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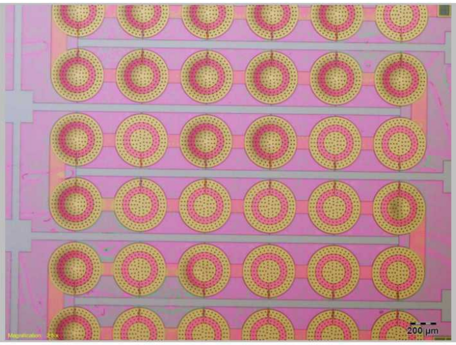

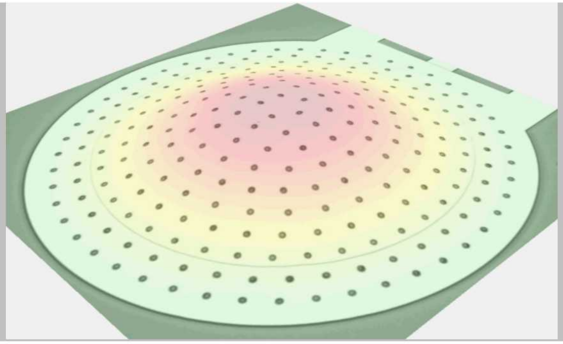

Post-CMOS Compatible Piezoelectric Micromachined Ultrasonic Transducers

Benjamin A. Griffin, Adam M. Edstrand, Sean Yen, and **Robert W. Reger**

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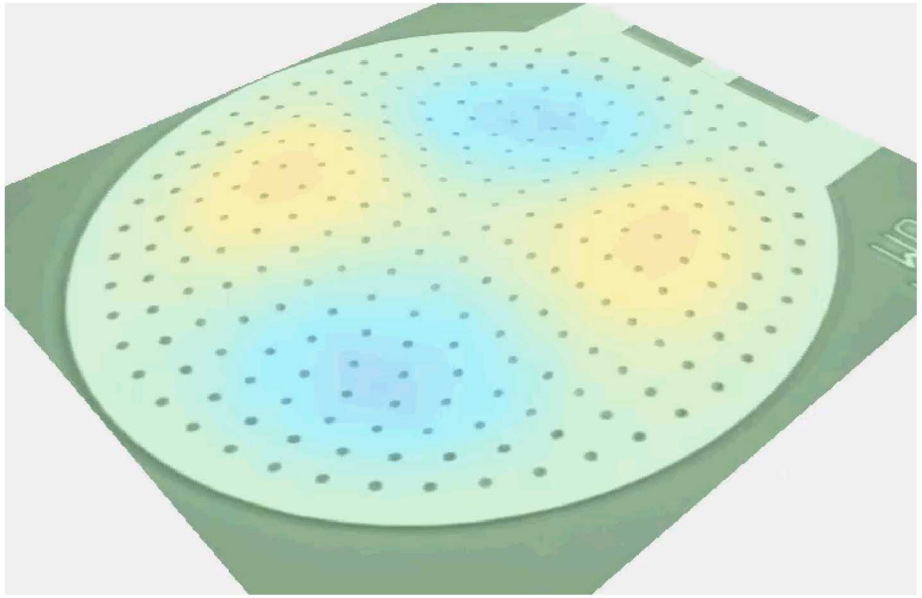
Outline

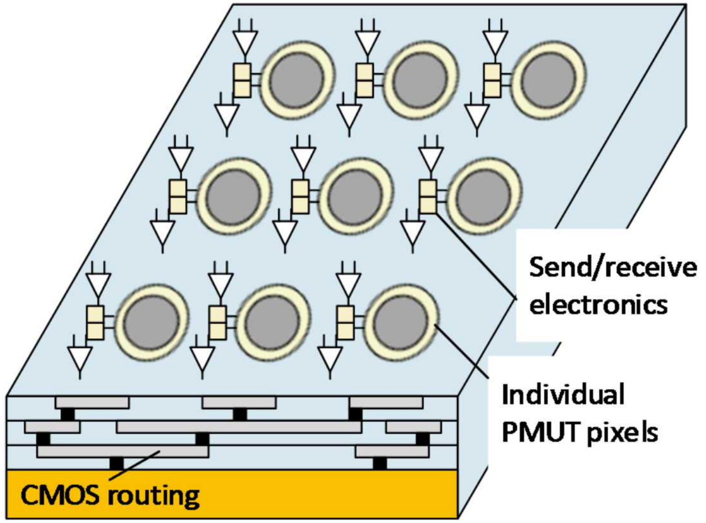
- **Ultrasonic Fingerprint Sensing**
- Piezoelectric Micromachined Ultrasonic Transducers Design
- Fabrication
- Experimental Results
- Conclusion and Future Work

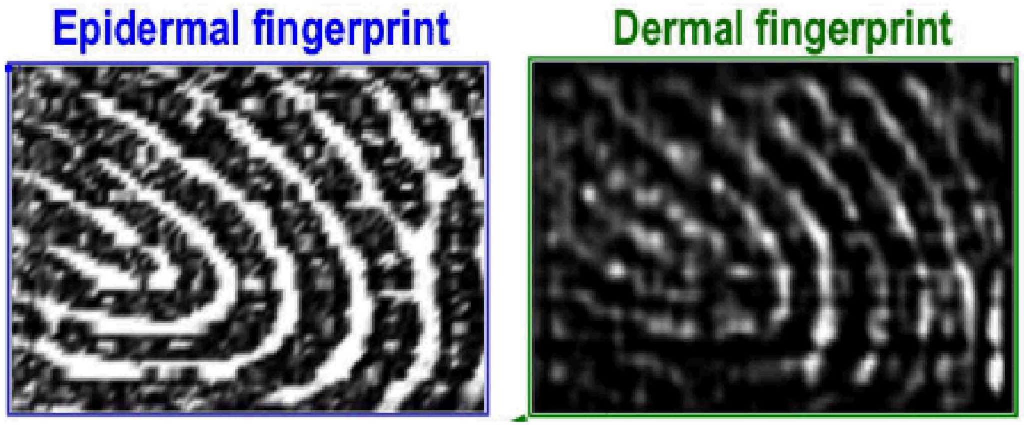
PMUT Pixel



Fingerprint Sensors

- With the advent of the smartphone, fingerprint sensors have become ubiquitous
- Current commercial fingerprint sensors rely on capacitive sensing
  - Unreliable in the presence of contamination (e.g. water, dirt, etc)
- An ultrasonic fingerprint sensor would:
  - Allow for deeper dermal imaging
  - Be more secure and reliable
  - Be robust to contaminants





H. Y. Tang *et al.*, "3-D Ultrasonic Fingerprint Sensor-on-a-Chip," *IEEE Journal of Solid-State Circuits,* vol. 51, no. 11, pp. 2522-2533, 2016

How does ultrasonic imaging work?

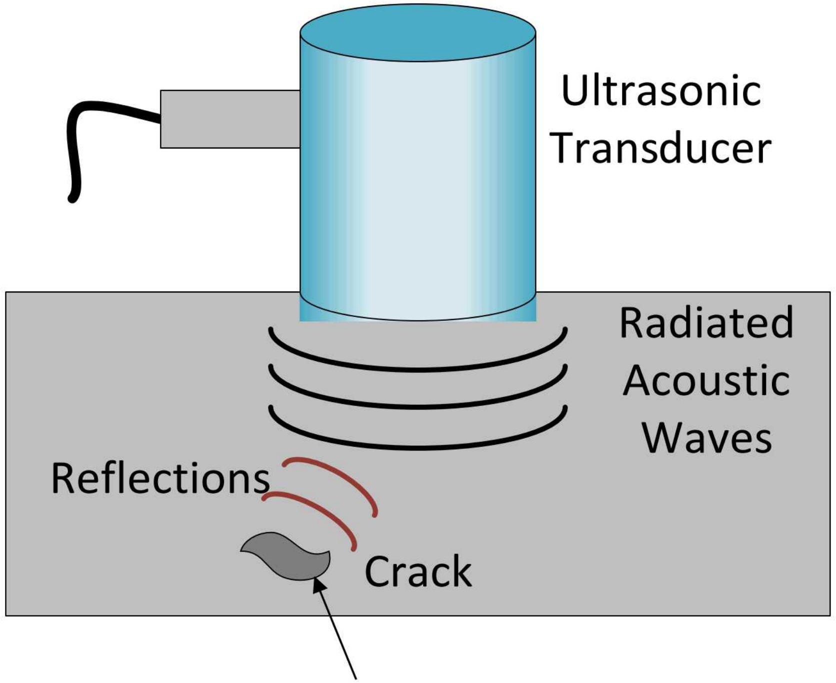
- High frequency sound waves are launched into the target medium from an ultrasonic transducer
- Sound waves reflect off differences in acoustic impedance
- Reflected waves are sensed by the ultrasonic transducer
- Similar to echolocation of bats or SONAR
- The time of flight determines the distance to the echo for a given speed of sound

Material acoustic impedance

$$Z_{ac} = \rho_0 c_0$$

Density Speed-of-sound

- Transducers are generally piezoelectric



Impedance mismatch -> reflections

Chip Scale Ultrasonic Imaging

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Conventional Ultrasonic Imaging System

Exampled: Linear Phased Array Probe

128 elements, ~10^5 mm^3

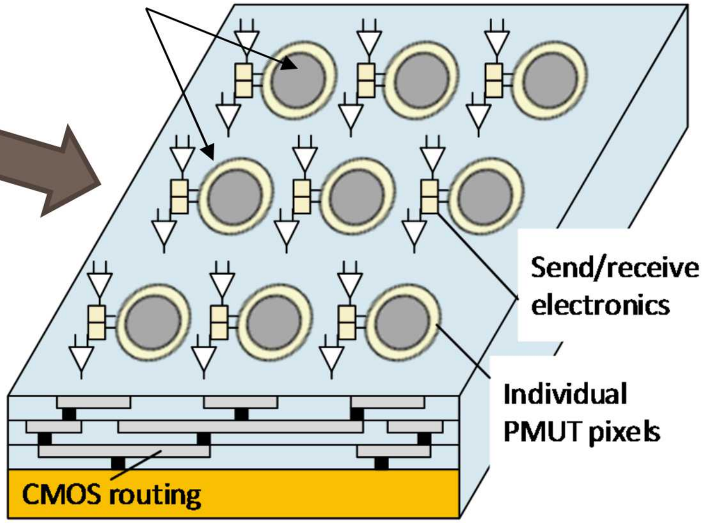
Example: Phased Array Instrument (contains send/receive electronics)

~10^7 mm^3

MEMS Single Chip Ultrasonic Imaging System

- Replace a conventional 2D ultrasonic phased array with a chip-scale ultrasonic imaging system for applications require SWAP superiority

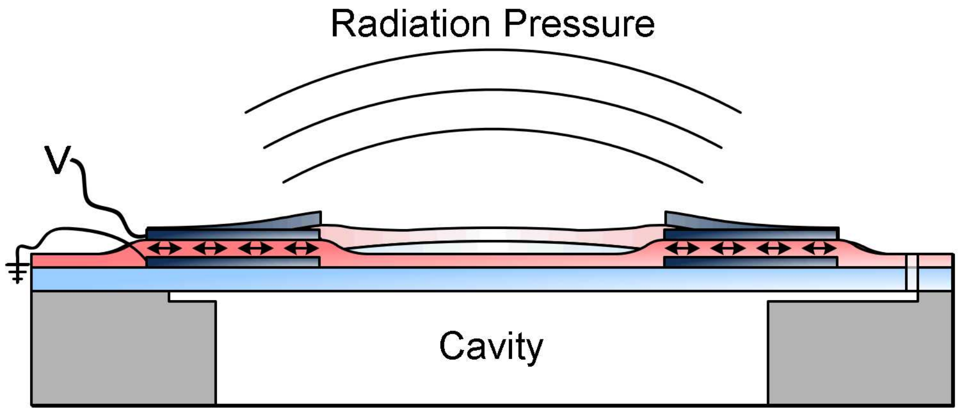
MEMS ultrasonic transducers

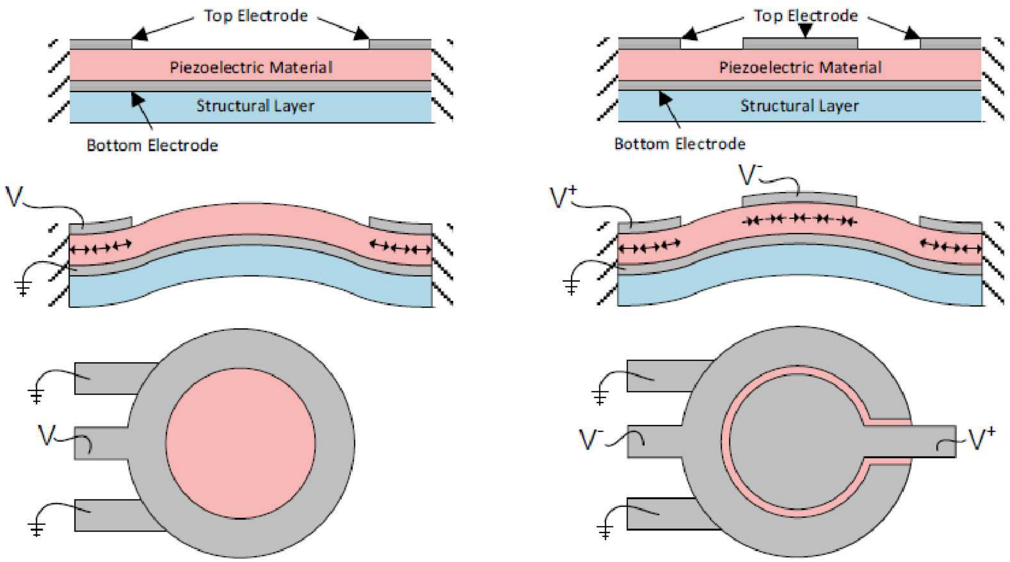


<u>>1,000 elements, ~15 mm^3</u>

PMUT Design

- Conventional ultrasonic transducers utilize thickness mode vibrations via d33
- PMUTs utilize the d31 coefficient to induce drum-head like bending
  - Allows for smaller devices with lower acoustic impedances
- Aluminum nitride based for CMOS compatibility
  - Direct integration onto CMOS will allow for tightly-packed PMUTs arrays to be fully controlled with a chip-scale solution
- Two electrode configurations investigated
  - The two-port PMUT allows for pulse-receive in a single pixel





Fabrication

a) Deposit 600 nm PETEOS followed by 2 µm PolySi

b) Deposit 2.6 µm PETEOS and CMP to expose PolySi

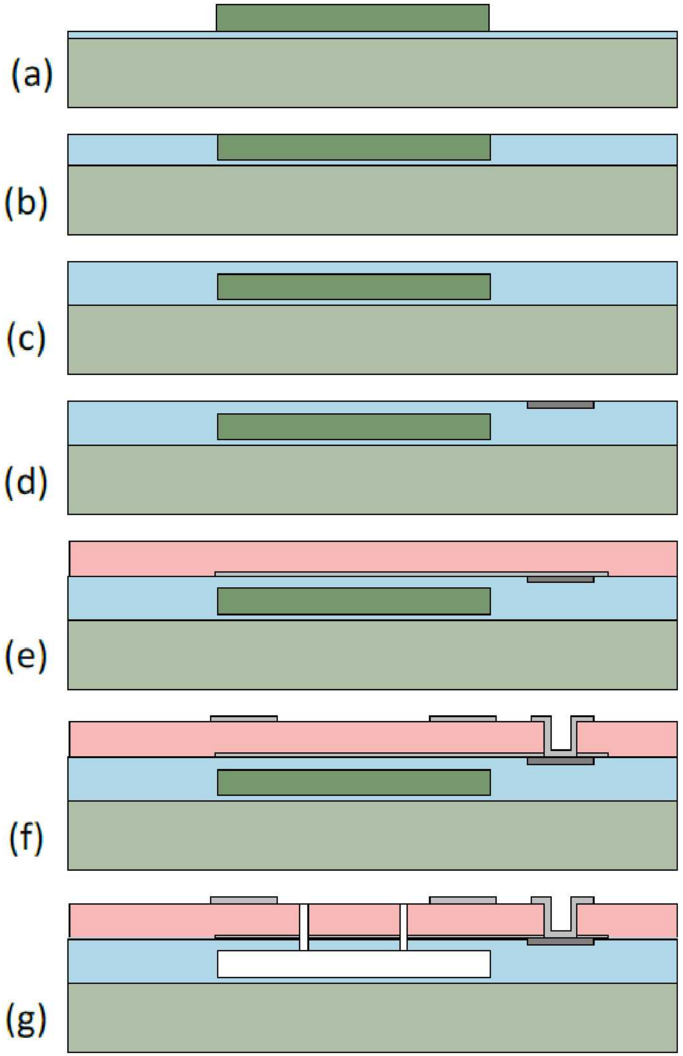
c) Deposit 1.5 µm PETEOS as structural layer for PMUT

d) Pattern and etch 0.6 µm into PETEOS; then deposit W and CMP, this will serve as a via etch stop

e) Sputter deposit bottom electrode of 20/25/100 nm Ti/TiN/AlCu; then sputter deposit 750 nm AlN

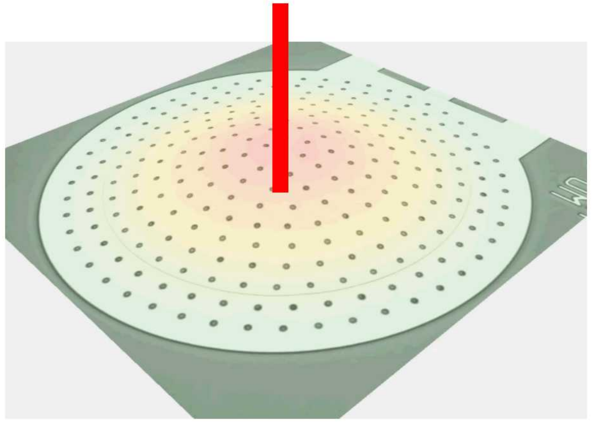
f) Pattern and etch vias to the W etch stop; then deposit and pattern top electrode of 200/25 nm of AlCu/TiN

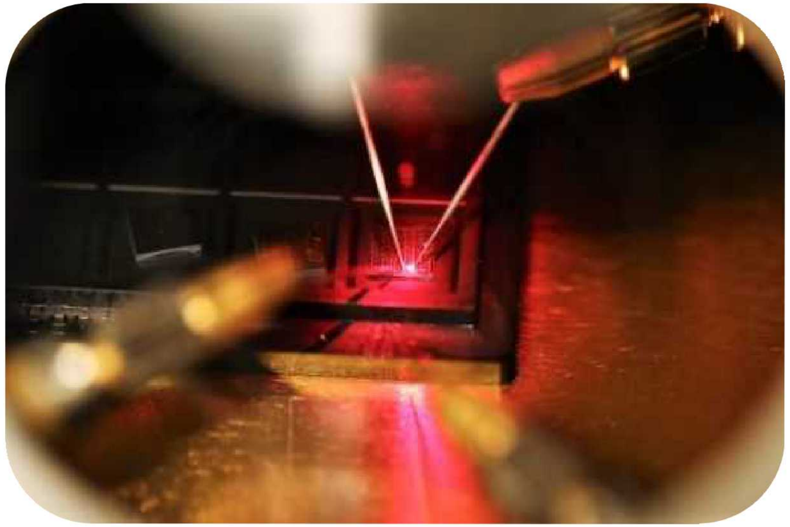
g) Pattern and etch release holes through AlN; then release the PMUT diaphragm using a XeF2 etch of the Poly Si



Test Setup

- Initial testing is performed via laser doppler vibrometry (LDV)
  - Utilizing a scanning LDV system in a vacuum capable chamber
    - Provide an AC input voltage excitation to the device
    - Measure the diaphragm vibration velocity output
- Measurements obtained in vacuum
  - Vacuum measurements allow us to accurately capture device electromechanics in the absence of fluid interaction

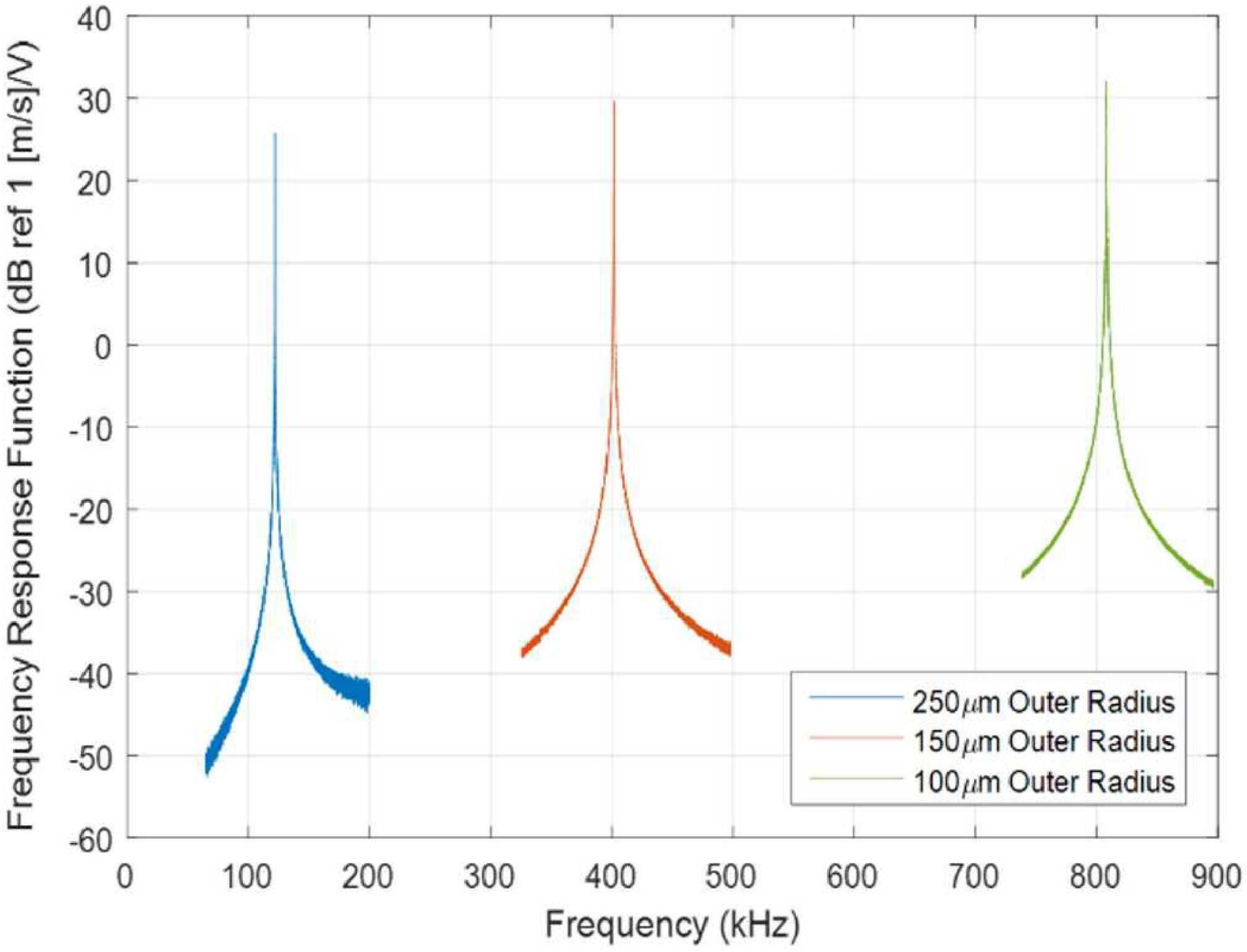




Experimental Results

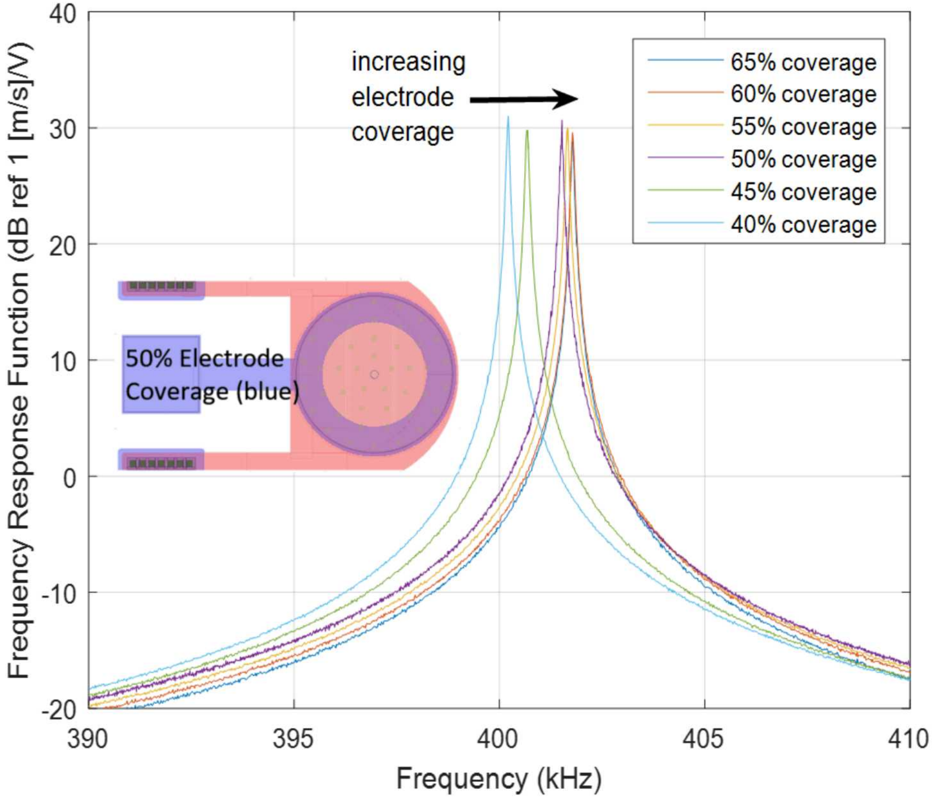
- PMUTs designed and fabricated to operate at three frequencies
  - 100, 400, 800 kHz
  - 100 kHz device is about 0.5mm laterally by 0.8mm thick
  - AlN based 100 kHz thickness mode device would be ~55mm thick
    - PZT based would be ~20mm thick

- High quality factors due to vacuum testing; expected to reduce significantly in application

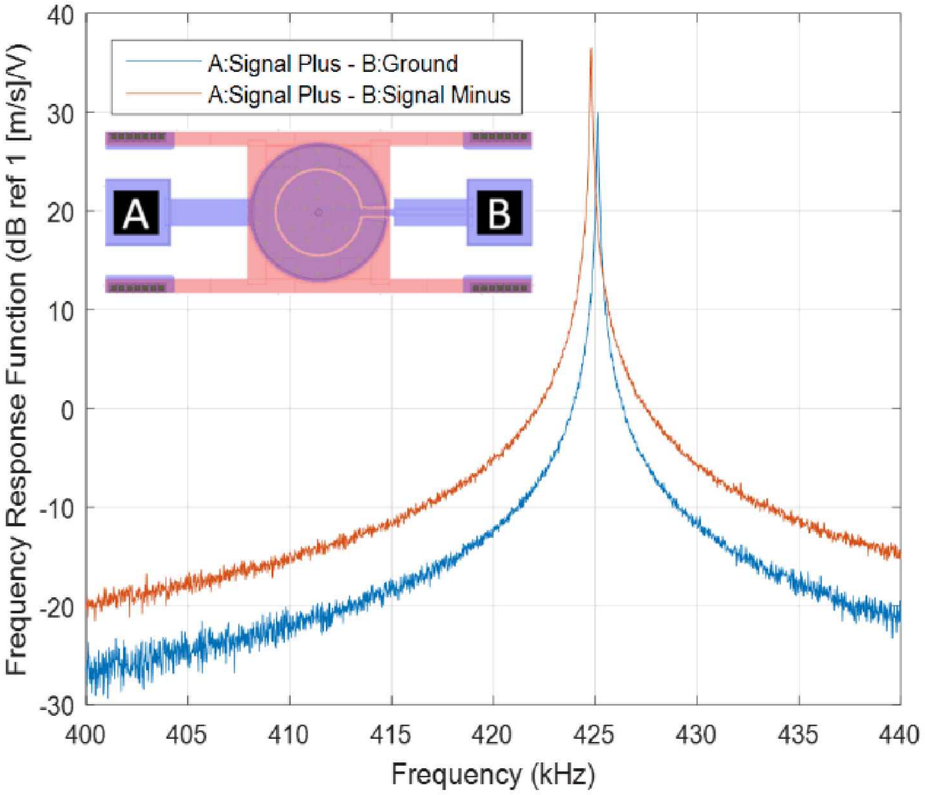


Experimental Results Continued

- Increasing electrode coverage causes:
  - Reduced resonant frequency
  - Small increase in sensitivity

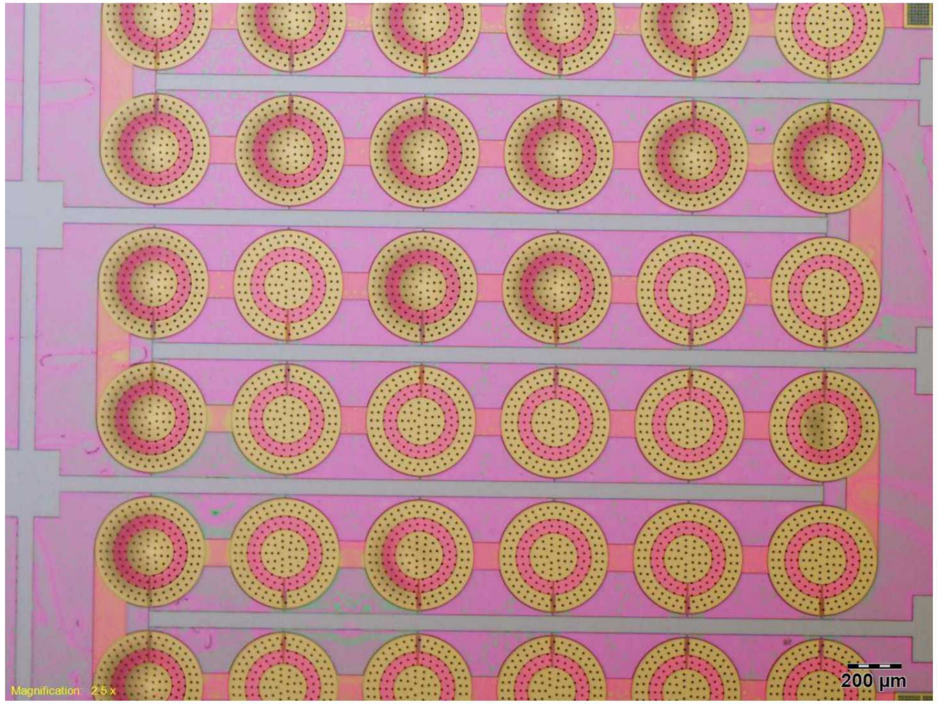


- Two-electrode PMUTs:
  - Increased output (6 dB, as expected)
  - Slight reduction in resonant frequency



Conclusions and Future Work

- Expanding market for fingerprint sensors
  - PMUTs enable sub-surface matching while capacitive sensors are unreliable in the presence of surface contamination
- Designed lateral mode PMUTs using piezoelectric aluminum nitride
  - Post-CMOS compatible allowing for densely packed PMUTs with electronic interface
  - Chip-scale access to lower frequencies and better penetration than traditional thickness mode devices
- Devices fabricated at 100, 400, 800 kHz
- Future direction is to array these devices to create an imaging system monolithically integrated with CMOS



Acknowledgements and Questions

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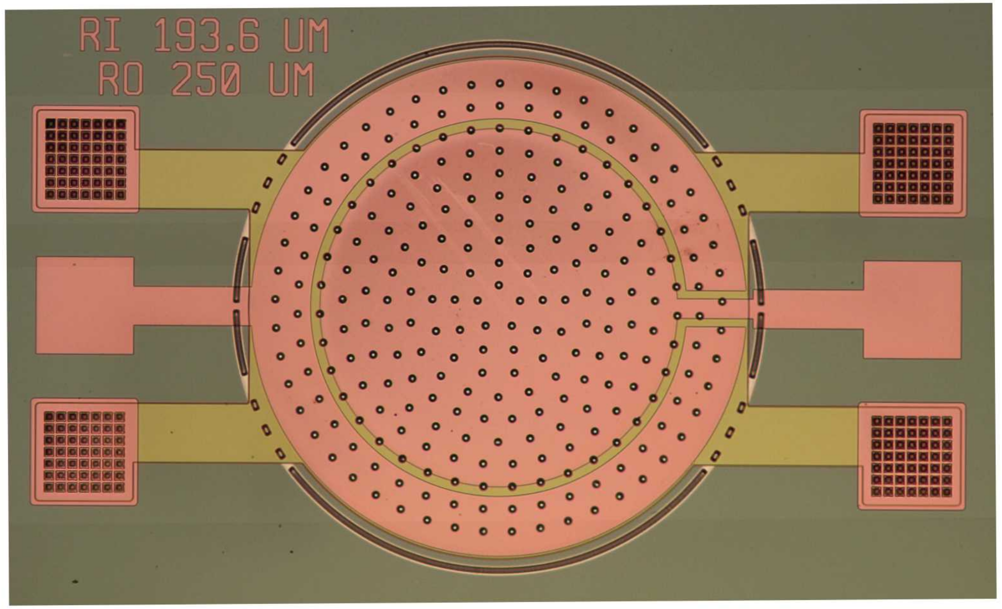
  - Thanks to MESA fabrication support for processing these devices, especially Peggy Clews



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Questions?