Freestanding Photonic Crystal Membranes in Lithium Niobate fabricated by Ion-Beam Enhanced Etching

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Photonic crystal (PhC) structures received significant attention in recent years, especially two dimensional air-hole PhC slabs, allowing for plentiful ways to manipulate light propagation. Whereas most reported effects of such photonic crystal (PhC) structures merely rely on linear optical properties, nonlinear optical effects, such as parametric frequency conversion, become increasing importance. The efficiency of those effects can be enhanced by, e.g., confining the light to very small volumes or by minimizing the group velocities of the interacting waves [1,2]. Both can be realized using PhC structures in planar waveguides. To optimize the overlap of optical mode and PhC it is desirable to have a symmetric waveguide with large index contrast to the surrounding medium. In this contribution the fabrication of a lithium niobate ($LiNbO_3$) PhC suspended in air realized as freestanding membrane is presented for the first time.

As a material system widely used in nonlinear and integrated optics, $LiNbO_3$ has a strong quadratic optical susceptibility, but it is highly resistant against standard structuring technologies. The patterning of the PhC membrane is facilitated by using ion beam enhanced etching (IBEE)[3]. At first, layers of fused silica and chromium are deposited on the $LiNbO_3$ wafer. The PhC structure is defined by e-beam writing and subsequent RIE and ICP-RIE dry etching into chromium and fused silica. Afterwards irradiation with argon ions of different energies and fluencies was performed leading to a homogenously damaged crystal in the unmasked regions all the way down to the desired membrane thickness (Fig. 1). Subsequently the masking layer is removed and a second irradiation is performed using helium ions with energies between 200 and 400 keV, corresponding to stopping ranges between 680 and 1000 nm, which defines the air gap underneath the membrane. For the presented structure the irradiation is done with 285 keV He-ions at a fluence of about $5x10^{16}$ cm^{-2} at 100K [4]. The amorphous $LiNbO_3$ is then etched in 3.7% hydrofluoric acid at 40°C for one hour. Before etching, the sample is thermally annealed at 300°C leading to a steeper damage profile and therefore increased etching contrast. A second annealing step is carried out after etching to completely restore the original crystallite structure assuring unperturbed optical functionality.

Corresponding to optical modelling, a membrane thickness of about 450 nm, hole diameters of 390 nm with 620 nm period in an hexagonal lattice were fabricated for a photonic band gap around 1.55 µm wavelength. Perpendicular side walls and smooth surfaces (5 nm rms) are further requirements that have proven to be met using IBEE (Fig. 2). The expected limits for patterning PhC structures using IBEE are periods of 300 nm and hole diameters down to 50 nm. Owing to mechanical stresses built up by the irradiated ions in the free standing membranes, the PhC structures lateral dimensions are limited to few hundred micrometers. In conclusion it has been demonstrated that IBEE allows for three dimensional structuring of $LiNbO_3$ on a submicron scale giving rise to the realization of various types of miniaturized active optical devices (Fig. 3), especially nonlinear PhC.

References:

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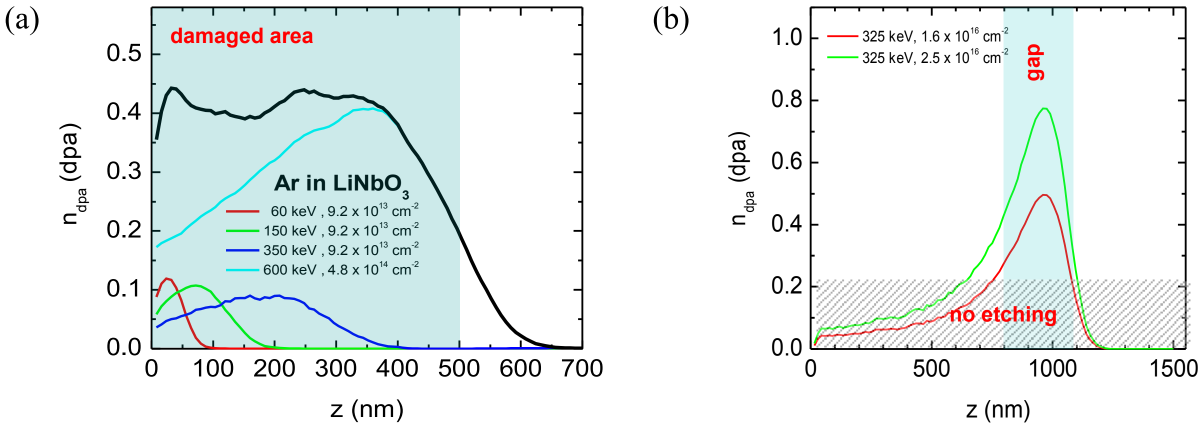

Fig. 1: Normalized fluence n_{dpa} calculated from the primary displacements versus depth z for (a) a series of Ar-ion irradiations showing the formation of an homogenously damaged area down to 500 nm and (b) He-ion irradiations defining the air gap under the membrane.

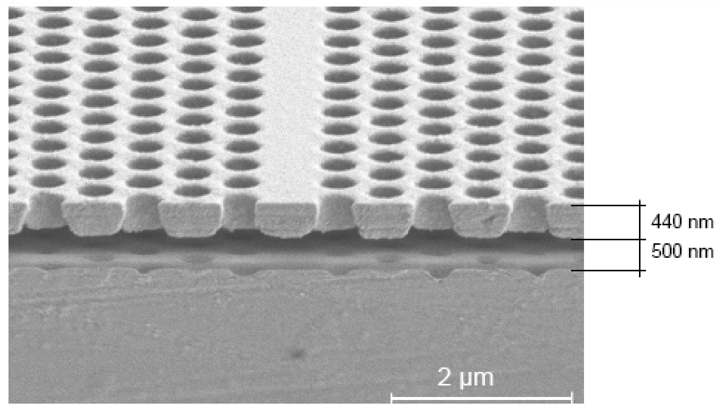

Fig. 2: Scanning electron micrograph of PhC structure with hole diameters of 390 nm and a period of 620 nm in an hexagonal lattice.

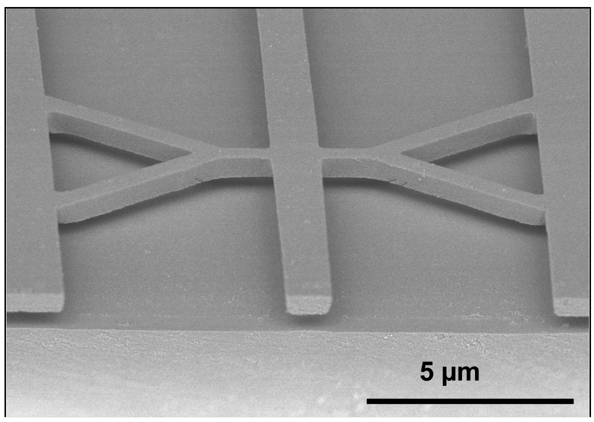

Fig. 3: Small mode volume optical waveguide suspended in air.