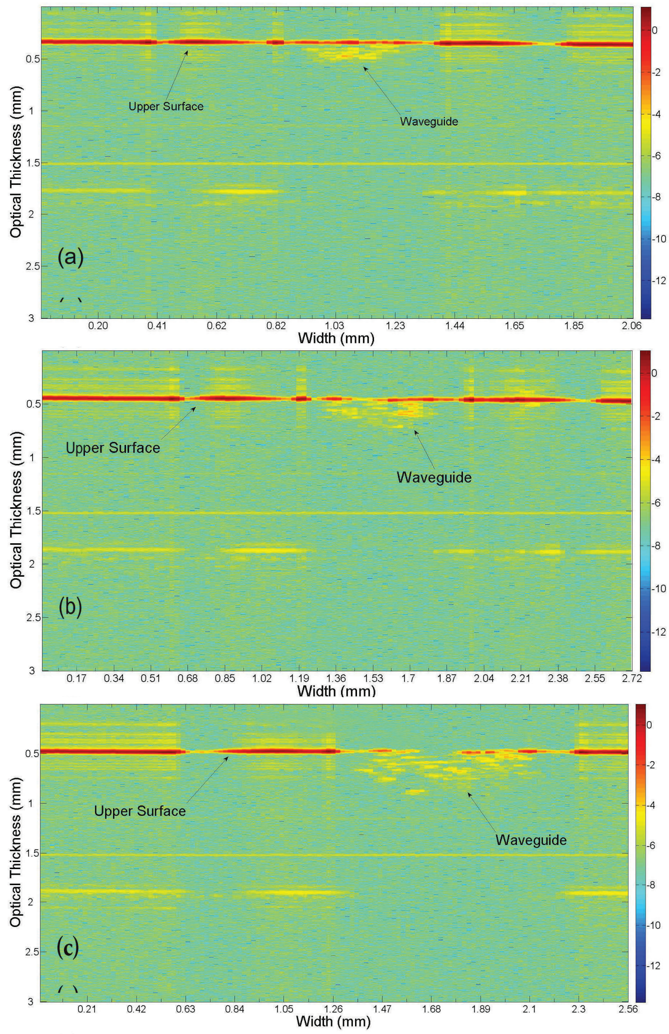

Fig. 2. Transversal tomographic images of the produced waveguides with: (a) lower illumination, (b) medium illumination, and (c) higher illumination with the writing laser beam.

Fig. 3(a) shows the experimental set-up employed to the characterization of the waveguides by near field diffraction measurements, while Fig. 3(b) shows the near field diffraction pattern obtained with this set-up for the waveguide recorded at v = 3 mm/s. Color scale depicts the diffraction intensity on the detector, from red (higher intensity) to violet (lower intensity). The two graphs with scales at bottom and right stands for the spatial distribution of this intensity along the guide cross-section. Full width at half maximum of the waveguide estimated from this diffraction pattern for the horizontal and vertical coordinates are about 120 µm and 30 µm, respectively. These dimensions correspond to the core of the waveguide, the region with guidance condition which insures wave propagation. The geometrical dimensions of the region where the refractive index was changed by the focused laser beam were estimated via OCT measurements. From Fig. 2(b), the horizontal and vertical dimensions of this area are approximately, 500 µm and 175 µm. Discrepancy between these values and the region with lower diffraction intensity positioned just bellow the main diffraction pattern in Fig. 3 (b) can be an indicative that just a fraction of the cross- section modified by the laser and shown in Fig. 2 is being effectively employed to guide the light.

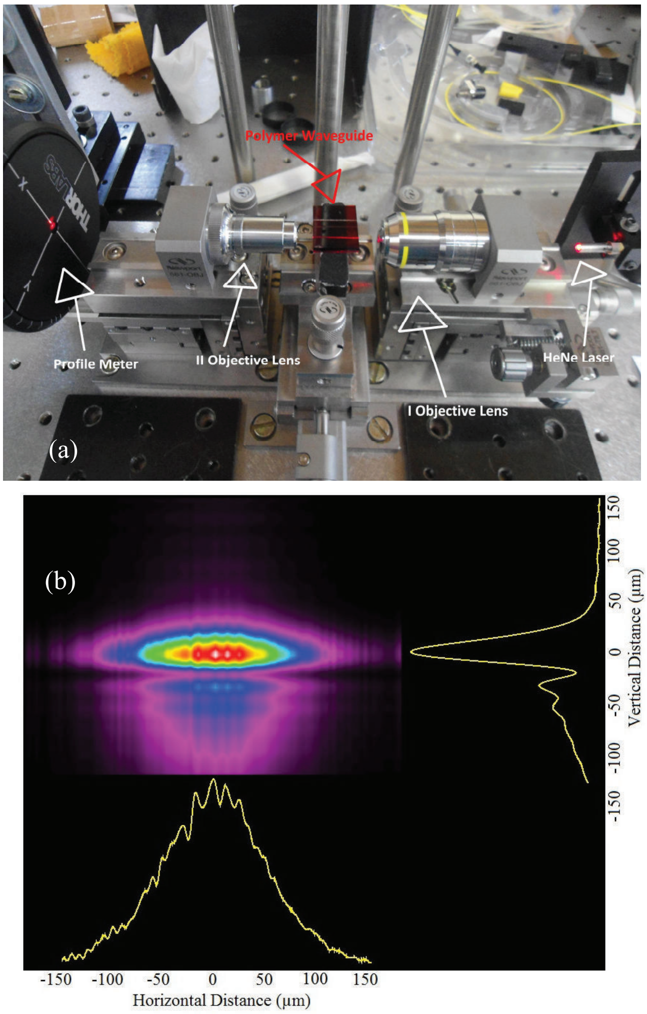

Fig. 3. (a) Set-up employed to measure the diffraction pattern of guided light; (b) near-field diffraction pattern of waveguide (shown in Fig. 2(b)).

IV. Conclusion

We showed the possibility of writing waveguides inside a PMMA slab by means of a simple technique employing visible laser illumination. By comparing images from OCT and near field diffraction, the characteristics of the waveguide can be easily designed by changing the writing parameters. Achieving these optimized characteristics is a fundamental step towards the development of refractive sensors with increased sensitivity.

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