Stress reduction and wafer bow accommodation for the fabrication of thin film lithium niobate on oxidized silicon

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Sub-micrometer thick lithium niobate on insulator (LNOI) is a promising integrated photonic platform that provides optical field confinement and optical nonlinearity useful for state-of-the art electro-optic modulators and wavelength converters.[1] Bonding to a silicon substrate is advantageous for electronic-photonic integration but is challenging because of debonding and cracking due to thermal expansion coefficient (TEC) mismatch between Si and LN. In this work, fabrication of ion sliced LNOI on a Si handle wafer is achieved by selecting optimized wafer thicknesses informed by structural modeling and accommodating for dissimilar wafer bows using a bonding apparatus.

Figure 1 shows an LN-oxide-Si structural finite element analysis of strain energy and stress, due to TEC mismatch at elevated temperatures, in the absence of He^+ implantation. The LN donor wafer and Si substrate diameters are 3 and 4 inches, respectively, and the oxide is 4 μm thick. High strain energy and stress can result in debonding and cracking, respectively,[2] therefore the analysis in Fig. 1 shows that thinner LN wafers are expected to be more robust at elevated temperatures required for exfoliation.

For ion-slicing, an x-cut LN donor substrate of 0.25 mm thickness is implanted with He^+ ions at 225 keV with a fluence of 3.5×10^{16} cm^{-2}. A die of implanted LN and a thermally oxidized Si handle wafer are cleaned using wet chemistry and directly bonded at room temperature. Thin implanted LN exhibits large wafer bow, relative to the bow of thick implanted LN. Bonding of the 0.25 mm thick LN die is facilitated, however, though a jig that deforms the Si handle to match the bow of the LN sample, verified by surface profilometry shown in Fig. 2. The bonded pair is annealed at 188 °C to exfoliate and transfer the LN thin film onto the oxidized Si wafer. Successful cm-scale film transfer is achieved. Figure 3 shows a transferred LN film thickness of 817 nm and an RMS surface roughness of 5.6 nm, measured by atomic force microscopy. Film thickness measurements agree with Transport of Ions in Matter (TRIM) calculations of 807 nm. A scanning electron micrograph of fabricated LNOI is shown in Fig. 4.

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[1] C. Wang, M. Zhang, X. Chen, M. Bertrand, A. Shams-Ansari, S. Chandrasekhar, P. Winzer, and M. Lončar, Nature **562**, 7725 (2018).

[2] C. Wang, Y. Li, Y. Liu, Z. Yuan, Y. Tian, C. Wang, and T. Suga, ECS Transactions **77**, 143 (2017).

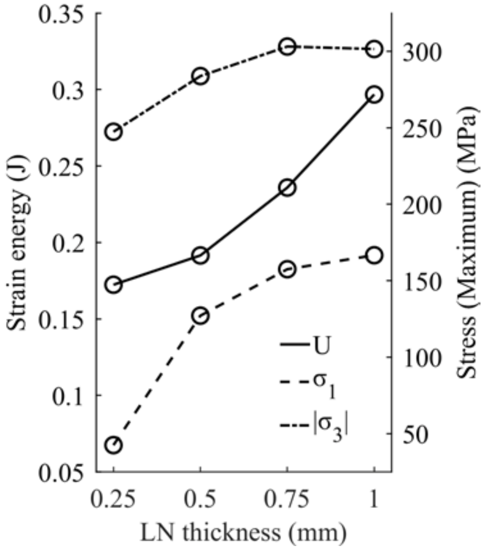

Figure 1. Computed total strain energy U, principal normal stress σ_1, and principal in-plane stress σ_3 of the LN wafer versus thickness at 190 °C. The Si thickness is 0.525 mm. The 0.25 mm thick LN exhibits the lowest strain energy and stress.

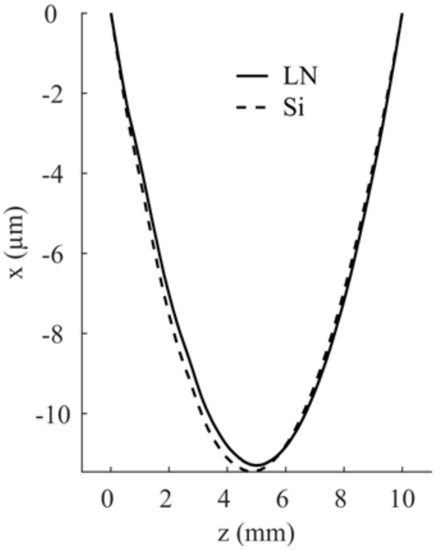

Figure 2. Surface profilometry of LN donor and deformed silicon handle wafer. Debonding of a 0.25 mm thick LN die is reduced by utilizing a jig that deforms the Si handle to match the bow of the implanted LN sample.

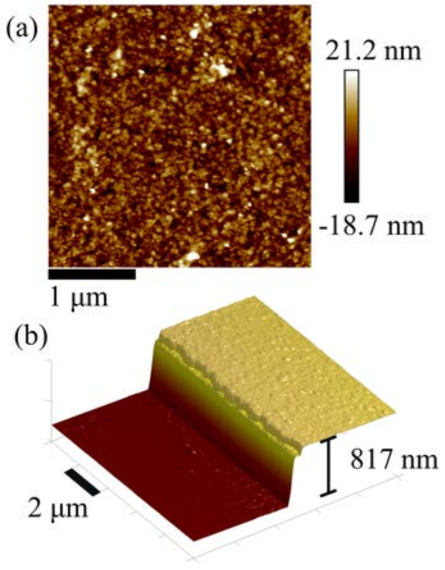

Figure 3. Atomic force microscopy scan of (a) surface and (b) edge of ion-sliced LN bonded to oxidized silicon wafer. Measured thickness agrees with TRIM calculations.

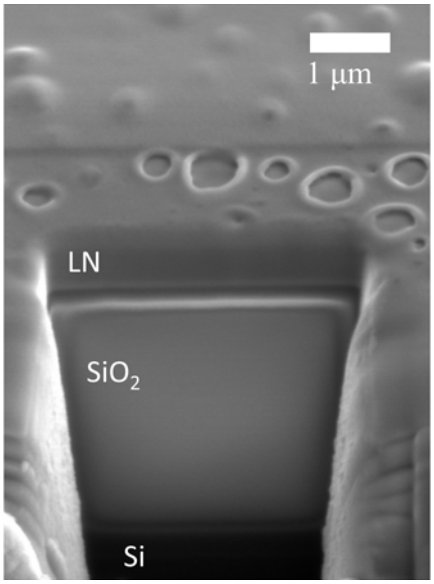

Figure 4. Cross-sectional scanning electron micrograph of LNOI on Si prior to chemical mechanical polishing. Helium blistering is visible on the surface.