High aspect ratio $LiNbO_3$ photonic crystals

Toward 3D $LiNbO_3$ micro and nano structures

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***Abstract*—We report easy to implement techniques for the fabrication of high aspect ratio $LiNbO_3$ photonic crystals. The methods rely on optical grade dicing followed by focused ion beam (FIB) milling. A 2D photonic crystal with an extinction ratio of -14dB is demonstrated. We show how the techniques can be combined for the development of 3D photonic crystals.**

$LiNbO_3$, ridge waveguides; photonic crystals,

I. Introduction

Writing photonic crystals (PhCs) in $LiNbO_3$ waveguides appears as a very attractive way of developing ultra-compact optical processing devices [1-2]. All the reported dynamic $LiNbO_3$ PhCs are integrated on annealed proton exchange (APE) waveguides. The photonic bandgaps that are experimentally observed in these PhCs exhibit rough spectral edges, whereas sharp bandgap edges would enable reduced driving power. This practical problem results from the conical shape of the holes and from the weak confinement of the optical guided mode [3].

To circumvent this issue, thin films of $LiNbO_3$ have been recently developed [4]. These films allow a tight confinement of the optical mode. An improvement of the-photonic bandgap edge sharpness is consequently expected. But the fabrication of thin layers of $LiNbO_3$ is a difficult task that implies in particular ion implantation. In this work we propose easy-to-implement alternative methods that improve the extinction ratio of $LiNbO_3$ based PhCs. These methods open the way toward 3D $LiNbO_3$ micro and nanostructures.

II. Description of the Process

The fabrication process can be used indifferently with X-cut, Z-cut $LiNbO_3$ substrates, and slice-cut samples. A first step consists in fabricating a planar waveguide either by Ti-indiffusion, by Annealed Proton Exchange (APE) or by Ti-APE which is a combination of both techniques. The ridge structure is realized in a second step by “optical grade dicing” with a circular precision saw (DISCO DAD 321) as described in [5]. The use of a dicing saw for the development of ridges had already been mentioned notably in [6], but the reported aspect ratios (width/depth) were not as high as what can be seen in Fig. 1(a). Indeed, we have managed to fabricate ridges with a width of 1µm and a depth of 526µm. Fig. 1(b) shows that the light can be guided through such extreme structures.

Even if this performance is not needed for the implementation of optical waveguides with low losses, it provides nevertheless an idea of the enormous capability of the method, notably for the development of thin $LiNbO_3$ layers. We have shown in [5] that propagation losses as low as 0.5dB/cm may be obtained through Ti-diffused ridge waveguide with a top width of 6µm and a depth higher than 20µm.

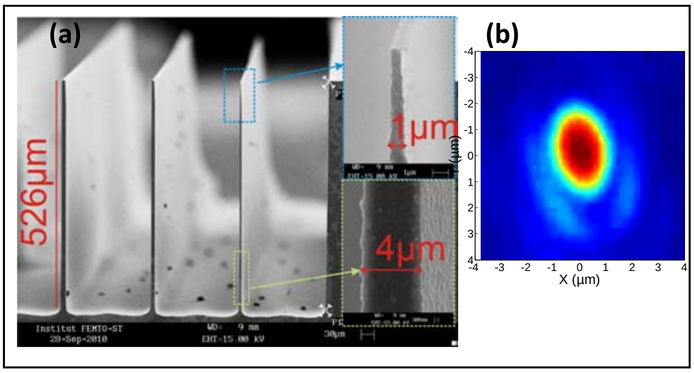

Figure 1. (a) SEM view of the ridge structures with a depth of 526 µm. The insets show zoom views of the thinnest ridge of the serie. (b) Output mode of a 526µm deep 6µm large ridge waveguide made by Ti-indiffusion followed by proton exchange.

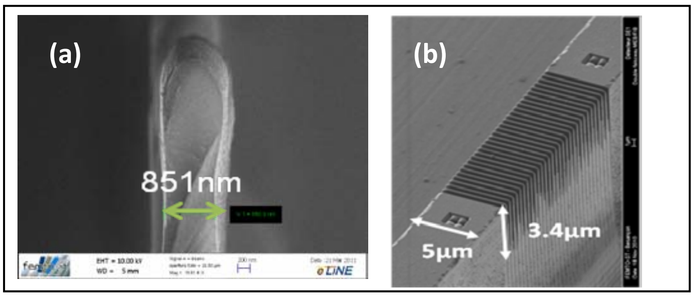

Figure 2. SEM views of ridge structures with a depth of 35 µm. (a) Ridge obtained by optical grade dicing followed by Ti-indiffusion. (b) Bragg gratings fabricated by FIB milling the top of the ridge.

In Fig. 2(a), we show that the top corner of the ridge can be smoothed if the Ti-indiffusion step is done after dicing the ridge. The process also helps reducing the roughness of the walls to 20nm. In what follows we propose to integrate PhCs into ridge waveguides by FIB writing

III. HIGH ASPECT RATIO AND 3D $LiNbO_3$ PHCS

Firstly, the ridge is diced in a Ti-indiffused planar waveguide. The PhC is then written on the top of the ridge by FIB milling. If applied to the fabrication of 1D-PhCs, the method can lead to 3.4µm deep gratings with a period of 1.1µm, as illustrated in Fig. 2(b). But from the resulting transmission response, we can conclude that this aspect ratio is not sufficient enough for obtaining large extinction ratios. This is due to the weak vertical confinement of light within the Ti indiffused waveguide. Similar results have been observed in 2D-PhCs written in Ti-indiffused ridge waveguides [7]. In what follows, the 2D-PhC is written on a Ti-APE ridge waveguide.

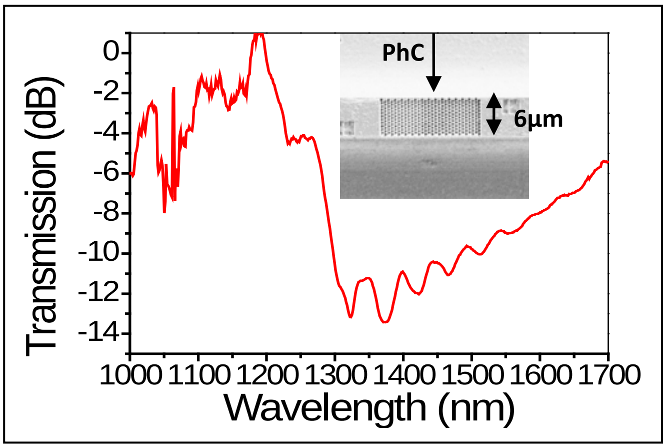

Figure 3. Normalised transmission spectrum through the PhC (TE wave). Inset : SEM view of the PhC structure.

The PhC is made of a triangular lattice of 12x15 holes. It is designed to have a spectral gap between 1300 nm and 1800 nm for TE-polarized waves. The diameter of the holes is D=312 nm, and the periodicity of the lattice is a=520 nm. The normalized transmission response through the PhC is measured by means of a LEUKOS® supercontinuum source and a Q8381 Advantest® Optical Spectrum Analyzer (OSA) as described in [7]. In Fig. 3, the transmission shows a photonic gap over the wavelength range [1300 nm-1700 nm[, which is in good agreement with numerical predictions. The extinction ratio is measured to be -14dB, which represents a significant improvement in comparison with the -2.2dB previously reported [7]. This improvement is due to a larger interaction length and to a stronger light confinement within the Ti-APE ridge waveguide.

IV. HIGH ASPECT RATIO AND 3D $LiNbO_3$ PHC

The method can advantageously be applied to the fabrication of 3D-PhCs if the ridge is tilted with an angle of 90° during the FIB milling step. A PhC can indeed be engraved on the edge of the ridge. Preliminary tests dedicated to the fabrication of Bragg gratings show that a large improvement of the aspect ratio can be reached in comparison with what is achieved by FIB milling the top of the waveguides. Indeed, the conical shape of the holes results from the redeposition of $LiNbO_3$ on sidewalls during the FIB milling process. This redeposition is partially avoided when the beam goes through the entire thickness of the ridge, because a part of the milled material is evacuated at the opposite side of the ridge.

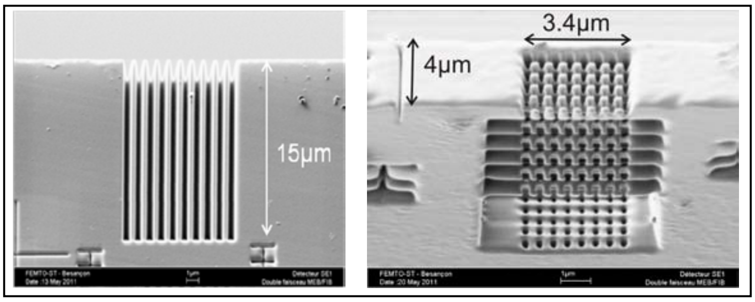

Figure 4. SEM views of $LiNbO_3$ PhCs made by FIB milling the edge of the ridge. (a) Deep gratings. (b) 3D $LiNbO_3$ PhC

This is illustrated in Fig. 4(a), where we can see gratings with a depth of 15µm and a period of 1.1µm. Moreover, this approach gives promising perspectives toward the fabrication of $LiNbO_3$ 3D-PhCs as can be seen in Fig. 4(b).
As a conclusion, we have shown that complex micro and nanostructures can be integrated in $LiNbO_3$ optical waveguides by combining optical grade dicing and FIB milling. In the presentation, we will show detailed optical characterization of the transmitted and reflected spectra through the 2D-PhCs. Alternative methods based on reactive ionic etching will also be presented.

ACKNOWLEDGMENT

The authors would like to acknowledge E. Lantz, L. Froehly, and T. Sylvestre for fruitful discussions. This work was supported by the Conseil general de Franche Comté under the grant 2011C-07322.

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