Lithium Niobate Photonic Crystal Nanocavities

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Primary CNF Tools Used: JEOL 9500 electron-beam lithography, AJA ion mill

Abstract:

Lithium niobate, with its wide applications in optics and mechanics, is a chemically inert material, and fabrication techniques for microscale and nanoscale structures of lithium niobate are to be developed. In this report, we demonstrate fabricating high-quality lithium niobate 1D and 2D photonic crystal cavities, using electron beam lithography and ion milling. Our devices exhibit high optical *Q* factors, paving the way for cavity nonlinear optics and cavity opto-mechanics of lithium niobate.

Summary of Research:

Lithium niobate (LN) exhibits outstanding electro-optic, nonlinear optical, acousto-optic, piezoelectric, photorefractive, pyroelectric, and photoconductive properties, that have found very broad applications in telecommunication, nonlinear/quantum photonics, microelectromechanics, information storage and sensing, among many others. Recently, significant interest has been attracted to develop LN photonic devices on chip-scale platforms, which have shown significant advantage in device engineering compared with conventional approaches [1-4]. Miniaturization of device dimensions dramatically enhances optical field in the devices which enables a variety of nonlinear optical, quantum optical, and optomechanical functionalities. In our work, we demonstrate LN 1D and 2D photonic crystal with more than optical *Q* around 10^5, more than two orders of magnitude higher than other LN nanocavities reported to date. In our 1D LN photonic crystal, the high optical quality together with tight mode confinement leads to extremely strong nonlinear photorefractive effect, with a resonance tuning rate of ~ 0.64 GHz/aJ, or equivalently ~ 84 MHz/photon, three orders of magnitude greater than other LN resonators. In particular, we observed intriguing quenching of photorefraction that has never been reported before. The devices also exhibit strong optomechanical coupling with gigahertz nanomechanical mode with a significant f • *Q* product of 1.47×10^{12} Hz.

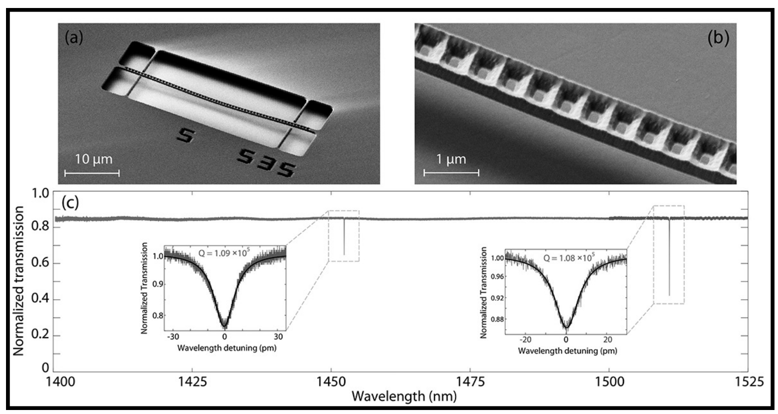

Figure 1: (a) (b) SEM images of a $LiNbO_3$ photonic crystal nanobeam. (c) Normalized transmission spectrum of the photonic crystal cavity, measured by two tunable lasers operating at different wavelength ranges (indicated as black and grey curves). Insets show detailed transmission spectra of the fundamental TE (TE0) mode and second-order TE (TE1) mode, respectively.

The fabrication process of our devices is pretty standard. First, we start with an X-cut lithium niobate-on-insulator wafer, which has a device layer of 300 nm sitting on a buried silicon oxide layer of 2 μm; then we spin ZEP-520A on the top of the wafer, and do patterning with JEOL 9500 electron beam lithography. Second, lithium niobate is etched with AJA ion milling, with ZEP-520A as the mask. Next, the remaining resist is removed by YES Asher oxygen plasma etcher. Finally, diluted hydrofluoric acid is utilized to remove buried silicon oxide and release our suspended structures.

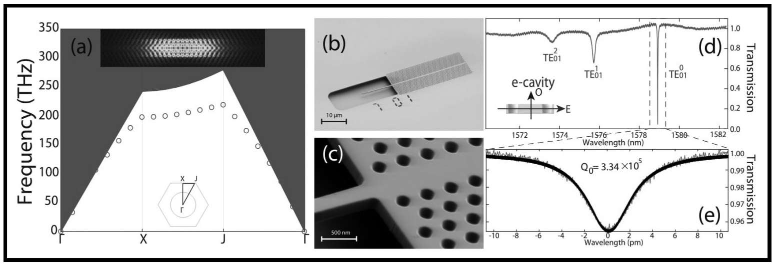

Figure 2: (a) Dispersion property of the fundamental transverse-electric-like (TE-like) guided mode inside the designed 2D photonic crystal slab. Optical mode field profiles of the fundamental mode are shown on the top. (b) Scanning electron microscopic image of a fabricated 2D LN PhC slab. (c) Zoom-in image of a section of the photonic crystal slab. (d) Laser-scanned transmission spectrum of an e-cavity. (e) Detailed transmission spectra of the fundamental cavity modes, with the experimental data shown in grey and the theoretical fitting shown in black.

Figure 1 (a)(b) shows the SEM images of a $LiNbO_3$ photonic crystal nanobeam, which show clearly the quality of device etching and dimension control. By launching a continuous-wave tunable laser into the cavity with a tapered optical fiber and monitoring the cavity transmission, we obtained the cavity transmission spectrum shown in Figure 1(c) for the transverse electric (TE) optical field with polarization lying in the device plane. Figure 1(c) shows two distinct cavity modes located at 1452 and 1511 nm, which correspond to the fundamental (TE0) and second-order (TE1) TE modes of the device, respectively. In particular, the two cavity modes exhibit optical Q as high as 1.09×10^5 and 1.08×10^5, respectively, which are more than two orders of magnitude higher than current state-of-the-art LN photonic crystal devices.

Figure 2 shows our design and fabrication result for our 2D LN photonic crystal. The dispersion property of the fundamental transverse-electric-like (TE-like) guided mode inside the designed 2D photonic crystal slab is shown in Figure 2 (a). Optical mode field profiles of the fundamental mode are shown on the top. The scanning electron microscopic image of a fabricated 2D LN PhC slab, shown in Figure 2 (b) and Figure 2 (c), indicates our high etching quality. For convenience, we denote the one perpendicular to the optical axis as an e-cavity since the dominant electric field polarizes along the optical axis, corresponding to the extraordinary polarization (Figure 2 (d)). Accordingly, we denote the one in parallel with the optical axis as an o-cavity as the dominant cavity field polarizes along the ordinary polarization. The highest Q we achieved in our O-cavity is 3.34×10^5. In particular, the peculiar anisotropy of photorefraction quenching and unique anisotropic thermo-optic nonlinear response have never been reported before.

In conclusion, we have developed the fabrication of high quality photonic crystal on lithium niobate-on-insulator platform using electron beam lithography and ion milling. High-quality etching of lithium niobate is verified by 1D photonic crystal nanocavities with Q of 10^5 and 2D photonic crystal nanocavities with Q of 3.34×10^5. Our work is of great potential for nonlinear optics, quantum photonics of lithium niobate on chip.

References:

[1] M. Roussey, et al., Appl. Phys. Lett. 89, 241110 (2006).
[2] G. Zhou and M. Gu, Opt. Lett. 31, 2783 (2006).
[3] N. Courjal, et al., Appl. Phys. Lett. 96, 131103 (2010).
[4] R. Geiss, et al., Appl. Phys. Lett. 97, 131109 (2010).