Wafer Scale Texturing of $LiNbO_3$

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We report a novel technique for micro texturing of $LiNbO_3$. Well-defined raised ridges and etched trenches are demonstrated. This technique is suitable for the realization of surface relief gratings and photonic crystals.

OCIS codes: (130.3730) $LiNbO_3$; (310.1860) deposition and fabrication

Lithium Niobate ($LiNbO_3$), is an industry standard for guided wave optical devices. This is due to its excellent electro-, acousto- and nonlinear optical properties, coupled with well established techniques for fabrication of low-loss optical waveguides. Recently, surface machining of $LiNbO_3$ has become an important technology for the realization of efficient modulators [1], gratings [2] and even photonic crystals[3].

Several surface machining techniques have been demonstrated. These include including Focused Ion Beam etching[4], Reactive Ion etching[5], wet chemical etching[6] and Laser ablation[7]. These techniques often only produce very shallow etch depths, can produce significant surface roughness and can be difficult to control due to the appearance of crystal facets. Each of these techniques also requires either a photolithographic masking process (limiting resolution) or must be achieved using direct writing (limiting scaling to wafer scale manufacture).

In this work, we demonstrate a novel technique for micro-texturing $LiNbO_3$. We present the first demonstration of wafer scale etching of $LiNbO_3$ using a novel electro-chemical process that occurs simultaneously with Ti in-diffusion. This has potential for the realization of etched trenches and waveguide facets and should be equally applicable to nano-scale features such as gratings and photonic crystals.

Our technique is based on the well established Ti diffusion process for optical waveguide fabrication in $LiNbO_3$. The Ti diffusion process is quite complex and has been studied by many authors. D. P. Birnie[8] presents an theoretical model for the diffusion process, describing the migration pathway for ions on either the lithium or niobium sub-lattices. An important conclusion of this theory is that during diffusion, the swapping of ions results in increasing positive charge on the Ti rib as it diffuses into the $LiNbO_3$ crystal. Our hypothesis is that the charging of the Ti strip will create a significant electric field. We propose that this field will be strong enough to dissociate high-temperature (1050°C) gases into their constituent ions. These energetic ions will drift under the influence of the fields, and will enhance both etching and deposition of material at various locations during diffusion. The fields will be localized to the Ti strips and thus any enhanced etching or deposition should be localized to these regions also.

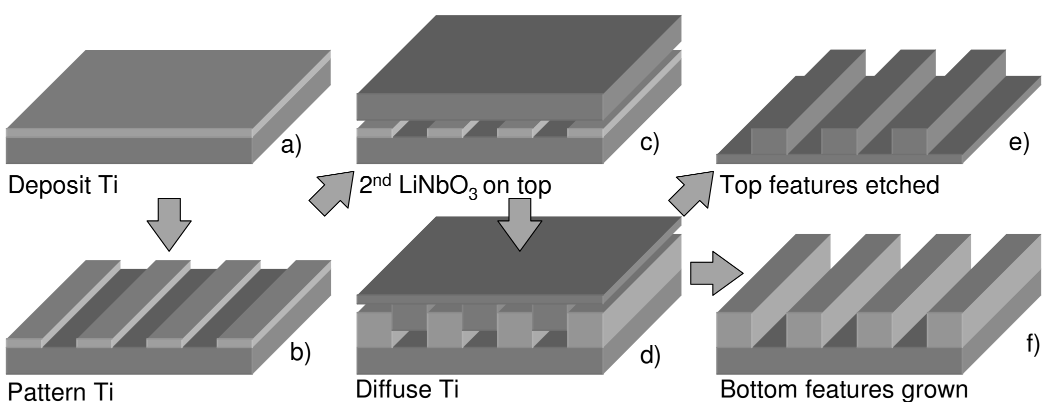

FIG 1: Method: a) Deposit 1000A Ti film on X-cut $LiNbO_3$, b) Pattern Ti c) 2nd $LiNbO_3$, wafer is placed on top d) diffusion at 1050C for 10 hrs in wet oxygen, samples separated into e) Top wafer with etched features (2300A), f) Bottom wafer with raised features (2500A).

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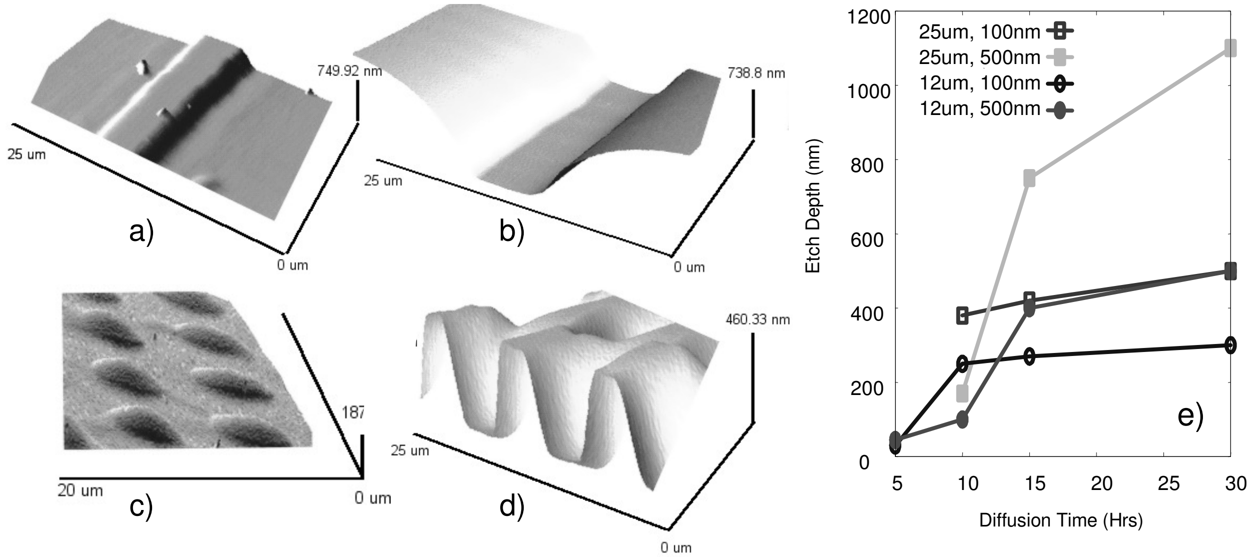

FIG 2: Atomic Force Microscope images of textured profiles in $LiNbO_3$ a) Raised strip feature on bottom wafer, b) etched strip feature on Top wafer, c) raised array of discs on bottom substrate, d) etched discs on top substrate, e) etch depth vs diffusion time for various conditions.

Figure 1 presents a schematic diagram of our experimental procedure. A layer of Ti (either 1000 Å or 5000 Å) was deposited on an X-cut $LiNbO_3$ substrate using e-beam evaporation (Fig 1a). Contact photolithography and chemical etching was used to pattern the Ti layer into strips of width ranging from 12μm to 25μm. (Fig 1b). In a departure from the traditional diffusion procedure, a bare $LiNbO_3$ wafer was placed on top of the strips (Fig 1c). The small air gap between the charged Ti strips on the bottom substrate and the uncharged top wafer will enable a strong, well localized field to form The two wafers were then heated to 1050˚C in a wet oxygen atmosphere for periods of 5, 10, 15 and 30 hours (Fig 1d). The two wafers were then easily separated (Figs 1e & 1f).

Figure 2 presents Atomic Force Microscope images of the two wafers. On the bottom wafer, Ti patterned regions were raised (Figs 2a & 2c). The bare top wafer exhibited significant etching in the regions where it had been in contact with the Ti strips (Figs 2b & 2d). The etched profiles were relatively smooth and well defined. The experiment was repeated for strip thicknesses of 1000 Å and 5000 Å, widths of 12μm and 25μm and diffusion times of 5, 10, 15 & 30 hrs. The resulting etch depths are presented in Fig. 2 e). The results show that the etch depth increases with diffusion time eventually saturating. Etching in excess of 1μm is possible.

The observed etching and deposition only in the regions of Ti patterning support our hypothesis of ion enhanced material interactions. Rigorous materials analysis is currently underway to isolate the electro-chemical processes that are responsible for forming these textures. The saturation of etching suggests that etching ceases once the Ti has been exhausted. This is supported by the fact that longer diffusion times are required to saturate the effect for thicker strips. These observations support the hypothesis that the etching is electrochemical.

Since this texturing is uniform across the wafer, it is anticipated that it will scale well to a full wafer manufacturing process. Further, we believe that the resolution will be limited by the texturing that can be achieved on the Ti film. Techniques to realize nanometer features such as gratings are currently being explored.

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