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Device Integration of Lithium Niobate Microring Resonators Patterned with a Silicon Hard Mask

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Introduction:

Nonlinear optical devices are powerful tools for controlling the propagation, phase, and polarization of light. Lithium niobate (LN) is a promising candidate for integrated optical devices due to its combination of strong electro-optical and nonlinear optical properties. Ring resonators made of LN with reduced device size allow for nonlinear applications such as optical storage, second harmonic generation, telecommunication, and sensors. In order for these devices to function, the ring resonator needs to have a sufficiently high quality factor (*Q*-factor) so as to achieve high gain at its resonant frequency. There have been numerous attempts to fabricate high *Q*-factor LN optical resonators by utilizing advanced manufacturing techniques including photolithography, ion-beam enhanced etching, and reactive ion etching using either chromium or nickel masks deposited on the device [1].

There are numerous advantages to the techniques listed above; nevertheless, these usually result in rough sidewall profiles, high surface roughness, reduced etch depth, and non-ideal sidewall angles. These process non-uniformities, especially surface roughness, scatter light leading to poor confinement in the waveguides and resonators.

This project highlights work done to address two significant issues, the first part seeks to improve fabrication process non-uniformities and roughness by using a silicon hard mask, and the second part of the project deals with device integration with SU-8 waveguides. The device coupling efficiency, which is essential in nonlinear optics experiments, may be enhanced by improving the coupling between the waveguide and fiber by overlaying and polishing SU-8 waveguides. These methods make the fabrication and optical test of LN devices more robust and increase the device performance by improving modal confinement and tunability.

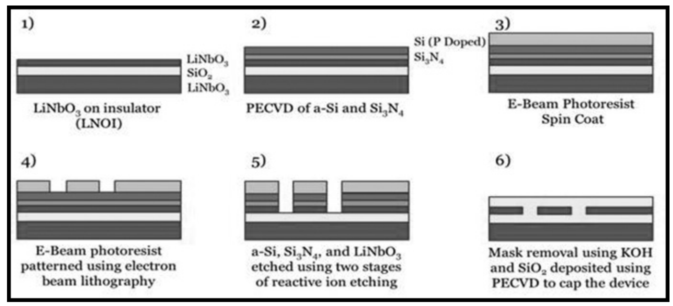

Figure 1: The fabrication process using a Si mask.

Methods:

The current process uses a FOX-16, hyrdrogen silsequioxane (HSQ) electron-beam resist, as an etch mask. However, HSQ is not crystalline and is physically soft; therefore, selectivity to LN is low, approximately 0.5, which leads to non-uniform lateral etching. To address the poor selectivity of the FOX-16 process, we tested a silicon mask, as shown in Figure 1, patterned by HSQ e-beam resist and a standard silicon (Si) dry etch process. The key points of this process were the testing of different thicknesses of amorphous silicon and e-beam resist, and the patterning of LN by a physical argon (25 sccm Ar^+) etch in a NEXX reactive ion etch (RIE) tool with an RF power of 250W and a pressure of 5 mTorr.

For the device integration portion, prior to a silicon dioxide (SiO_2) cap, SU-8 waveguides were overlaid on the sample and attached to existing waveguides to act as coupling pads for a lensed fiber. The key process was the cleaved sample polish using an Allied Polisher with 30 μm, 6 μm, 1 μm, 0.3 μm, and 0.05 μm lapping films; the first three pads were diamond and the remaining aluminum oxide.

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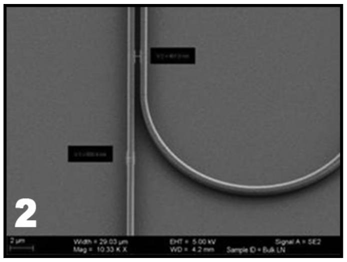

Figure 2: FESEM image of an Si mask demonstrating low surface roughness.

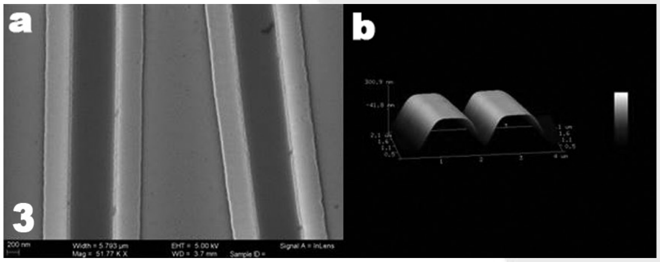

Figure 3: a) SEM image after silicon mask removal of a waveguide and ring resonator with noticeably low surface roughness and sidewall profile. b) AFM 3D image of the waveguide.

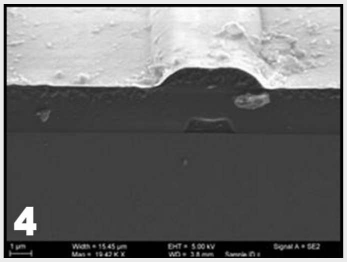

Figure 4: SU-8 waveguide after polishing.

Results:

The silicon mask, shown in Figure 2, has an acceptable sidewall profile and low surface roughness making it a promising hard mask. FOX-16 e-beam resist yielded the most favorable process for the two mask thickness based on field-emission scanning electron microscope (FESEM) images. The thicker resist layer protected the mask from being damaged by the RIE process.

The LN etch resulted in a smooth sidewall, which is important for the confinement of light in the waveguide, see Figure 3. The surface roughness of the structure (Figure 3) was a root mean square (rms) of 0.549 nm surface and 3.52 nm profile as measured with a Vecco NanoMan atomic force microscope. These values represent a relatively low surface roughness compared to results obtained using other fabrication methods. Based on these results, it may be concluded that the silicon mask thickness played an important role on surface roughness. The 800 nm silicon mask yielded a smoother sidewall profile and surface than the 600 nm mask due to better resistance to RIE damage.

Following the fabrication and optimization process, device integration using the SU-8 waveguides appeared to be greatly improved. The waveguides clearly extended to the edge of the sample, and are available to couple in light. The polished ends, as shown in Figure 4, will also be sufficient to not scatter the coupled laser light.

Conclusions:

Fabrication of LN devices with smooth sidewalls and a high aspect ratio has been demonstrated by using a silicon hard mask and RIE. This method has been used to show the potential to fabricate both ring resonators as well as a photonic crystal cavity structures using a silicon mask accompanied by RIE. The next step for the silicon mask process will be to optimize the mask thickness and the LN RIE process to create a steeper sidewall by tuning the RF power [1]. After the LN etch has been optimized, the quality factor, coupling coefficient between the resonator and the waveguide, and the laser coupling coefficient for the SU-8 will be tested. The design process can then be modified to deposit electrodes in order to electrically tune the resonator so as to create a fully functional and tunable modulator for potential use in telecommunications.

Acknowledgments:

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References:

[1] S. Benchabane, L. Robert, J. Rauch, A. Khelif, V. Laurde, "Highly selective electroplated nickel mask for lithium niobate dry etching," J. of Applied Physics, Vol. 105, pp (094109-1)-(094109-6) (2009).

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