# Freestanding Photonic Crystals in Lithium Niobate

Reinhard Geiss, Holger Hartung, Severine Diziain, Michael Steinert, Frank Schrempel, Ernst-Bernhard Kley, Thomas Pertsch, and Andreas Tünnermann
*Institute of Applied Physics, Abbe Center of Photonics,*
*Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743, Jena, Germany*
*geiss@iap.uni-jena.de*

Lithium niobate ($LiNbO_3$) is a material system widely used in nonlinear and integrated optics. The growing interest in miniaturized optical systems, like photonic crystal (PhC) cavities, requires techniques to fabricate sub-micron structures in $LiNbO_3$. Amongst others, ion-beam enhanced etching (IBEE) in combination with e-beam lithography has proven to provide high quality structuring of photonic micro and nano structures in $LiNbO_3$[1]. It relies on the reduced chemical stability of ion-beam irradiated $LiNbO_3$ that, as a result, becomes vulnerable to hydrofluoric (HF) acid[2]. For applications in fundamental research the focus is on single devices and short processing times, which makes focussed ion-beam milling (FIB) an ideal tool. Now, the combination of both, IBEE and FIB, was successfully used to fabricate freestanding PhC structures as follows (Fig. 1): A piece of congruent, optical grade x-cut $LiNbO_3$ was irradiated with He ions with energies of 285 keV and a fluence of $5 \cdot 10^{16}\,cm^{-2}$ at a temperature of 100 K. This irradiation leads to a buried damaged layer. This layer is later selectively etched to form the air gap underneath the PhC membrane. After sputtering of a conductive Au layer, the $LiNbO_3$ was patterned by Ga-ion FIB milling. Subsequent wet etching with diluted HF acid (4%, 40°C for 5 min) now removed the buried damaged layer through the FIB milled holes, forming the final suspended PhC structure. In these structures, independent on feature size and shape, a systematic deviation of 20 nm from the original layout was found. It originates from the contamination of $LiNbO_3$ with Ga after FIB milling. During milling with 30 keV Ga ions, $LiNbO_3$ is sputtered and, at the same time, a surface layer of damaged $LiNbO_3$ containing Ga forms. The thickness of this layer was calculated with the software SRIM to be 17 nm, which is in good agreement with the observed deviations. The Ga has been detected with energy-dispersive X-ray spectroscopy (EDX) before the final HF etching. After the etching no residual Ga could be detected. It is therefore believed that the damage to the crystal structure induced by the Ga ions led to a reduced chemical stability, similar to the He ion irradiation, and to removal by wet etching. To ensure the required good crystalline, and consequently optical, quality of the $LiNbO_3$ after FIB patterning it is therefore essential to perform HF etching. In conclusion, the combination of IBEE and FIB allows for PhC with hole diameters of down to 150 nm and membrane thicknesses of 300 nm. The optical characterization of such PhC cavities (Fig. 2) eventually showed resonances with Q-factors of several hundred according to the designed device performance.

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[1] H. Hartung et al., Optical Materials, 33, 19 (2010)

[2] F. Schrempel et al., Nuclear Instr. and Methods in Physics Res. Sec. B, 250, (2006)

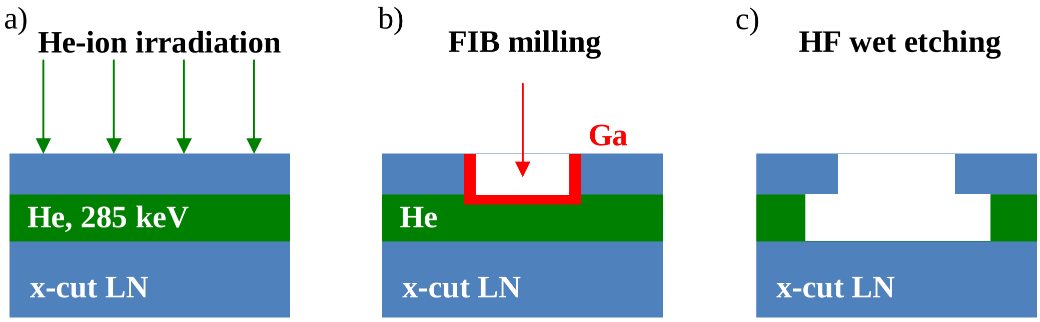


*Figure 1:* Schematic process flow of fabrication of photonic crystals by combining ion-beam enhanced etching and focused ion-beam (FIB) milling. a) Irradiation with helium ions of 285 keV energy. b) FIB milling with gallium contamination at the side walls. c) Wet etching in diluted hydrofluoric acid removes damaged material resulting in a freestanding patterned membrane.

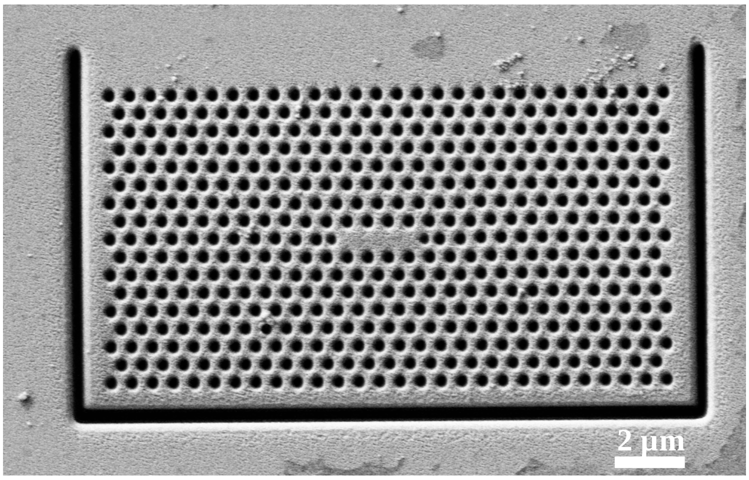


*Figure 2:* L3 photonic crystal cavity in a 400 nm thick $LiNbO_3$ membrane with conductive gold layer.

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