Highly-Selective Etching of Micro-Transfer-Printed Thin-Film Lithium Niobate for Low Coupling Losses

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Abstract: Efficient low-loss coupling to micro-transfer-printed lithium niobate remains a challenge. We developed a highly-selective lithium niobate etch that enables selective etching of tapered coupling structures into the lithium niobate thin film after micro-transfer printing.

Introduction

Micro-transfer printing of thin-film lithium niobate (LN) introduces high-speed modulation and efficient frequency conversion to the silicon photonics platform at a back-end level [1, 2]. For modulators, low insertion losses are desired, while for nonlinear and quantum processes, such as the generation of squeezed states, losses can be extremely detrimental. Therefore, efficient coupling to the printed lithium niobate slabs is crucial. Conventional LN etching is based on argon milling, but has very low selectivity due to the sputtering nature of the process. This makes it difficult to use on transfer-printed lithium niobate without damaging the exposed silicon photonics circuit underneath. In this work, we have developed a highly-selective wet etch that allows us to pattern tapered coupling structures into transfer-printed lithium niobate thin films.

Highly-selective lithium niobate etch

The developed wet etch consists of NH_4OH:H_2O_2 (1:4), which etches lithium niobate at an average rate of 10 nm/min at 85 °C. We measured a selectivity of 30 relative to SiO_2, implying that a 100 nm oxide hard mask is sufficient for fully-etched LN waveguides. In contrast, argon milling has a typical selectivity of 1 which makes the fabrication of fully-etched waveguides challenging. Due to the chemical nature of the etch, some anisotropy is observed, as seen in Figure 1a for x-cut LN. The RMS roughness after etching 300 nm LN is measured to be 0.33 nm (Figure 1b), which conforms with earlier reported propagation losses of 0.2 dB/cm and Q-factors of 10^6 [3, 4].

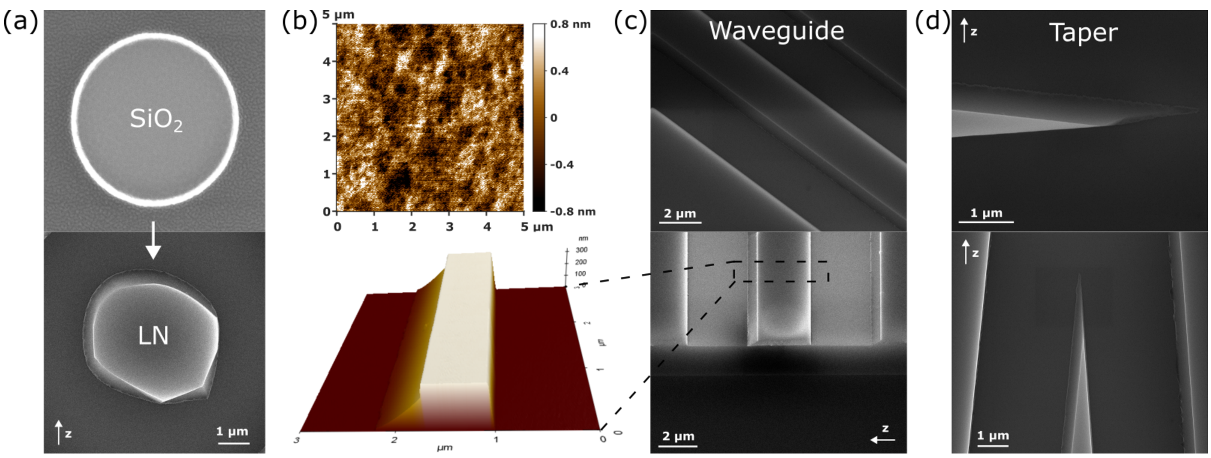

Fig. 1. (a) Anisotropy of LN etch: (top) SiO_2 hard mask, (bottom) resulting LN pattern, (b) AFM roughness measurement, (c) SEM and AFM images of patterned waveguides, (d) SEM images of patterned inverted tapers.

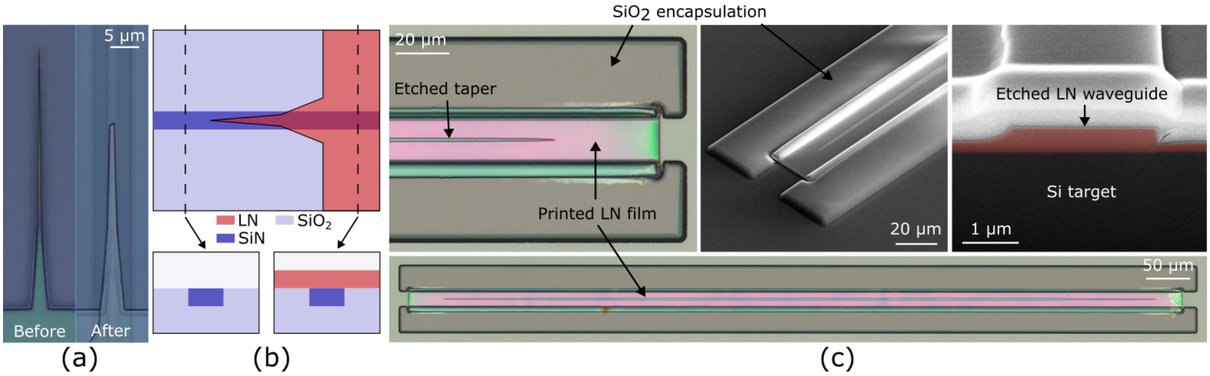

Fig. 2. (a) LN taper before and after the transfer process, (b) Sketch of a tapered coupling structure to the LN film, (c) Microscope and SEM images of LN films etched after printing: (left) an etched taper, (middle) SEM of etched LN taper, (right) cross section of an etched LN waveguide, (bottom) a 1 mm printed LN film with etched tapers and waveguide.

To demonstrate patterning of the thin-film lithium niobate, we start from a LNOI stack (300 nm x-cut LN/ 2 µm SiO_2 / Si) and fabricate waveguides (Figure 1c) and inverted tapers (Figure 1d). Due to the low roughness and controlled etching, sharp taper tips can be fabricated that allow for adiabatic transitions.

Patterning inverted tapers in transfer-printed lithium niobate thin films

During the transfer-printing process, a suspended lithium niobate thin film is picked and printed on a silicon photonics target wafer with a PDMS stamp. Due to the mechanical requirements of the transfer, pre-fabricated inverted tapers can be too fragile for suspension or the transfer itself, causing them to break (Figure 2a). Nevertheless, a mode transition must be made for low-loss coupling, as sketched in Figure 2b. The selective wet etch allows for patterning of tapered coupling structures after the transfer printing without damaging the photonic circuit underneath. This significantly increases the yield of the transfer process due to the absence of fragile taper structures. Additionally, the wet-etched coupling structures rely on electron-beam lithography alignment to e.g. the silicon nitride waveguide below and are not limited in length. In contrast, pre-fabricated tapers must be short to be mechanically robust and misalignment-tolerant due to the transfer-printing accuracy ($\pm$ 500 nm 3σ) [5]. Figure 2c shows images of transfer-printed lithium niobate films that are patterned after printing with the wet etch. Silicon oxide is deposited at the sides to protect the bonding interface between the film and the target. Long inverted tapers and waveguides are etched, and a cross section is shown of a rib waveguide on top of the silicon target, which resembles the waveguides in Figure 1c.

Conclusion

We have developed a lithium niobate wet etch with high selectivity and low roughness, which can be used to etch fully-etched waveguides and sharp taper tips. We have demonstrated its compatibility with micro-transfer printing and have fabricated waveguides and tapered coupling structures on transfer-printed lithium niobate slabs. This method will enable us to couple efficiently to heterogeneously-integrated high-speed modulators and other nonlinear components on the silicon photonics platform.

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