ETCH-A-SKETCH RESONATOR

[1]R. Wang, [1]S. A. Bhave and [2]K. Bhattacharjee
[1]Cornell University, Ithaca, NY, USA
[2]RF Micro Devices Inc., Greensboro, NC, USA

ABSTRACT

This paper demonstrates AFM-based post-release piezoelectric domain engineering [1] on a Lithium Niobate (LN) MEMS resonator. We "Etch-A-Sketch" a poling pattern on the membrane resonator that redefines the electro-mechanical coupling of the mechanical vibration modes. This technique introduces a new resonance peak at 681 MHz to the original un-poled admittance spectrum of the resonator. In addition, this method only requires 80V (magnitude) to achieve domain inversion, which is over 100× lower than the poling voltage required for bulk LN.

FABRICATION PROCESS AND DEVICE CONCEPT

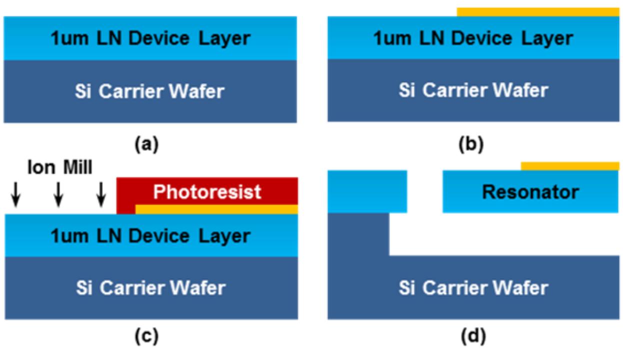

Figure 1. Fabrication of Etch-a-Sketch resonator: (a) Lithium Niobate thin-film bonded to Si substrate. (b) Top gold electrodes are defined by lift-off, (c) ion milling etches the LN to define device geometry, and (d) XeF_2 is used to release the resonator.

Fabrication of the Etch-a-Sketch resonator begins with a 1µm thin[2] white LN thin film directly bonded on a Si substrate, with crystal z-axis normal to plane of the wafer. Z-cut LN does not provide modes with high coupling coefficient, k_{eff}^2, that can be easily excited using interdigitated transducers (IDT). However, we chose this cut for a proof-of-concept demonstration as domain inversion is well-studied on z-axis LN [1]. Top electrodes are defined by lift-off, followed by ion milling through the LN film with a photoresist mask to define the resonator geometry [3]. Finally, the membrane resonator is released from the substrate using XeF_2 (Fig. 1). Fig. 2 shows an SEM of the released device, where the IDT fingers oriented perpendicular to the crystal y-axis

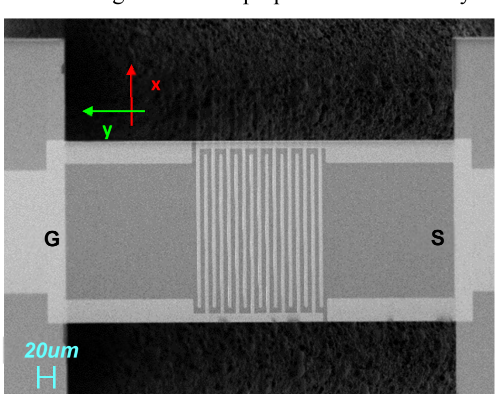

Figure 2. SEM of the z-cut LN Etch-A-Sketch resonator.

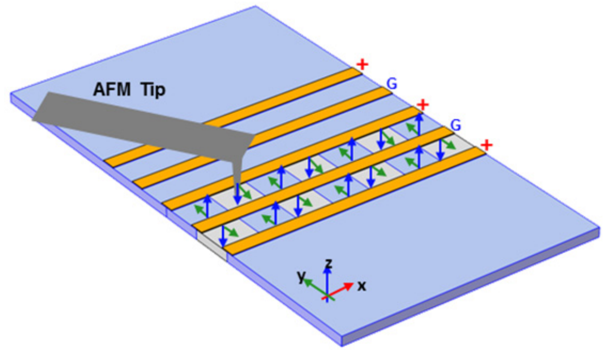

Figure 3. "Writing" the resonator frequency by AFM tip poling checkerboard patterns on the LN resonator. Green and blue arrows mark +y-axis and +z-axis domain directions respectively.

are spaced by 4.5µm. The width (x-direction) of the resonator is 72µm. Before performing domain patterning, the admittance of the resonator is measured as baseline for comparison with the admittance after poling.

An Asylum AFM system was used to perform the domain patterning of the resonator. The membrane was scanned continuously between the IDT electrodes in contact mode while applying periodic voltage to the AFM tip to invert the domain direction of the membrane in a checkerboard pattern (Fig. 3). A low spring constant (8N/m) solid platinum AFM tip (Model No.: 25Pt400B, Rocky Mountain Nanotech.) was used to minimize the stress on the membrane during domain writing, while providing good electrical contact.

In addition to excellent spatial control (25nm resolution), a key benefit of Etch-a-Sketch poling is the focused E-field from the sharp AFM tip which penetrates the thin film LN. This reduces the voltage required to achieve domain inversion relative to bulk LN poling by over 100×. In this work, 80V (magnitude) was sufficient to surpass the coercive field of LN [4], and ensured high contrast domain inversion. The poled domain pattern was verified by piezo-response force microscopy (PFM). Fig. 4 shows the phase of the piezo-response which exhibits a clear checkerboard pattern.

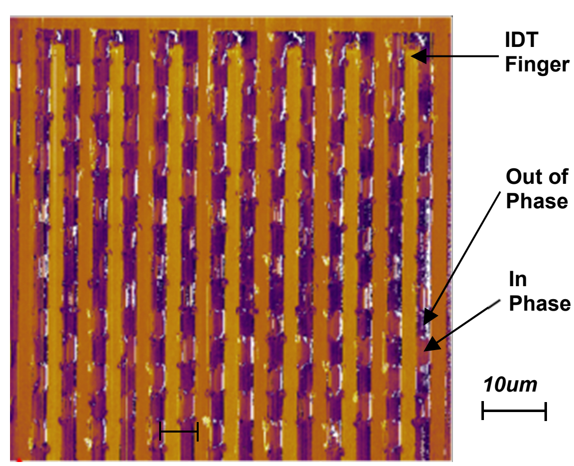

Figure 4. Phase response of the PFM after domain poling.

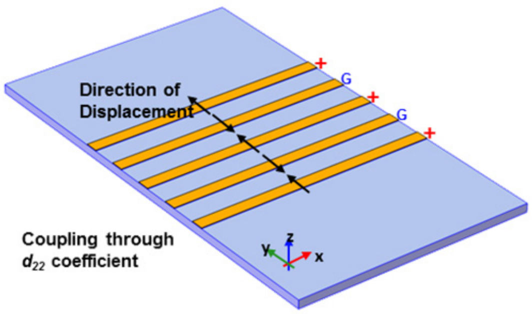

Figure 5. Without poling, E-field couples to mechanical motion in y direction through d_{22} coefficient.

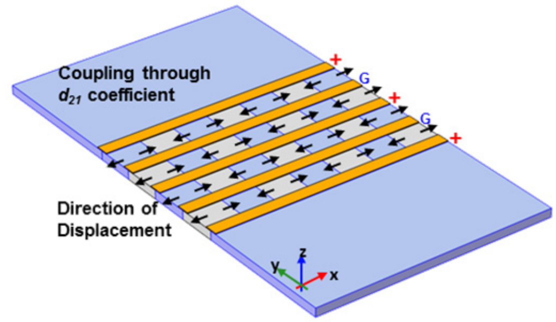

Figure 6. After poling, E-field couples to motion in x direction through d_{21} coefficient.

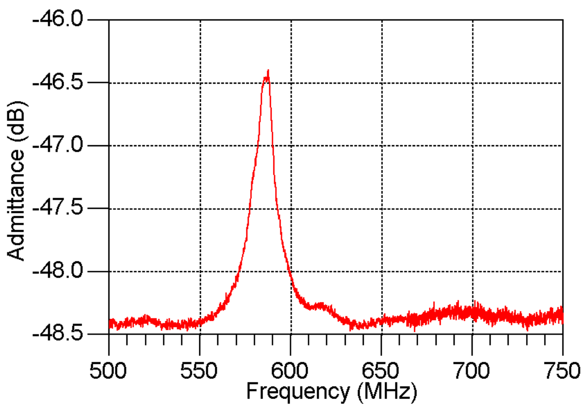

Figure 7. Admittance of the resonator before poling.

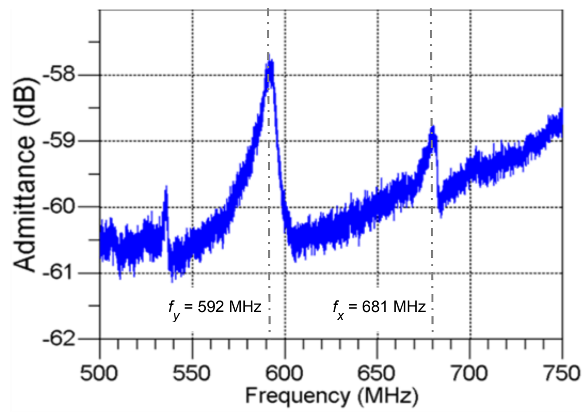

Figure 8. Admittance of the resonator after poling.

The poled pattern has a period of 4µm in the x-direction. The dark violet color indicates the thin film moves out of phase with the PFM excitation, and orange indicates in phase motion (opposite polarity). Metal electrode fingers appear in light yellow. It should be noted that as the domain inversion happens, both the y-axis and z-axis of the domain are inverted, while the x-axis remains unchanged [5].

In the absence of the periodically poled pattern, the primary resonance frequency is defined by finger spacing. The acoustic wave is excited through the d_{22} coefficient, and travels parallel to the crystal y-axis. Therefore, this device behaves like a traditional contour mode resonator without periodical poling (Fig. 5). After we Etch-A-Sketch the checkerboard pattern in the LN, the two domains with opposite crystal orientation bounded by two adjacent fingers are excited out-of phase in the x-direction through the d_{21} coefficient. Simultaneously, the two adjacent domains separated by electrode finger move in phase (Fig. 6) because both the E-field and crystal axis have opposite polarizations. As a result, all the domains move collectively as a high-order contour mode vibrating in the x-direction. In this case, the frequency is determined by the periodicity of the domain pattern. By writing domain patterns with different period, we can control the resonance frequency of the resonator.

EXPERIMENTAL RESULTS

RF characterization was performed in air using a standard 1-port measurement with signal configuration as indicated in Figs. 5 and 6. No de-embedding was performed. Fig. 7 shows the admittance of the device before poling, with a 592 MHz peak corresponding to the y-axis contour mode. This resonance matches well with analytical derivation for 4.5µm IDT spacing. Since the Etch-a-Sketch poling does not affect this mode, the 592 MHz resonance serves as a reference for mapping the frequency and wavelength of the resonance generated by domain patterning. Fig. 8 shows the admittance after domain patterning (4µm period in x-direction) which generates a new resonance at 681 MHz, next to the y-axis mode. As expected, the measured frequency ratio $f_x/f_y = 1.14$ between the two peaks is almost identical to the ratio of the IDT spacing and poling pattern (4.5µm/4µm = 1.125), validating the Etch-A-Sketch concept.

In conclusion, we demonstrated an Etch-A-Sketch resonator, in which resonance frequency can be programmed by "writing" periodic domains on the resonator with an AFM tip. Initial results from this device demonstrate targeted generation of x-axis resonance with predictable and controllable frequency. Integrated with AFM tip arrays (e.g. [6] by Intel), such devices can achieve wide range in-field tuning of the resonance frequency, and facilitate the realization of reconfigurable RF MEMS front-ends.

REFERENCES

[1] B. Rodriguez, et al., "Domain growth kinetics in Lithium Niobate single crystals studied by piezoresponse force microscopy," APL 86, 012906 (2005).

[2] S. Gong and G. Piazza, "High electromechanical coupling resonators using ion sliced X-cut LiNbO3 thin film," IEEE Microwave Symposium, pp. 1-3, 2012.

[3] R. Wang, et al., "High $k_t^2 \times Q$, multi-frequency Lithium Niobate resonators," MEMS 2013, pp.165-168, 2013.

[4] S. Kim, et al., "Coercive fields in ferroelectrics: a case study in Lithium Niobate and Lithium Tantalate," APL 80, 2740 (2002).

[5] T. Sono, et al., "Reflection second harmonic generation on a z-cut congruent lithium niobate crystal," PRB 74, 205424 (2006).

[6] S. Severi, et al., "CMOS-integrated poly-SiGe cantilevers with read/write system for probe storage device," Transducers'09, pp. 2409-2412, 2009.