Crystal Anisotropy in Surface Energy Engineering (SEE) of $LiTaO_3(110)$ Piezo-Electric for Low Temperature (< 453 K) Nano-Bonding™ to Si and α-Quartz SiO_2

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GOAL: This project's goal is to bond *anisotropic* $LiTaO_3$ to Si via Nano-Bonding™,[1-2], which aims to minimizes thermal stress during bonding and maximizes density molecular cross-bonds via Surface Energy Engineering (SEE). SEE planarizes surfaces at three length scales to achieve direct "nano–contact", at the nano-, micro-, and macro-scale. SEE uses Three Liquid Contact Angle Analysis (3LCAA) and the van Oss-Chaudhury-Good theory to measure hydro-affinity (HA) and surface energies (γ^T). These indicate the degree of interaction between surfaces. 3LCAA can map γ^T along different crystal orientations, thus detecting the effect of $LiTaO_3$'s anisotropy on SEE and Nano-Bonding™.

EXPERIMENTAL RESULTS OF NANO-BONDING™ $LiTaO_3$ TO SI:

Hydrophobic $LiTaO_3$ nano-bonds at RT in air to hydrophilic SiO_2[2]. During nano-contacting, the nano-bonded area increases over time, but the bonding is non-uniform[2] as shown in **Fig.1**.

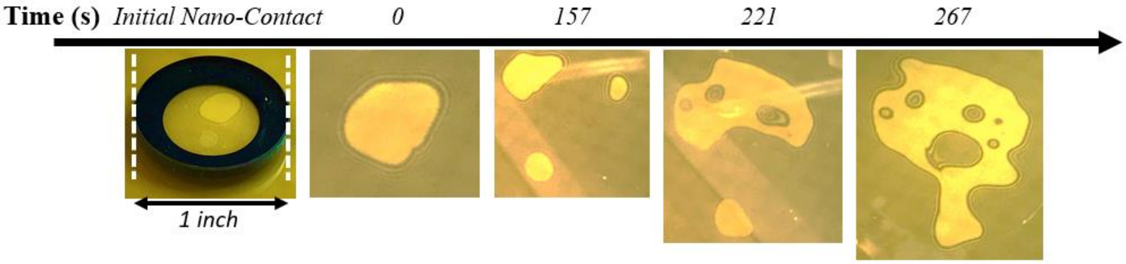
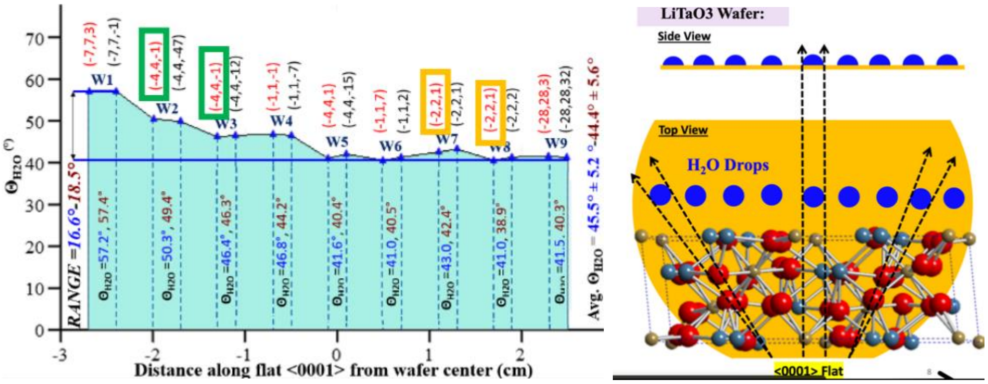


Fig. 1 *Optical obsvervation of nano-bonded area between $LiTaO_3$ and α-Quartz SiO_2 changing over time.*

QUANTIFYING THE ROLE OF ANISOTROPY: To understand how $LiTaO_3$'s anisotropy plays a role in Nano-Bonding™ of $LiTaO_3$ to Si, elliptical distortion of the 3LCAA drops is measured in addition to water contact angle (θ_{H2O}) and Surface Energy (γ^T) as a function of crystal orientation, as shown in **Fig.2**.

RESULTS AND INTERPRETATIONS:



(a) **(b)**

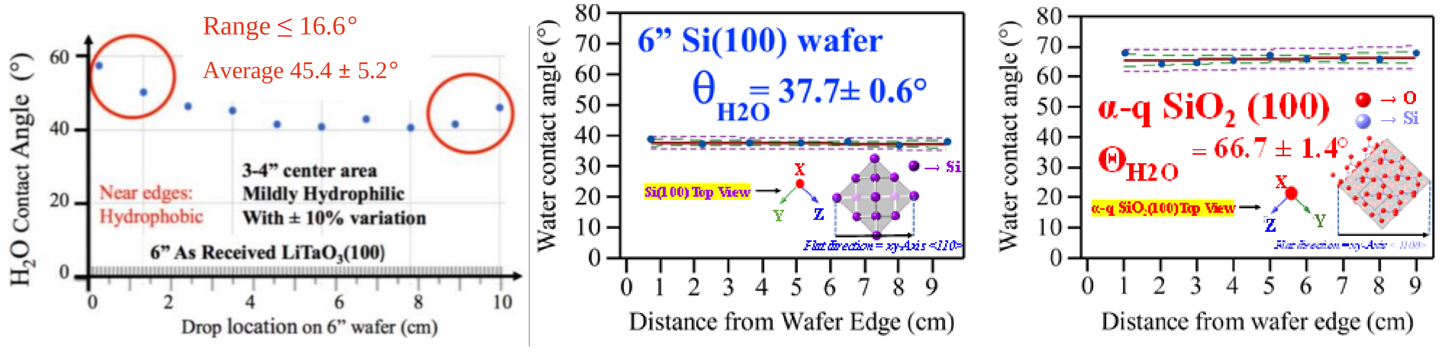
Fig.2 (a) *and* ***(b)*** *θ_{H2O} mapping across 15 crystal planes intersecting $LiTaO_3$ before SEE.*

Fig. 2 (a) shows θ_{H2O} mapping across 15 crystal planes intersecting $LiTaO_3$ before SEE. This shows that θ_{H2O} varies significantly, by 40%, with crystal direction when mapped across a 150 mm (6") $LiTaO_3$ (100)

[1] US & International Patents Herbots N et al., n° 6,613,677 (2003); 7,851,365 (2005); 9,018,077 (2015); 9,589,801 (2017)

[2] Baker, B et al., J. Vac. Sci. Tech. A37, no. 4 (2019): 041101

wafer diameter. It averages 45 ± 5.4° along <0001> direction intersecting the (110) surface plane, with a range, R, of 17 ± 1°. This is a significant variation as R is > $3\sigma = 3 \times 5.4° = 16.2°$. The Miller indices of the crystal planes in (a) intersecting the location where each of the eighteen θ_{H2O} are measured, are listed and (b) depicts how measured θ_{H2O} correlates to crystal direction. θ_{H2O} is measured four times for the (-4,4,-1) plane, averaging 48.1 ± 1.8°, and the (-2,2,1) plane, averaging 41.3 ± 1.6°. This shows that with 4 data points, the experimental error is 1.7° for these two planes, 10 x less than the measured range R.



(a) **(b)** **(c)**

Fig. 3 *Comparison of water contact angle θ_{H2O} mapped across* ***(a)*** *$LiTaO_3$* ***(b)*** *Si, and* ***(c)*** *α-Quartz SiO_2 wafers highlighting the uniformity of θ_{H2O} on Si and α-Quartz SiO_2 versus the non-uniformity $LiTaO_3$.*

Fig.3 compares θ_{H2O}'s mapped across **(a)** 6" $LiTaO_3$ (110) along <0001> **(b)** 6" Si (100), and **(c)** α-Quartz SiO_2 (100). Si and SiO_2 exhibit much more uniform θ_{H2O} mapping than $LiTaO_3$ by at least a full order of magnitude. $LiTaO_3$'s intersecting crystal planes each represents a uniquely different chemical arrangement of atoms and stochiometric composition of elements, affecting the surface dipole and γ^T at each location on $LiTaO_3$ (110). In comparison, cubic Si (100) and almost cubic piezoelectric α-Quartz SiO_2 (which has also a trigonal like $LiTaO_3$, but with much closer a,b,c, lattice constants) don't have very different chemical structures based off of location on wafer, thus resulting in much more θ_{H2O} uniformity.

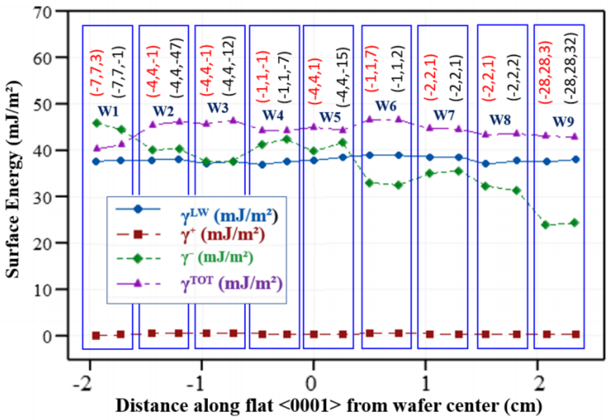


Fig. 4 *Mapping of total surface energy (γ^T) and its components (γ^{LW}, γ^+, γ^-), at each water drop position on the $LiTaO_3$ wafer. γ^T varies by ± 6%, which is significantly less than the 40% variation of θ_{H2O}.*

Fig. 4 shows that the variations in the electron acceptor γ^- and electron donor γ^+ cancel each other out, thus resulting in a rather uniform γ^T.

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