Lithium Niobate Micromachining for On-Chip Photonics

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Introduction

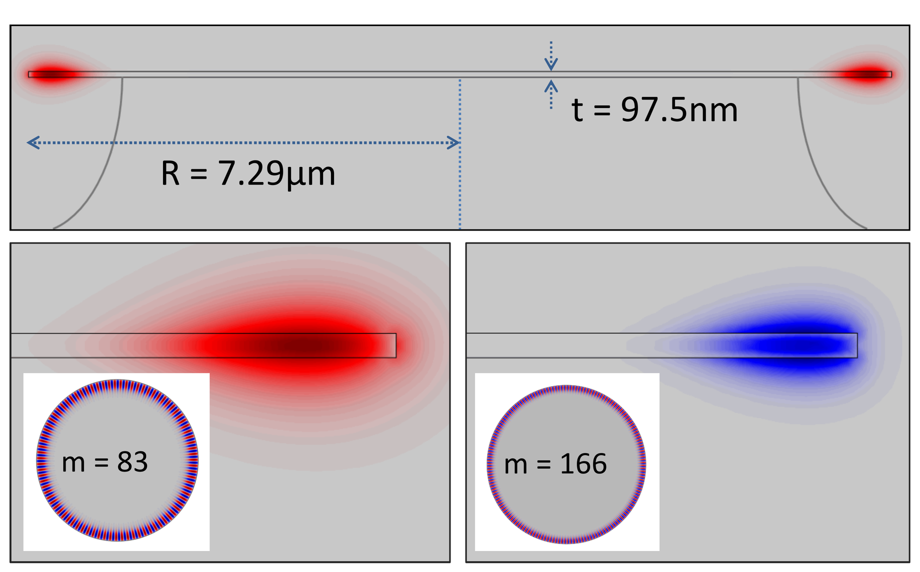
Lithium niobate ($LiNbO_3$) is an important material for many applications. In particular, its large nonlinear optical and electro-optic coefficients have led to its use in laser frequency conversion, optical modulation, and a variety of other photonics applications.

We present a method which uses standard fabrication technology to produce on-chip optical devices from $LiNbO_3$. Microdisk resonators are micromachined from bulk wafers using ion implantation and a combination of wet and dry etching. We optically characterize whispering gallery modes of the microdisks via a tapered optical fiber coupler, measuring a maximum unloaded quality factor of 7,000. We also present an application of this technology for phase matched second harmonic generation in microdisk resonators.

Application - Nonlinear Optics

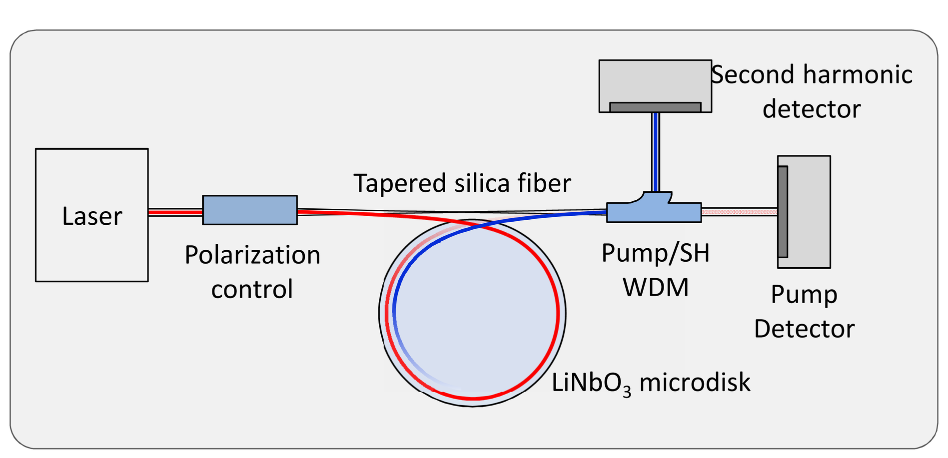
The fabricated $LiNbO_3$ microdisks provide a platform for demonstrating nonlinear optical effects. For example, the dimensions of the disks can be chosen to realize efficient second harmonic generation (SHG).

Below a critical thickness of ~100nm, geometric birefringence of whispering gallery modes becomes so great that a radially polarized cavity mode at 738 nm can be perfectly phase-matched to a vertically polarized mode at 369nm at room temperature (numerically simulated modes shown to the left).



Simulated pump (738nm) and second harmonic (369nm) modes of a $LiNbO_3$ microdisk. Geometric dispersion allows the two modes to be phase matched.

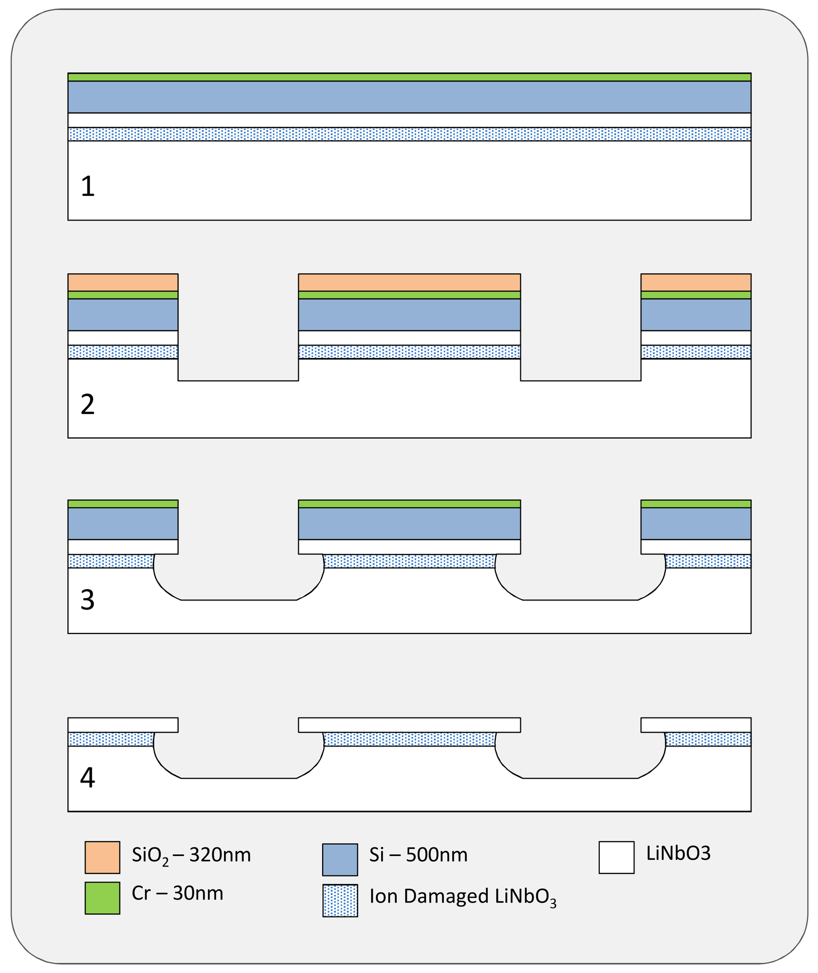
Using the cross-polarized second-order nonlinear optical coefficient, the combination of perfect phase matching and resonant conversion enhancement can allow for efficient on-chip SHG from a low power, CW source.



Schematic of setup for SHG in a microdisk resonator

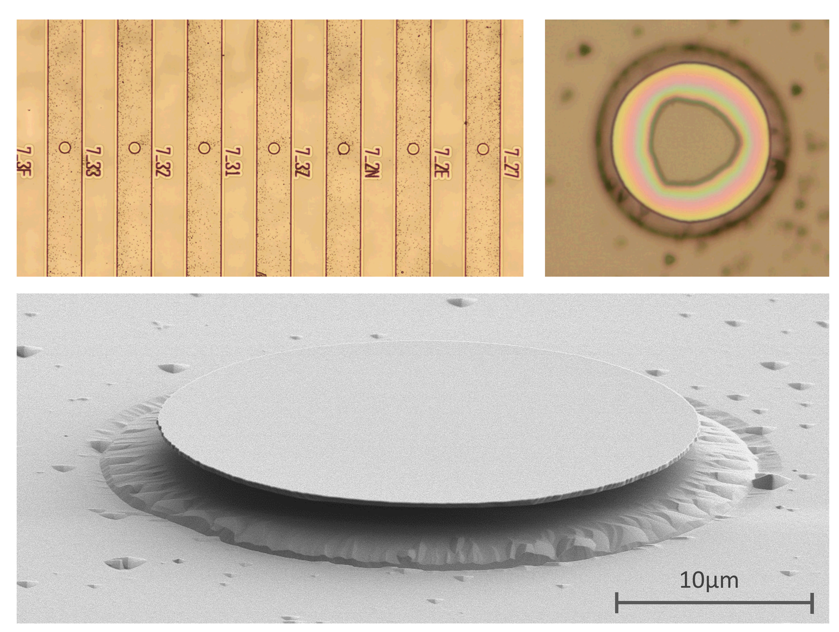
Fabrication

Fabrication begins with a z-cut MgO:$LiNbO_3$ wafer. A combination of ion implantation, reactive ion etching, and wet etching in hydrofluoric acid (HF) produces suspended structures.



Micromachining process for $LiNbO_3$ on-chip photonic structures

1) Ion implantation creates a damaged layer in $LiNbO_3$. Silicon and chromium control the implant depth in the $LiNbO_3$ and protect the surface from ion implantation damage.
2) Silicon dioxide is deposited as a hard mask and patterned with a reactive ion etch. A second RIE transfers the oxide hard mask pattern deep into the $LiNbO_3$ (past the damaged layer).
3) HF undercuts the etched pattern to create suspended structures supported by posts.
4) Si, Cr, and SiO_2 are stripped to complete the fabrication.



Fabricated $LiNbO_3$ microdisks

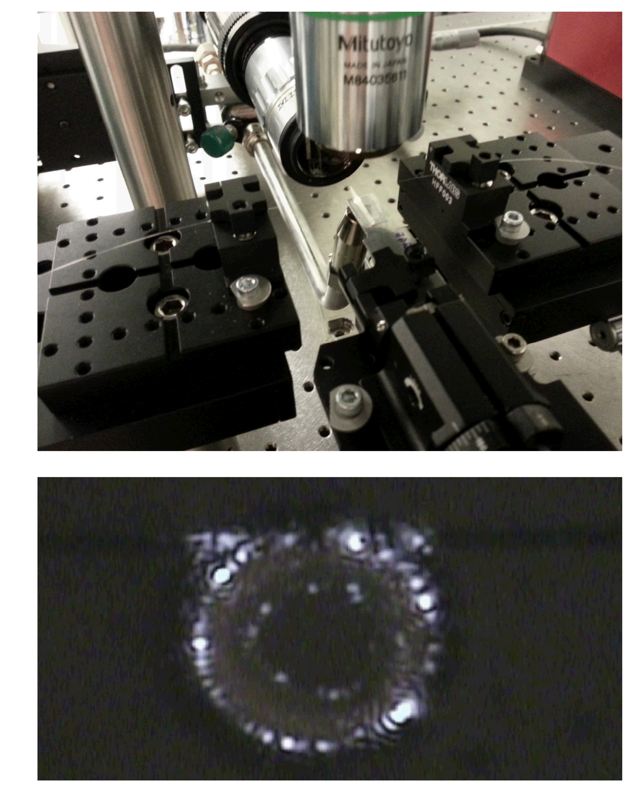
Fabricated microdisks are shown to the left.

Optical Characterization

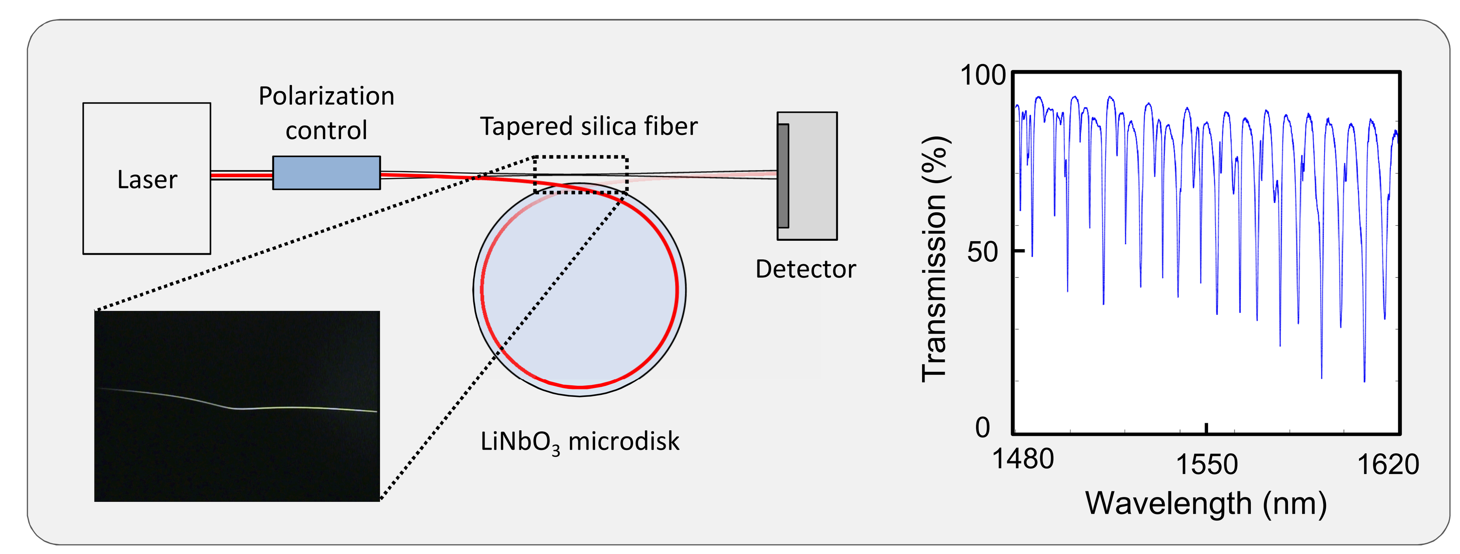
$LiNbO_3$ microdisk resonators are fabricated and optically characterized. We observe whispering gallery modes around 1550nm, with a maximum unloaded quality factor of 7,000.

The microdisks are probed with a tapered optical fiber. A standard SMF-28 fiber is stretched over a hydrogen flame, reducing its diameter to approximately 1µm. In the narrow tapered region, laser light is no longer confined completely inside the fiber and propagates partially in the air. When the edge of the microdisk is placed near the taper, light evanescently couples to whispering gallery modes of the disk.

In order to place the fiber near the disks, the tapered region is "dimpled" by pushing a cylindrical mold against the fiber and annealing. The tapered region then dips below the rest of the fiber.



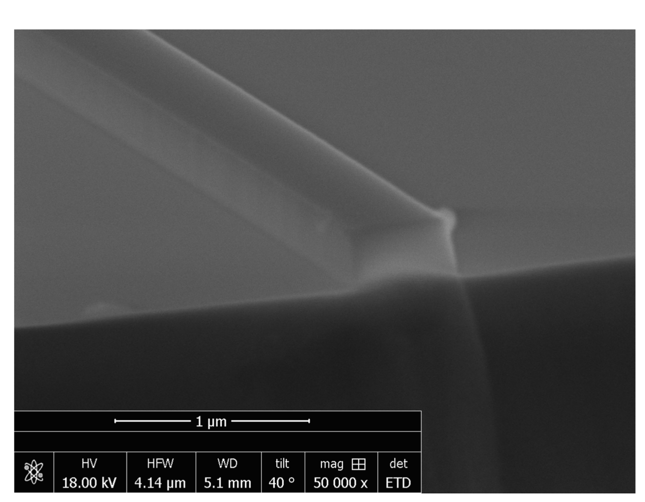
Optical fiber tapering apparatus (top) and 780nm light scattering from disk edges after coupling from the tapered fiber (bottom)



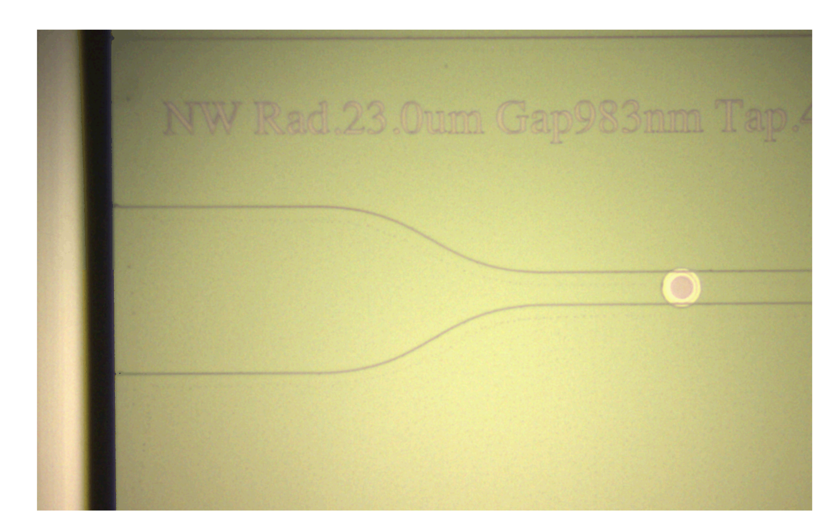
Schematic of measurement setup (left), micrograph of dimpled taper (lower left) and optical transmission spectrum of $LiNbO_3$ microdisk at 1550nm (right)

Conclusion and Future Work

The presented $LiNbO_3$ micromachining process provides a platform for producing on-chip photonic devices, including the microdisk resonators described above. A tapered fiber coupler provides a means of optically interrogating the microdisks, allowing the potential demonstration of phase matched second harmonic generation and other nonlinear optical effects. The development of on-chip waveguides which couple efficiently to fiber v-groove arrays will provide a more robust interface between the fabricated photonic devices and the light source. Processes developed at CINT in silicon nitride produce on-chip waveguides (right) with smoothly etched end facets (left) to provide efficient coupling (-1.4dB) on and off the chip.
We plan to design similar waveguide and coupling structures using the $LiNbO_3$ process described here.



Etched facet of silicon nitride waveguide for fiber to chip coupling, fabricated at CINT.



Silicon nitride microdisk with waveguides running to the chip edge, fabricated at CINT.

The authors would like to thank Matthew Tomes and Ian Frank for providing the Si_3N_4 device images.