Low-loss $LiNbO_3$ integrated photonic crystals

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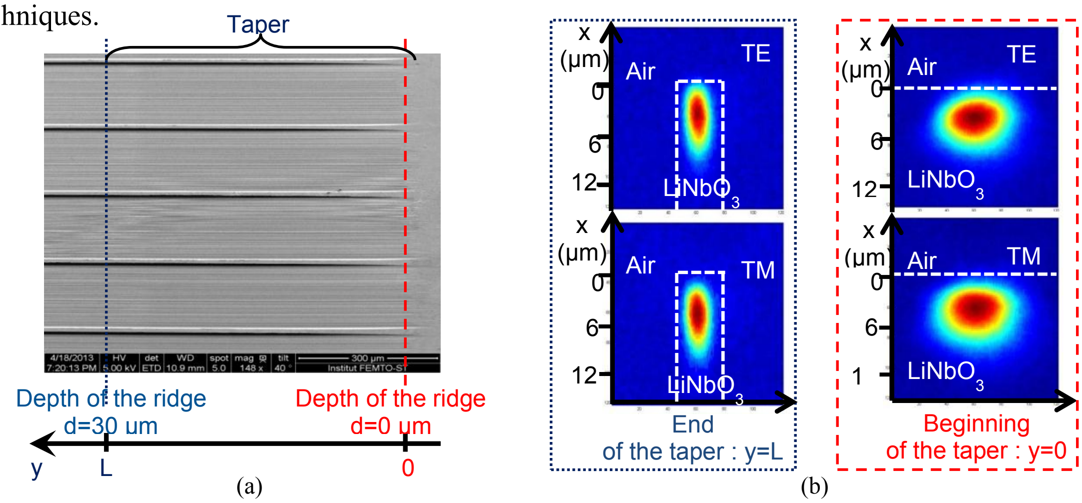
Abstract: We report $LiNbO_3$-based photonic components consisting of low-loss ridge waveguides and high aspect ratio photonic crystals. The components include spot-size converters to efficiently couple light from a SMF28 fiber into the ridge waveguide. The coupling losses and propagation losses are measured to be as low as 0.8 dB per facet and 0.2 dB/cm respectively, for both TE and TM polarizations. High aspect ratio photonic crystals are inscribed in the confined ridge waveguides by focused ion beam (FIB) milling. These developments open the way to compact low-power photonic circuits. For the sake of example, we present ultra-sensitive temperature sensors with an active length of only 30 µm and new photonic structures.

Tunable photonic crystals (PhCs) represent a stimulating challenge for advanced functionalities in compact optical devices. Lithium niobate ($LiNbO_3$) substrates appear as excellent candidates for such realizations, due to their well-known nonlinear, piezoelectric and electro-optic properties. However, the integration of $LiNbO_3$ PhCs in photonic circuits faces two major issues. The first one is related to the weak confinement of light in $LiNbO_3$ waveguides: the maximum index change produced by standard techniques is quite small ($\Delta n<0.01$), and the resulting mode is broadly distributed. Thin films of $LiNbO_3$ providing strong light confinement are now available [1], but the confinement is achieved at the expense of the insertion losses. Secondly, the production of high aspect ratio PhCs is severely hindered by the matter redeposition occurring during the dry etching processes.
Here we show an alternative approach that relies on high aspect ratio ridge waveguides [2,3] with low insertion losses. The guided light is submitted to a large lateral index contrast resulting in a strong lateral confinement of light. An innovative vertical transition enables low coupling losses between the SMF28 fiber and the ridge. These ridges can lead to temperature sensors with unexpectedly high temperature sensitivity (8 nm/°C), and to high aspect ratio photonic crystals with insertion losses lower than 5 dB.

Firstly a planar waveguide is produced either by Ti-indiffusion, Annealed Proton Exchange (APE) or by a combination of both techniques. The ridge structure is made in a second step by “optical grade dicing” with a circular precision saw (DISCO DAD 321) [1]. Hence, ridges with aspect ratios (width:depth) larger than 500 can be achieved. The optimal propagation losses are as low as 0.2dB/cm for both TE and TM polarizations, and the related confinement is twice stronger than the one of standard waveguides. Stronger confinements can be achieved by combining Ti-indiffusion and APE techniques.

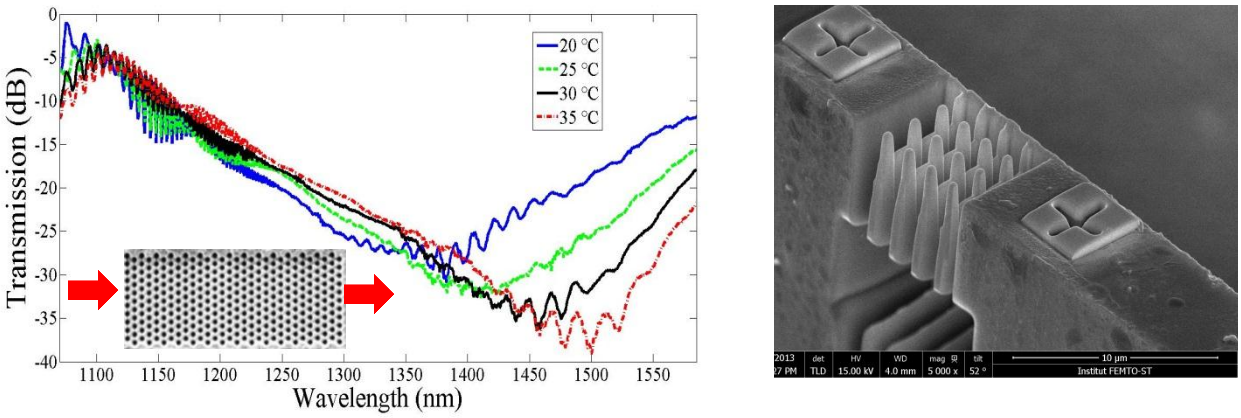


(a) (b)

Figure 1. Vertical tapers made with a circular precision saw. (a) SEM view of five tapered ridges: the depth of the ridge is progressively increased. (b) Optical modes visualized with an infrared vidicon camera and a X20 microscope objective. Lefts: Mode at the end of the taper. Rights: the mode at the input of the taper. Width of the Ti-indiffused ridge: 6µm.

New challenges arise with the achievement of confined waveguides. Indeed, standard SMF28 fibers exhibit a broadly distributed mode that weakly overlaps with confined modes. This issue is addressed with a vertical taper between the ridge and the fiber in order to ensure a spot size conversion of the guided mode. The taper is made simply by lifting the blade before the end of the ridge waveguide (see Figure 1(a)). As a result, the section of the waveguide in contact with the fiber is weakly confined and strongly overlaps with the fiber's mode, while the end of the taper in contact with the ridge is strongly confined for both TE and TM polarizations (see Figure 1(b)). The taper contributes to reduce the coupling losses from 2.8 dB (ridge in direct contact with fiber) to 0.8 dB (taper in contact with fiber) per facet: this achievement is of great relevance for the production of compact low-power PhCs-based components.

Photonic structures are made in a second time by focused ion beam (FIB) milling. These developments have been successfully exploited for the experimental demonstration of low-power-consuming tunable PhCs. For the sake of example, a single triangular PhC inscribed in a Ti-indiffused APE ridge waveguide has shown an enhanced temperature sensitivity of 8 nm/°C (Figure 2(a)), which can be regarded as a record in comparison with other all-dielectric temperature sensors. The device could be advantageously exploited as temperature or electric field sensors.



(a) (b)

Figure 2. (a) Measured optical transmission through a triangular lattice of holes in a (Ti-APE) $LiNbO_3$ ridge waveguide, as a function of temperature. The results have been obtained by normalizing the optical intensity light transmitted through the nanostructured waveguide with the intensity through a single ridge waveguide made in the same conditions without any PhC. The guided light is TE-polarized. Insert: top view of the PhC (b) SEM views of a free standing 3D $LiNbO_3$ photonic crystal

Recently we have also demonstrated photonic crystals with extremely high aspect ratios by inscribing the photonic patterns through the side of the ridges [3]. An illustration is given in Figure 2(b), where a SEM picture shows a free standing three dimensional $LiNbO_3$ photonic crystal. Optical characterizations have been performed on various high aspect ratio $LiNbO_3$ PhCs: the reflectivity is now measured to be higher than 80% in the photonic bandgap for both TE and TM polarizations, and the insertion losses are lower than 5 dB. Such PhCs with high reflectivity can advantageously be implemented into photonic resonators. It is worth noting that the characterization method relies on an optical coherence tomography (OCT) based system that works in reflection as well as in transmission. This approach enables the assessment of reflectivity, transmission and losses, which is of great relevance for the optimization of various photonic structures.
These results open the way toward low consumption compact electro-optic components.

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