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Lithium niobate photonic crystal waveguides: Far field and near field characterisation

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Abstract

In this paper, we experimentally investigate photonic crystal waveguides in a X-cut lithium niobate substrate. The transmission response is measured through the ΓM direction of a triangular lattice structure and the results coincide with the theoretical predictions. In addition, a scanning near-field microscope is used in collection mode to map the optical intensity distribution inside the structure putting in evidence the guiding of the light through lines of defects. This study offers perspectives towards lithium niobate tunable photonic crystal devices.

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Photonic crystals (PCs), also known as photonic bandgap materials, are attractive optical materials for controlling and manipulating the flow of light. Their structure consists basically on periodic changes of the dielectric constant on a length scale comparable to optical wavelengths. Multiple interference between scattered light waves can eventually lead to some frequencies that are not allowed to propagate, giving rise to forbidden and permitted bands, similar to the electronic bandgap in a semiconductor. The band structure depends on the geometry and the material refractive index. Hence, an attractive feature of photonic crystals consists in tuning the substrate refractive index controlling therefore the transmission response. With tunable photonic crystals, the path is open towards high density ultra-compact photonic circuits. This perspective has motivated various studies on tunable photonic devices [1–5].

Among optical tunable materials, the combination of excellent electro-optical, acousto-optical, non-linear optical properties, electro-mechanical (piezoelectric) properties, chemical and mechanical stability makes lithium niobate (LN) an attractive host material for application in photonic crystal devices. Moreover, LN high electro-optical coefficient and its low optical losses make it very adequate for optical communication systems.

In our two previous works [6,7], we have shown the fabrication by focused ion beam (FIB) milling of a triangular lattice of nanometric-sized holes with etching depths of 2 μm on an annealed proton exchanged (APE) lithium niobate waveguide [7]. We have also shown both theoretically as well as experimentally the presence of a photonic bandgap (PBG) with an extinction ratio lower than −12 dB.

Recently, an alternative fabrication technique that consists of electric poling and subsequent etching has confirmed the interest in LN-based nanodevices [8].

In this work, the possibility of guiding the light is experimentally evaluated for photonic crystal waveguides. We present a far field as well as a scanning near field experimental characterization of a photonic crystal waveguide fabricated on a lithium niobate waveguide.

As mentioned above, our final objective is the fabrication of photonic bandgap structures in which transmission can

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be tuned by changing the refractive index. We have already theoretically shown [7] that in the case of a triangular array of holes, the optimal sensitivity to the refractive index is obtained when the direction of propagation is ΓM, and the polarization of the electric field is TE (parallel to the substrate plane and perpendicular to the direction of the holes). The ΓM propagation direction exhibits the additional advantage of requiring a lower number of rows to obtain a photonic gap. Indeed, we have shown in Ref. [7] that the ΓM direction requires only 15 rows to get a −12 dB extinction ratio as opposed to the 30 rows that would be necessary to achieve the same gap in the propagation direction ΓK. Due to the well-known difficulty to etch lithium niobate, this property has strongly motivated our choice. In addition, with such a configuration we have experimentally demonstrated the existence of a photonic gap.

To complete the analysis of this configuration, we have fabricated two alternative structures, based on the same array as in our previous work, but with one (PCW1) or three lines (PCW3) of defects. The aim is to investigate the possibilities of a tunable guiding of the light through the crystal. The geometrical parameters are chosen to get a transmission zone around 1550 nm within the bandgap.

The photonic crystals are fabricated on a 0.3 mm thick X-cut $LiNbO_3$ wafer. In a first step, an optical gradient index waveguide is fabricated by annealed proton exchange. This step is realized through a SiO_2 mask in benzoic acid at 180 °C during 1.5 h. The process is followed by an annealing of the optical waveguide at 333 °C for 9 h. These parameters are chosen to position the core of the optical mode as close as possible to the surface (approximately 1.4 μm) while keeping single mode propagation at 1.55 μm.

The photonic crystal structure was fabricated in the central region on the optical channel waveguide as shown in Fig. 1(a). It consists of a triangular lattice of 48 × 26 circular holes. The lithium niobate substrate (300 microns thickness) is metalised with a thin Cr layer (100 nm) to avoid charging effects. This Cr layer is deposited by electron gun evaporation (Balzer, B510). The sample is grounded with a conductive paste before introduction in the FIB vacuum chamber (10^{-6} Torr). The FIB used is a FEI Dual Beam Strata 235. Ga^+ ions are emitted with an accelerated voltage of 30 keV and focused down with electrostatic lenses on the sample with a probe current of 120 pA. The Gaussian beam shape spot size is about 20 nm at the sample surface. The etching time of the structures PCW1 and PCW3 (48 × 26 triangular hole lattice, hole diameter = 255 nm, periodicity = 510 nm, etching depth = 1500 nm) was 20 min each. We would like to point out that the removal of material by FIB milling is achieved without the use of a patterned resist mask and therefore, high-precision complex structures can be directly fabricated. A FIB image cross-section of the holes is shown in Fig. 1(b). The angle between the FIB beam and the holes axis is 52°.

In order to couple the conventional TE APE mode (4 μm size) to the photonic crystal waveguides (approxi-

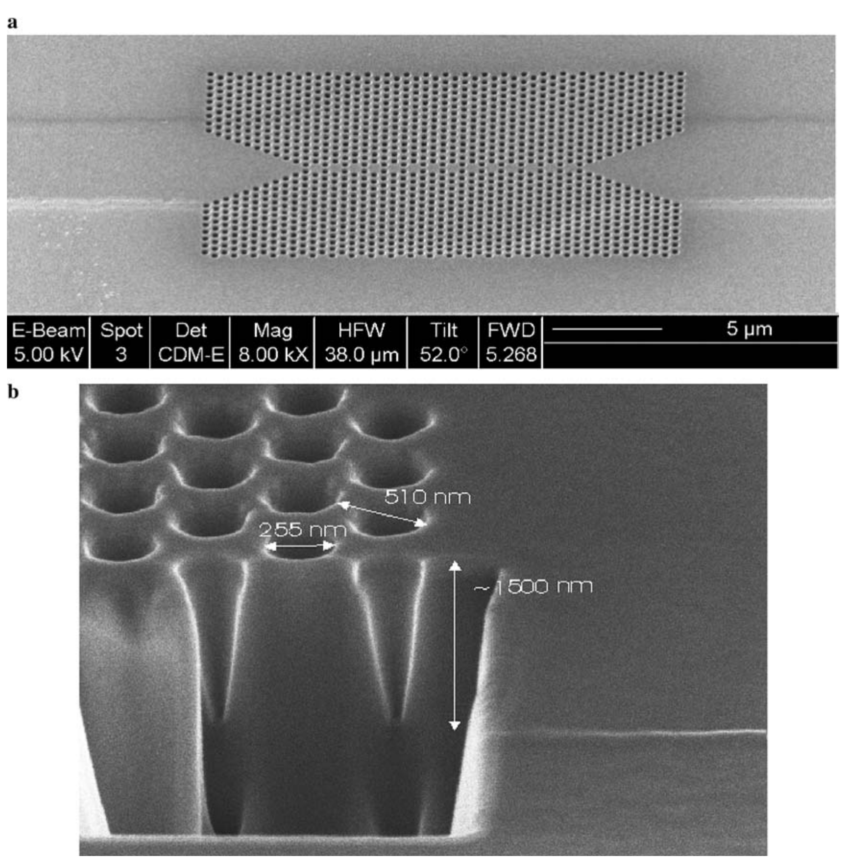

Fig. 1. SEM view of the: (a) triangular lattice PCW1 and (b) its cross-section.