Three-Dimensional Microwave Kinetic Inductance Detectors

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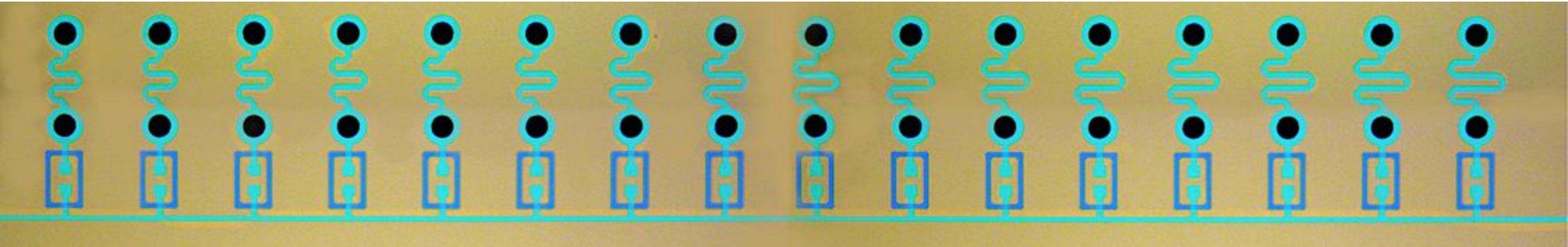
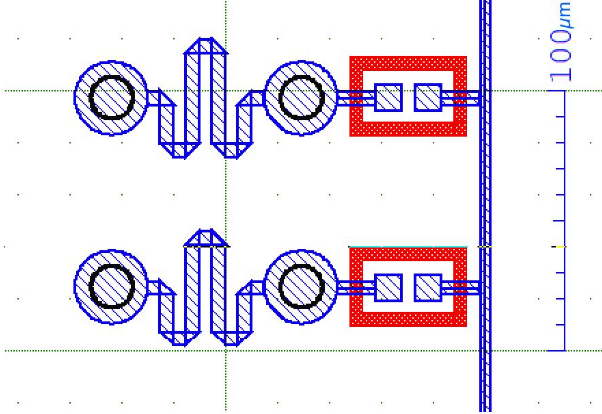


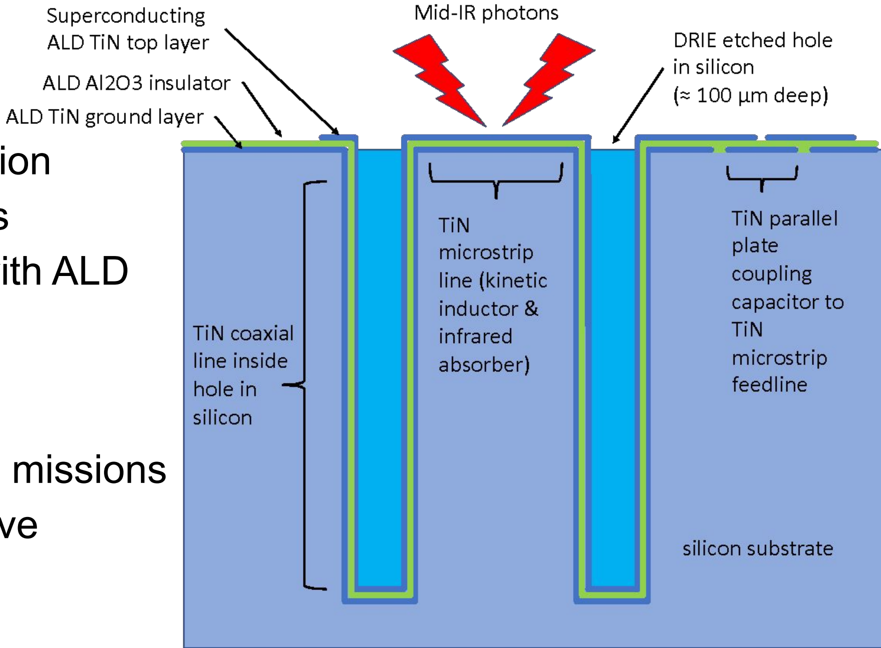
What are 3D MKIDs?



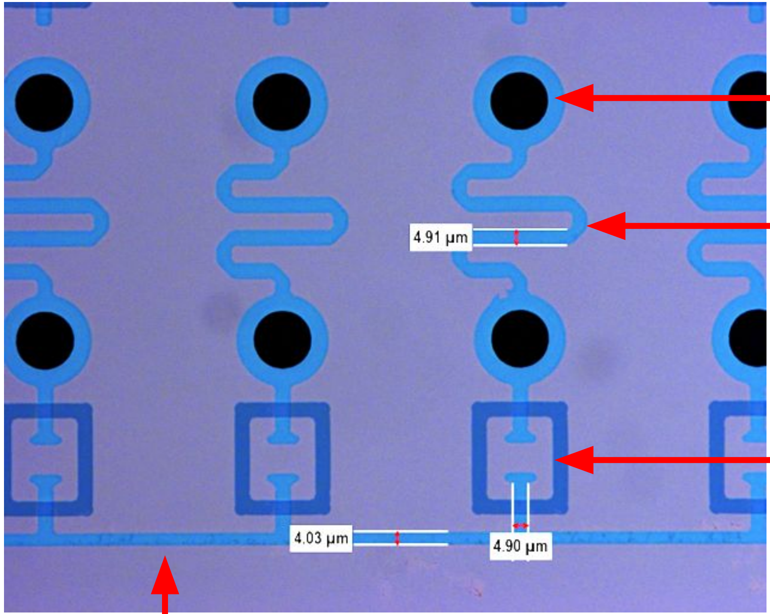
- Microwave Kinetic Inductance Detectors
  - Easily multiplexed infrared/microwave sensors
  - Pixel footprint typically dominated by large 2D capacitors
  - Majority of focal plane is not photon-sensitive

- 3D MKIDs
  - Minimize capacitor footprint by using third dimension
  - Smaller resonator footprint → Denser focal planes
  - Deep etch holes into silicon and conformal coat with ALD

- Applications
  - Dense focal plane arrays for future mid and far-IR missions where size, mass, and cooling power are expensive



Prototype device fabrication

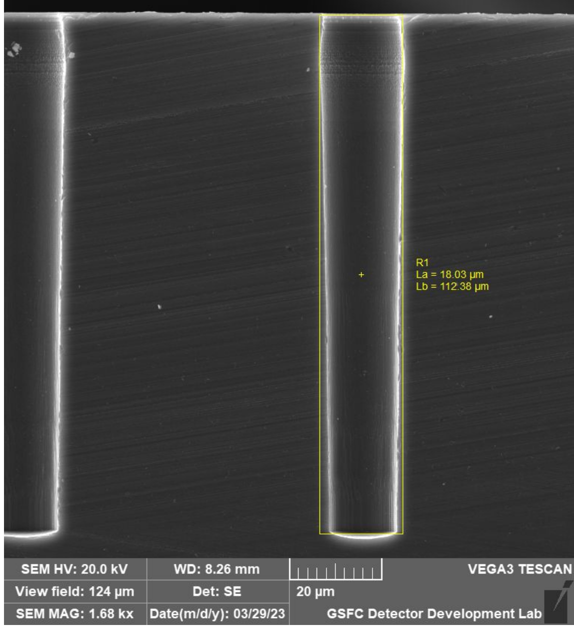


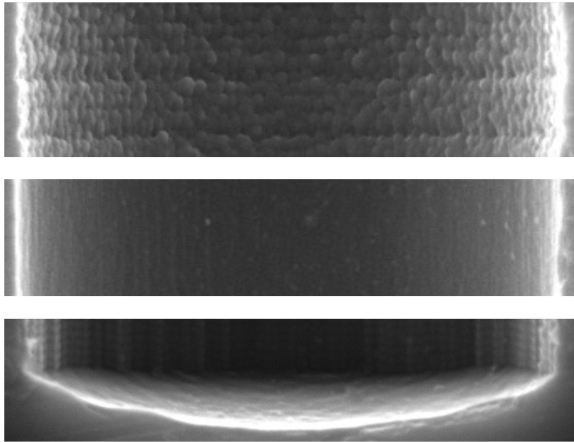
Deep etched cavities with ALD coatings inside

Meandered inductor

Parallel plate coupling capacitor

TiN microstrip over TiN groundplane





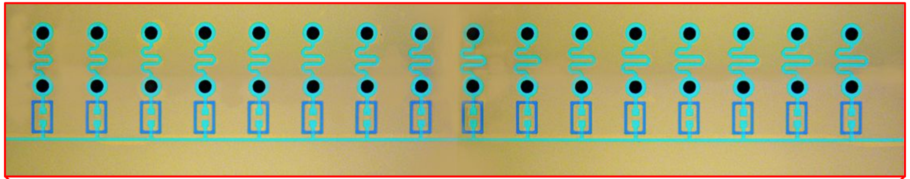
<u>Measured ALD layer properties:</u>

TiN#1 T_c = 3.64 K, R_s = 33 Ω/sq

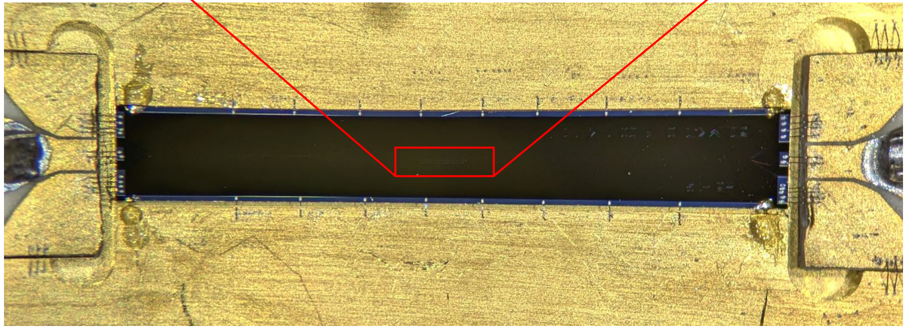
Al2O3 ε_r = 8.75

TiN#2 T_c = 3.97 K, R_s = 40 Ω/sq

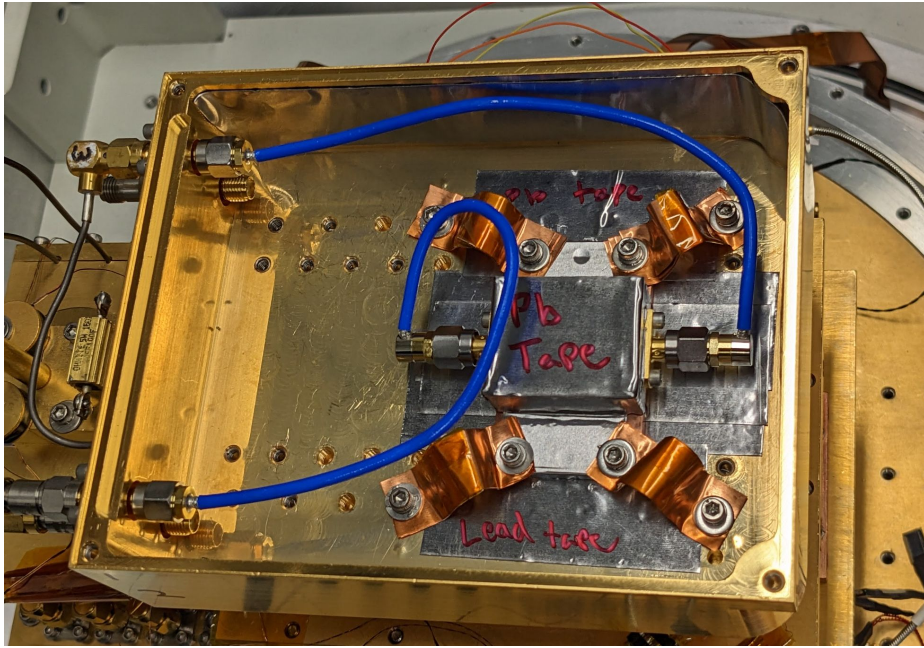
Packaging and cryogenic testing



Micrograph of sixteen 3D MKID array



3D MKID resonator array chip in test package

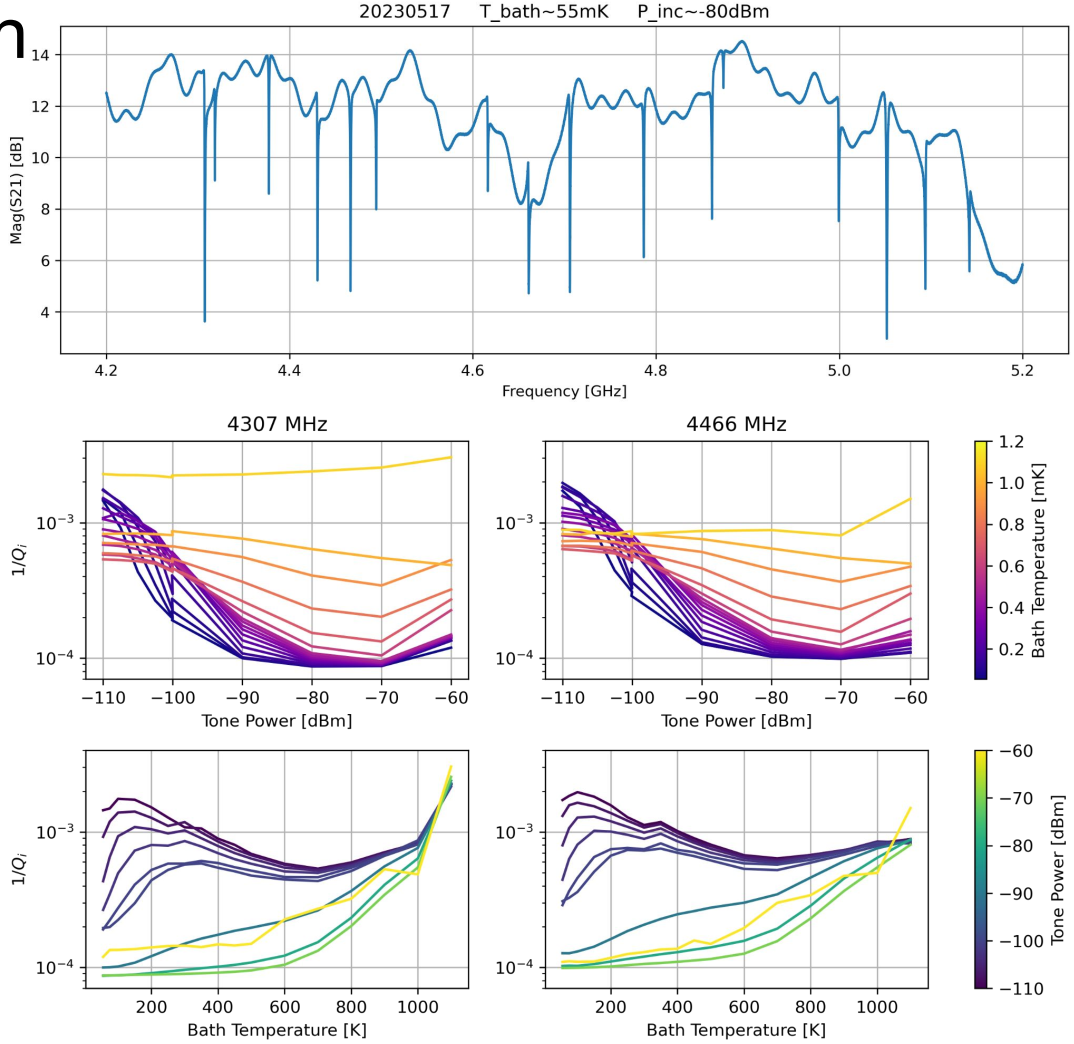


3D MKIDs installed in ADR cryostat, wrapped with lead tape for magnetic shielding

Prototype Characterization

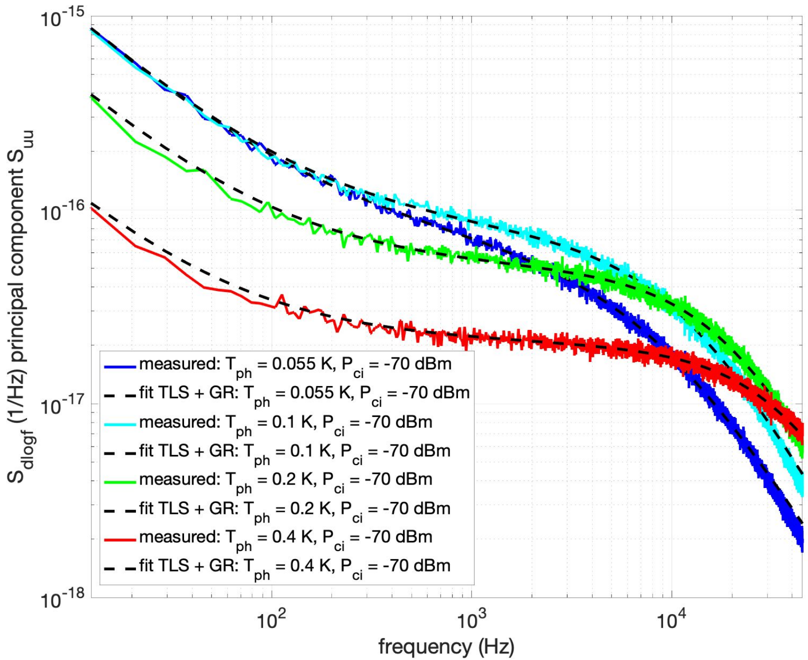
- Yield
  - 16 of 16 resonators found (100%)
  - Successful on multiple wafers
  - Resonator frequencies near expectation given measured T_c

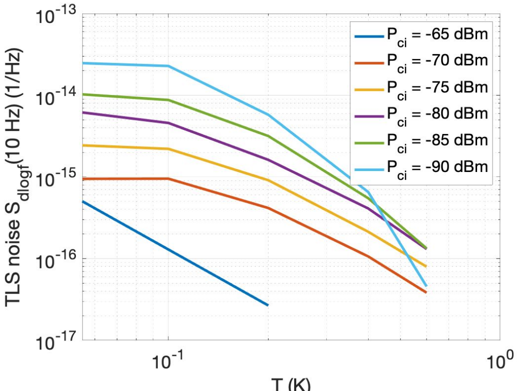
- Uniformity
  - Consistent quality factors
  - Consistent response to temperature
  - Consistent response to tone power
  - Best performance at ~ -75 dBm

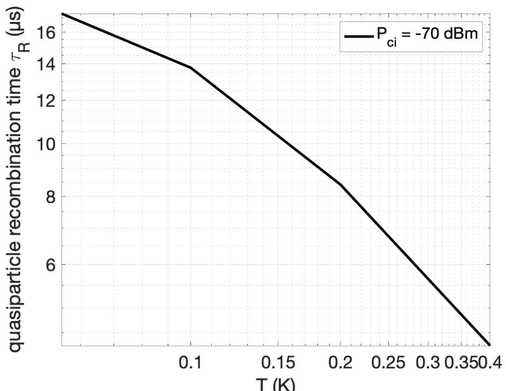


Noise Performance

- Fractional frequency noise
  - TLS and GR contributions
    - TLS noise suppressed at high drive powers
    - Where Q_i is maximized
  - Short quasiparticle lifetimes
    - GR roll-off softened by 50 μs outdiffusion
    - At 55 mK, fitted recombination lifetime 15 μs

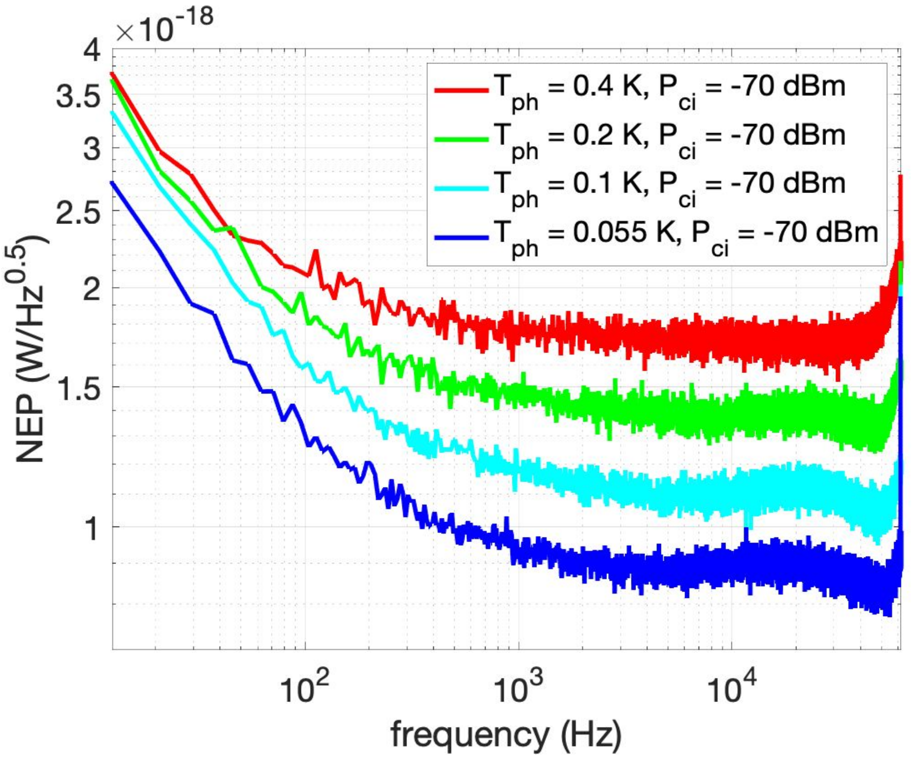






Prototype Device Sensitivity

- Noise equivalent power estimate
  - Using expected density of states for our TiN
  - And inductor volume 22 μm^3
  - NEP < 1.3x10^{-18} W/rtHz for f > 100 Hz
  - To be confirmed by upcoming optical measurements at λ = 25 μm



Conclusions and Next Steps

- Prototype 3D MKIDs
  - Successful fabrication demonstrated well-controlled etch and ALD processes
    - 100% yield, great reproducibility and uniformity
  - 3D MKIDs prefer high tone powers, good for TLS suppression
  - First devices show NEPs < 1.3×10^{-18} W/rtHz for f > 100 Hz

- Future work
  - Confirm NEP estimate via optical testing with 25 µm blackbody source
  - Explore different absorber designs to maximize sensitivity and footprint
  - Add high-T_c quasiparticle traps around absorber to optimize for low optical loads
  - Increase array size to kilopixel and eventually 10s and 100s of kilopixels