Th1E-1

# A mm-Wave Trilayer AlN-ScAlN-AlN Higher Order Mode FBAR

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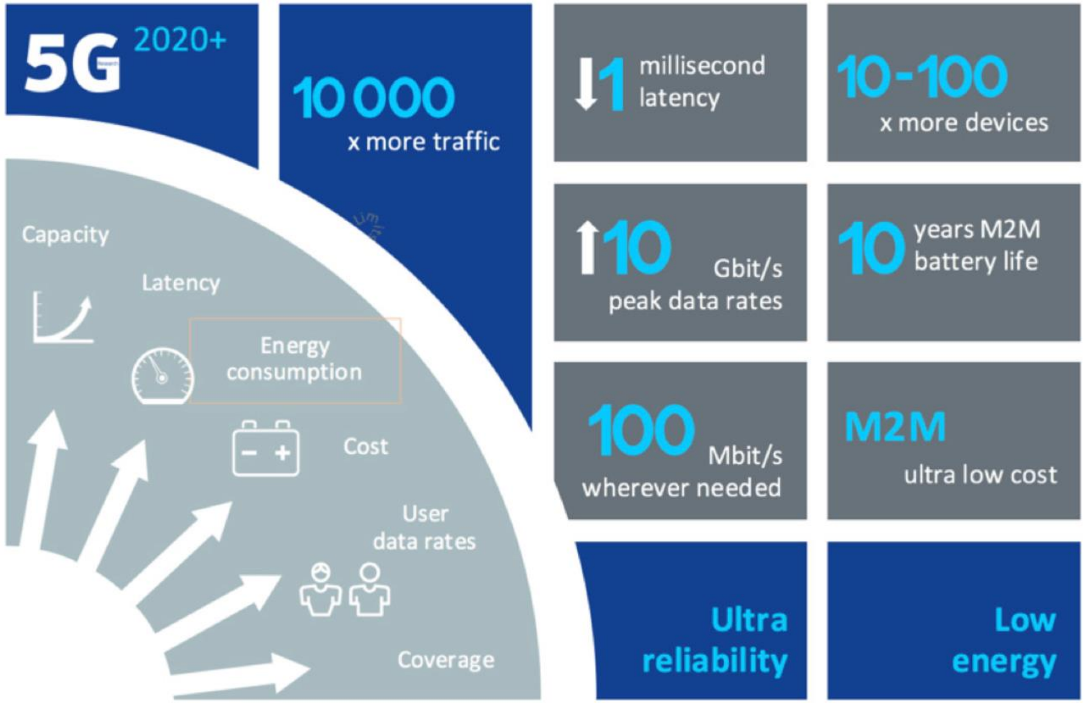
# Outline

- Introduction
- Trilayer FBAR Design
- Fabrication Process
- Experimental Results
- Conclusion

# Motivation



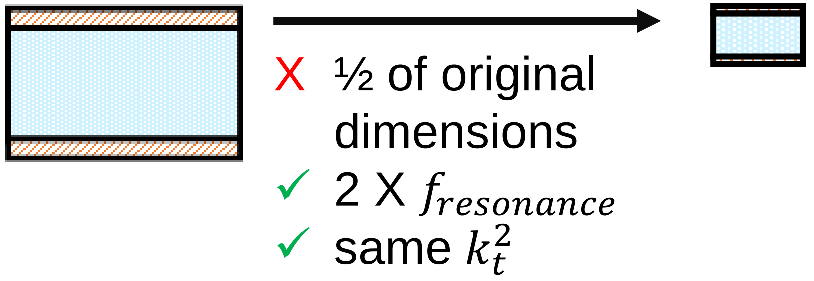
- **No competing technology for acoustic filters** in a mobile phone (cost, size)
  - Current cellphones contain hundreds of piezoelectric resonators and RF switches
- 5G technologies requires greater performance from front-end filters
  - Support for legacy bands as well as new bands (below 6 GHz and higher frequencies **with wide transmission bandwidths**)



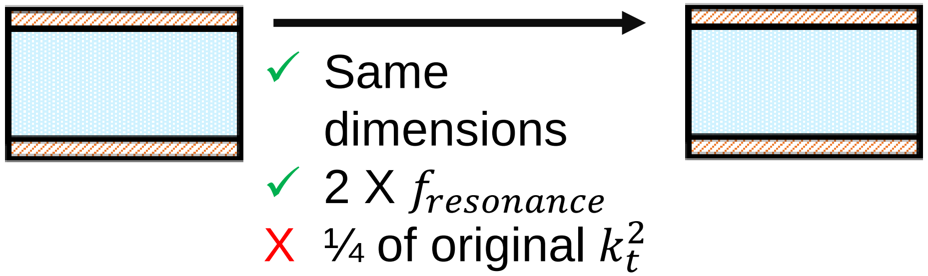

AWR white paper: 5G Communications

# RF Acoustics Scaling to mm-Wave

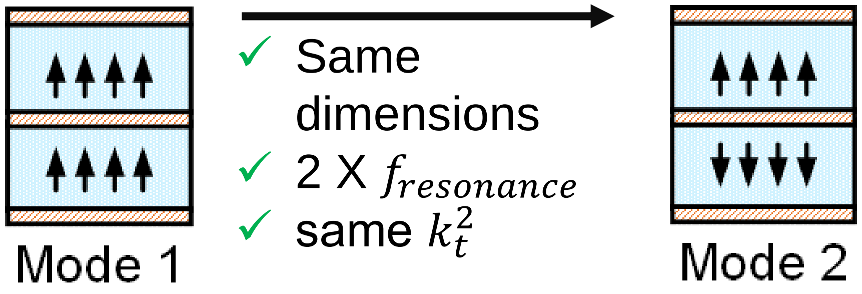
1. Frequency scaling of conventional FBAR
   - Device tolerances, power handling, fragile
   - Requires precise thickness control




2. Overmoded single layer piezoelectric FBAR
   - $k_t^2$ drops with mode number $n$ $\left(\frac{1}{n^2}\right)$




3. Polarity controlled multilayer FBARs
   - Control over the polarity of each layer reliably

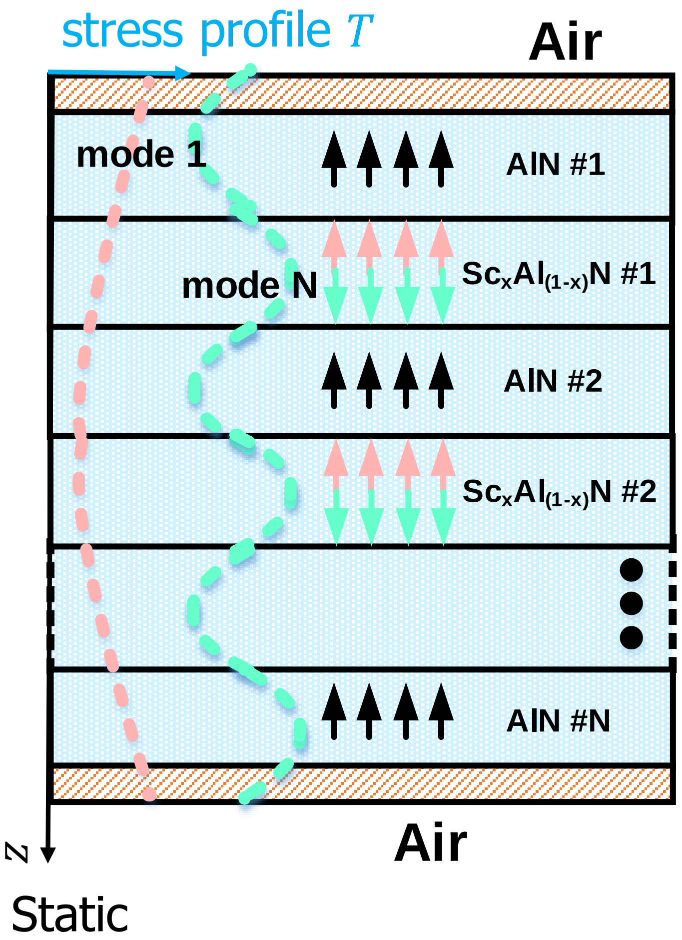


# Multilayer ScAlN FBAR Approach

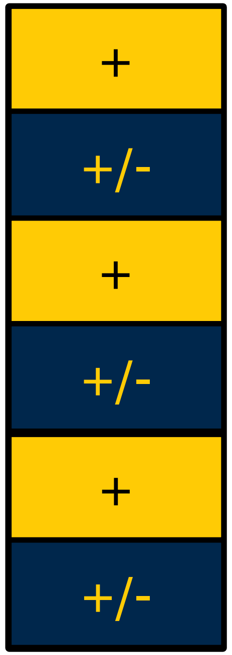
- N layers of piezoelectric with alternating polarities operating in mode N

$$K_{eff}^2 = \frac{U_m^2}{U_e U_d}$$

$$U_m = \frac{1}{2}\int_V d_{eff}(TE)dV$$




piezo profile $d_{eff}$




Piezoelectric profile set to match the stress profile of mode N, thereby maximizing the mutual energy between stress and electric field

Operating at resonant mode N, without scaling down total piezoelectric thickness

Scale FBAR to higher frequency without compromise in performance ($k_t^2$, power handling, etc.)

Ferroelectric poling of ScAlN switches the resonator between two modes

Incorporate light and soft electrode materials to reduce $U_e$ and increase $k_t^2$

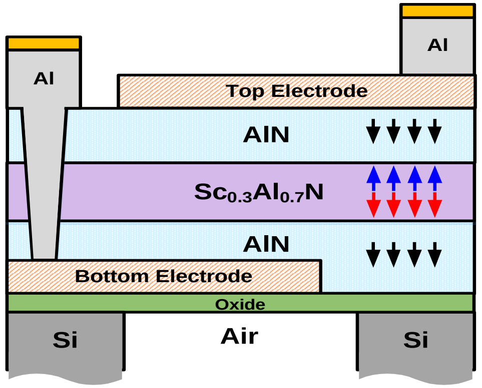

M. Z. Koohi and A. Mortazawi, "Switched Mode Thin Film Bulk Acoustic Wave Resonators," *2019 IEEE MTT-S International Microwave Symposium (IMS)*, 2019, pp. 528-531, doi: 10.1109/MWSYM.2019.8700959.

M. Z. Koohi and A. Mortazawi, "Negative Piezoelectric-Based Electric-Field-Actuated Mode-Switchable Multilayer Ferroelectric FBARs for Selective Control of Harmonic Resonances Without Degrading Keff²," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 67, no. 9, pp. 1922-1930, Sept. 2020, doi: 10.1109/TUFFC.2020.2988632.

# Trilayer FBAR Design and Simulation

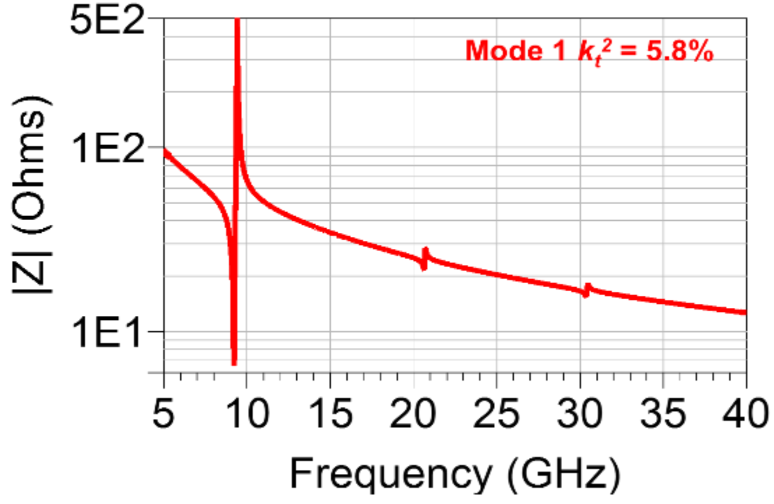


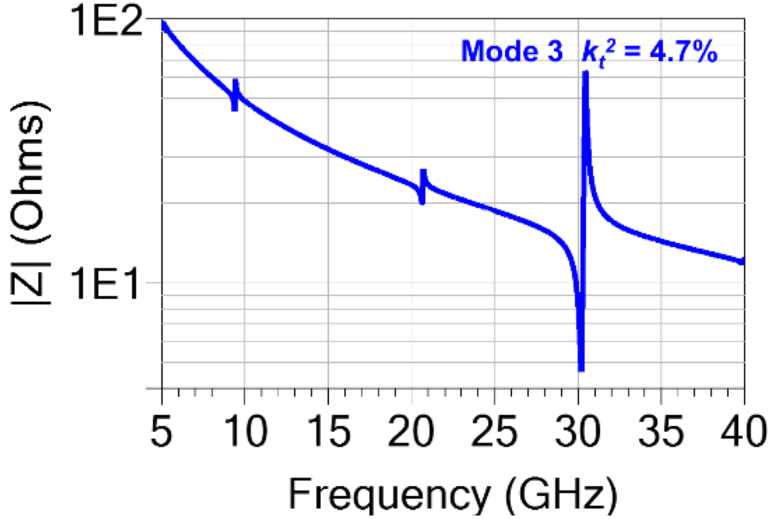
- Trilayer (AlN–$Sc_{0.3}Al_{0.7}N$–AlN) FBAR
  - Control of piezoelectricity sign in middle ScAlN film through the electric field bias applied onto electrodes
  - Resonators designed with 1-D Mason Model and COMSOL



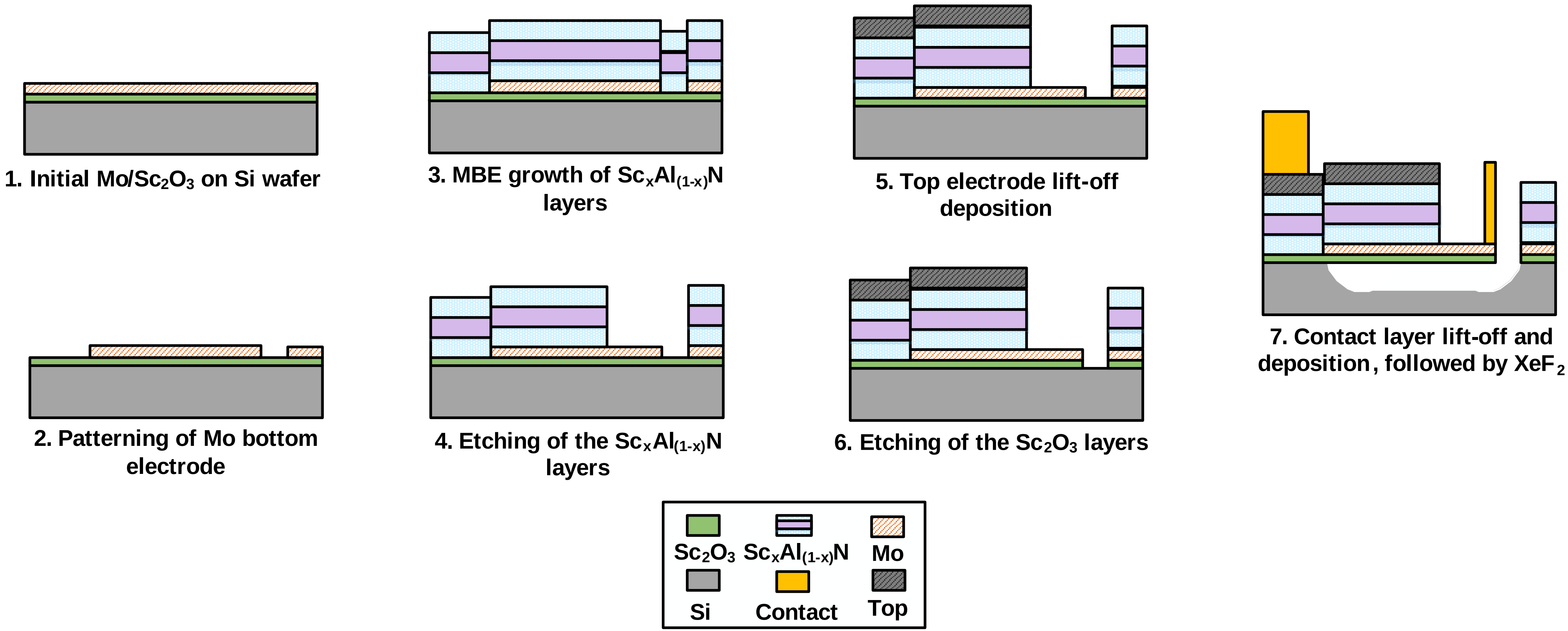

Final design dimensions

| Layer | Thickness |
|---|---|
| AlN1 | 95 nm |
| $Sc_{0.3}Al_{0.7}N$ | 85 nm |
| AlN2 | 120 nm |



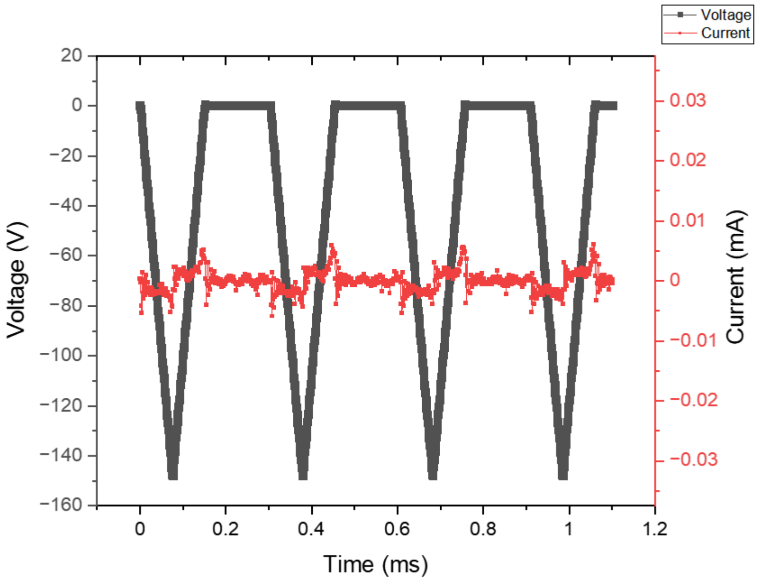
# Fabrication Process



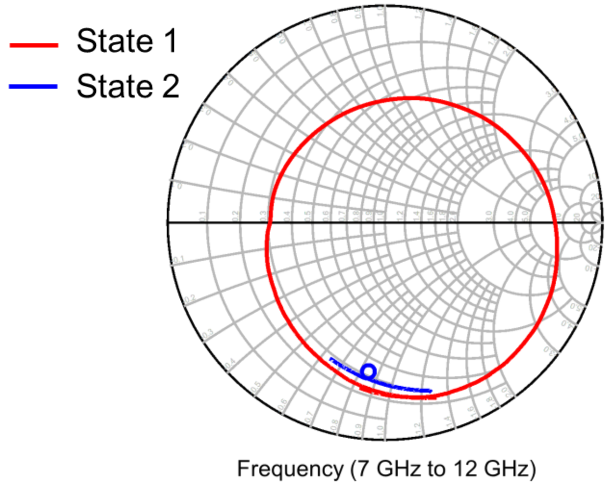

All lithography for ion milling and wet etches conducted with SPR 220 (3.0) photoresist

# Polarization Switching Measurement

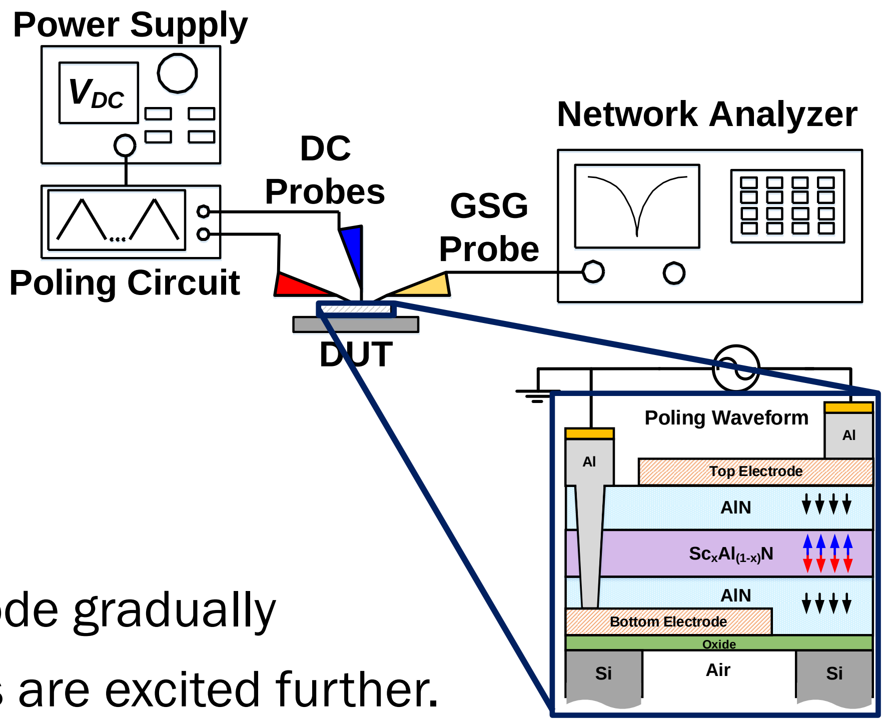
- FBARs were poled through multiple cycles of 150 V, lower than unreleased devices
- Trilayer resonators after gradual poling remain stable for greater than one month




Since the trilayer FBARs are gradually poled at a reduced voltage, there is no transient current spike.

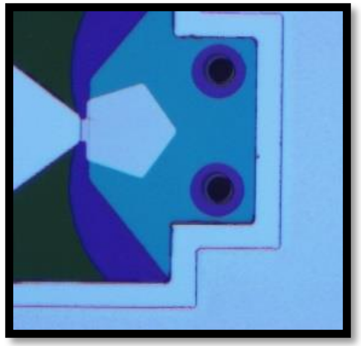



During poling, fundamental mode gradually disappears while higher modes are excited further. A small fundamental mode (low $k_t^2$) remains.



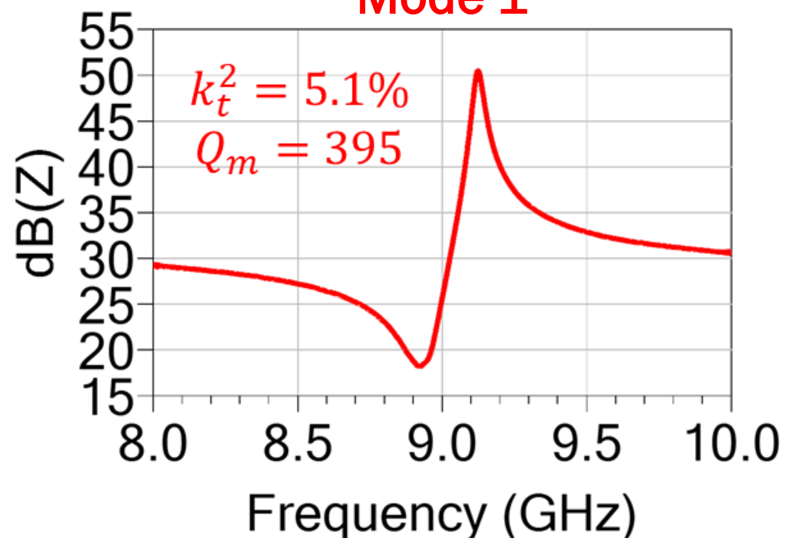
# Trilayer Frequency Response

- Trilayer FBAR fundamental mode measured directly after release (no poling conducted)
- Third mode response measured after application of 150 V triangular waves cycles
- Active area of 1024 μm$^2$

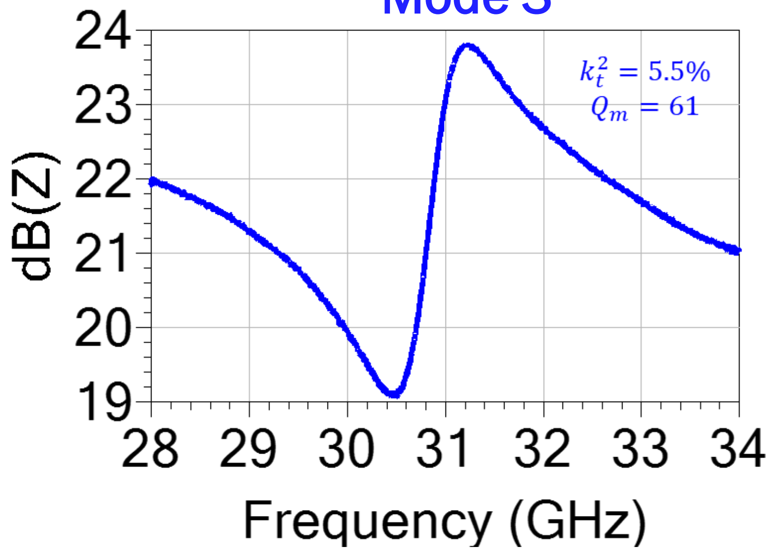


Photograph of measured trilayer resonator

Mode 1




Mode 3



# Conclusion



- First demonstration of a higher order multilayer composite (ScAIN/AIN) FBAR with electromechanical coupling of 5.5% at 31 GHz (Fundamental mode 5.2% at 9 GHz)
- Polarization switching of ScAIN between two AIN layers to achieve higher order mode without the use of intermediate electodes
- Provides a method to scale FBARs into the mm-Wave operation **without degradation of coupling**