Coupling a Macroscopic Piezoelectric Resonator to a Superconducting Electrical circuit

Characterizing Mechanical Resonators

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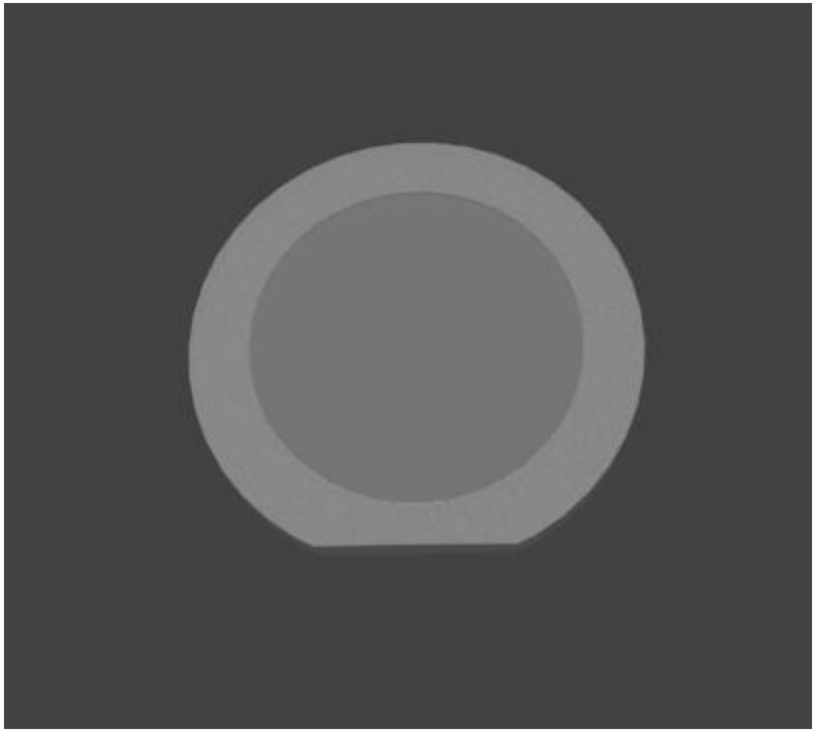
Motivation

- GOAL: Measuring mechanical motion with high precision
- Sensitive force and displacement detector
- Quantum behavior in mechanical resonator
- Architecture for quantum computing

Resonator properties I

- Quartz disc resonator
  - 8.580 MHz
  - d ~ 6 mm
  - t ~ 0.25 mm

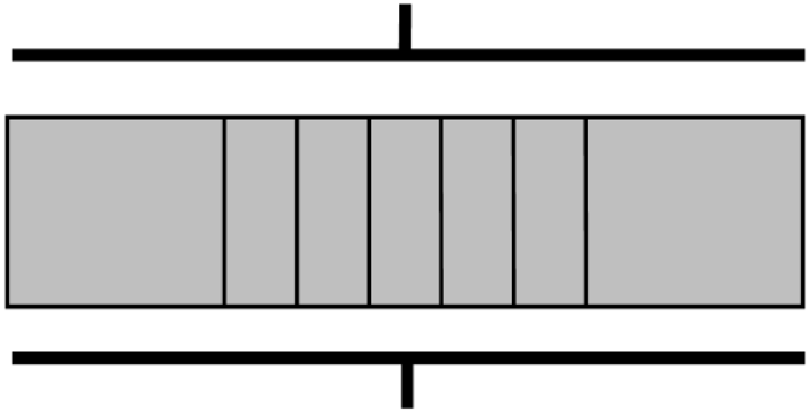


Resonator properties II

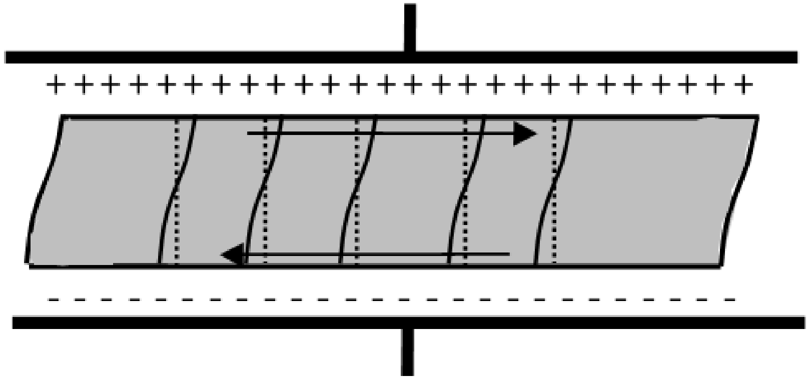
- Advantage
  - Long phonon lifetimes
  - Large mechanical displacements
  - High quality factors
- Disadvantage
  - Large mass
  - Low frequency (< 100 Mhz)

Resonator properties III

- Piezoelectricity: Mechanical motion generates electrical signals and vice versa
- Resonance frequencies are odd multiples of the fundamental frequency



Quartz Crystal– No Applied Potential



Quartz Crystal– Under Applied Potential

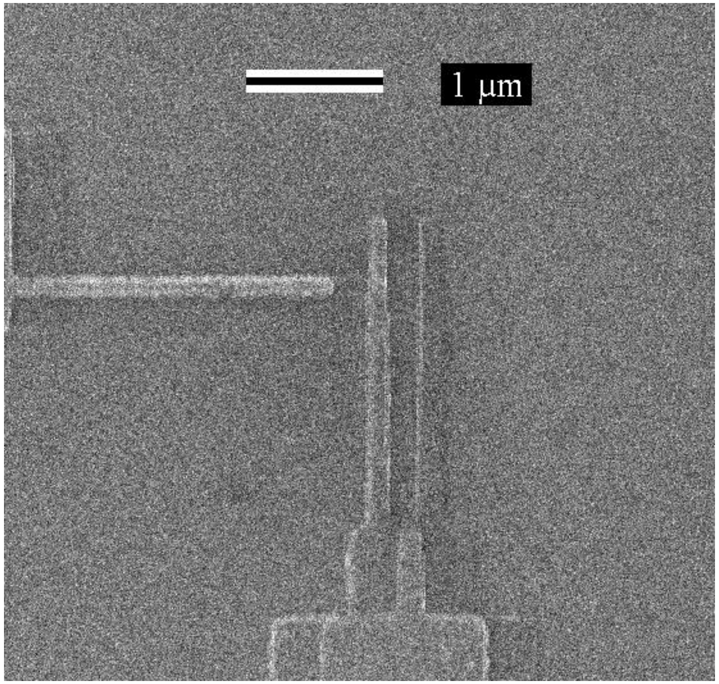
- Strong coupling to the electrical circuit

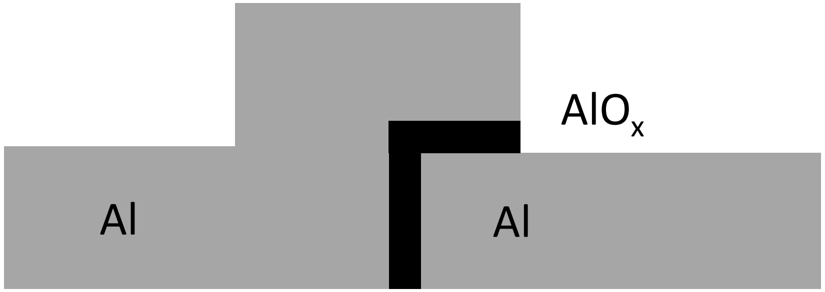
Quality factors

- Describes the rate of energy loss in oscillating systems
- Vital to have high Q factor for quantum mechanical measurements
- Energy relaxation time $T_1 = \frac{Q}{\omega_s}$

Josephson junctions

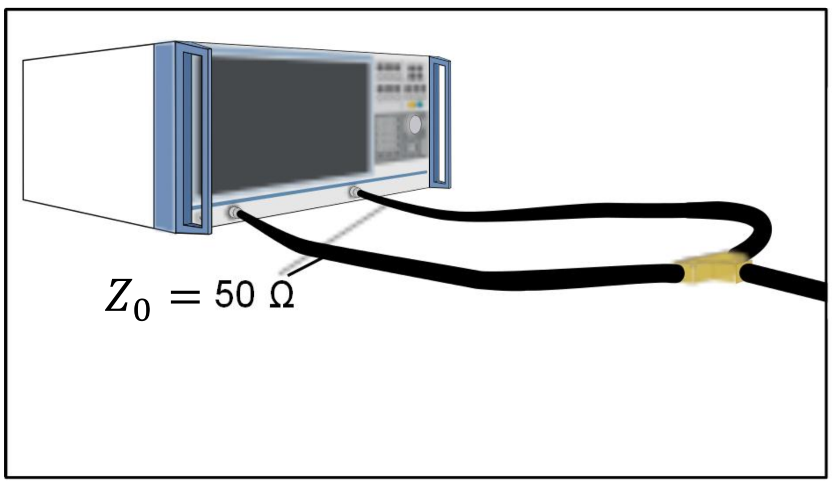
- Josephson junction based electrical circuit
- Excellent way to detect quantum modes

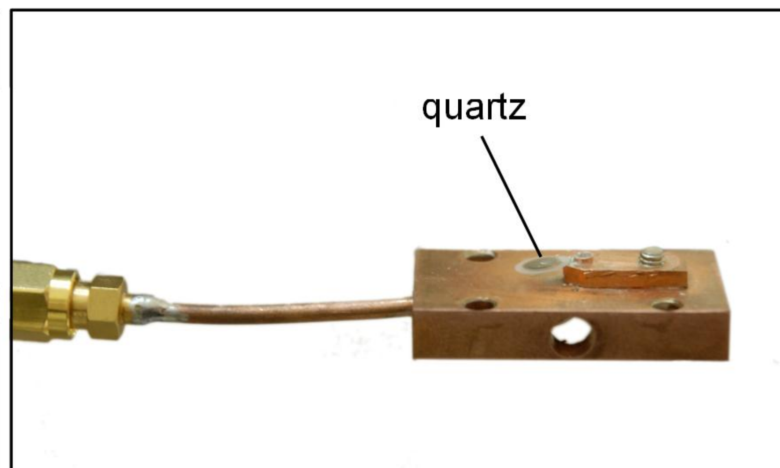




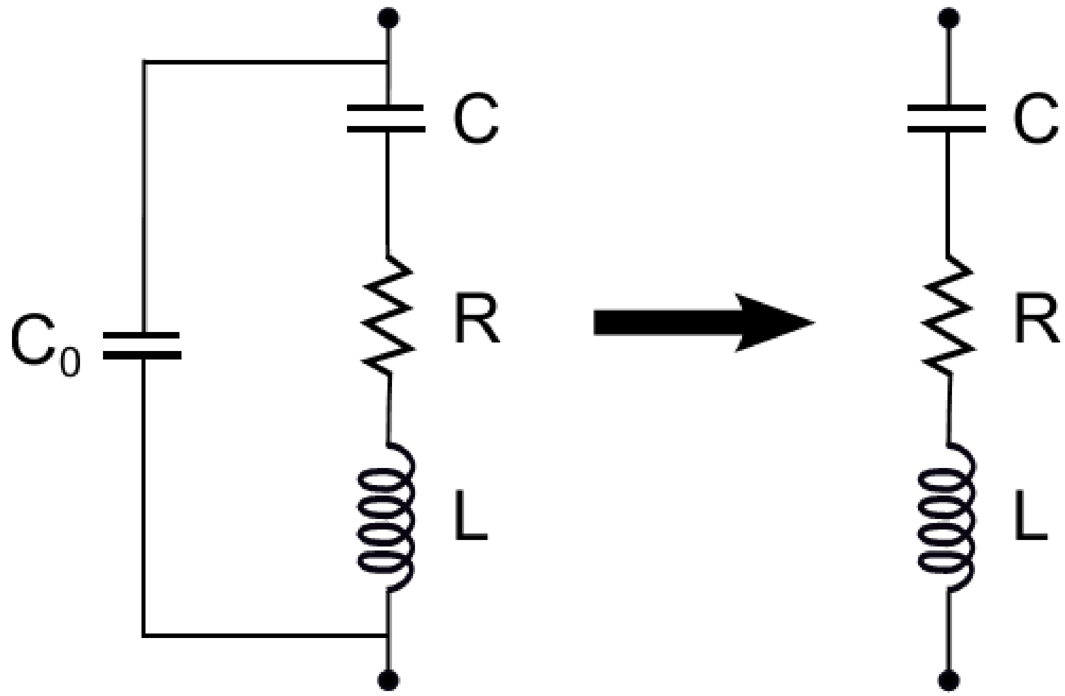
Experimental Techniques

- Reflection coefficient measurements
- $\Gamma = \frac{Z - Z_0}{Z + Z_0}$





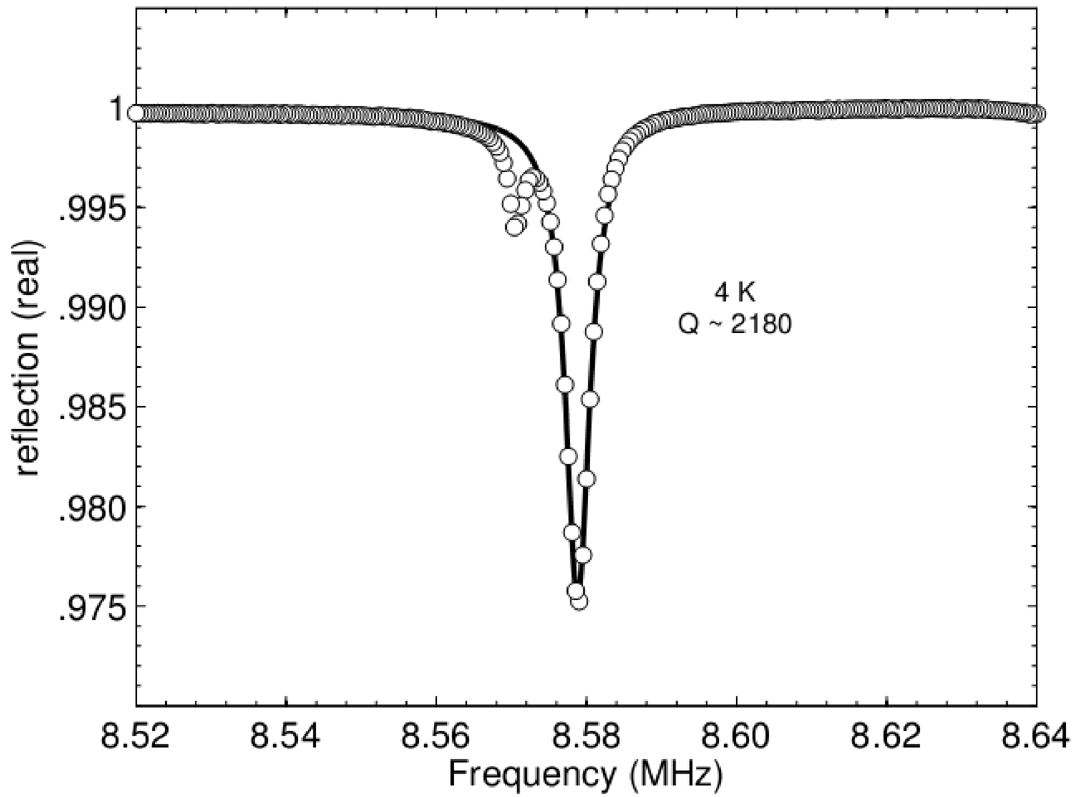
Equivalent circuit



- Equivalent circuit RLC simplification

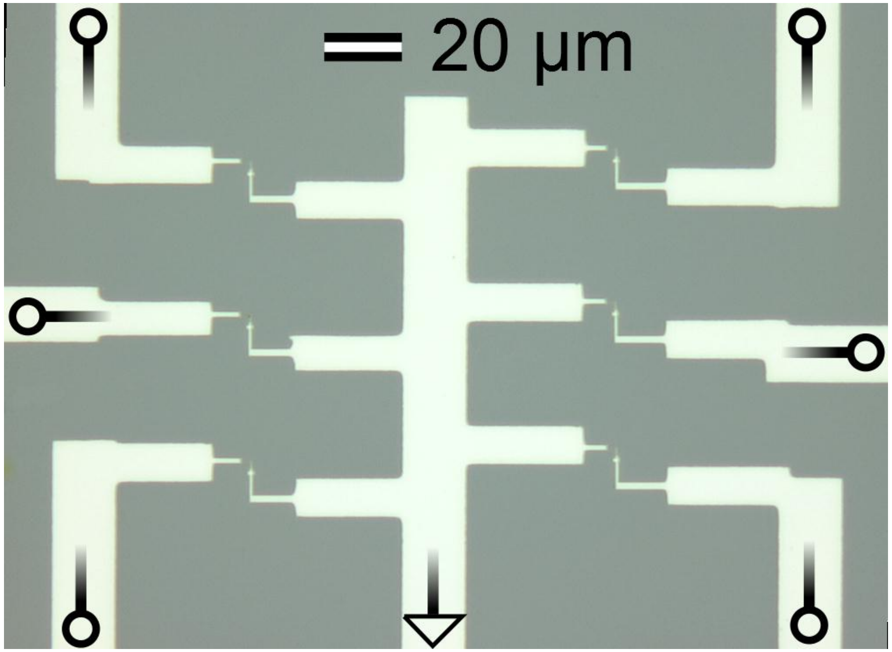
Results I

- Up to 13th overtone at 111 Mhz
- At 4 K: Maximum Q of 10,000
- $T_1 \approx 40\mu s$



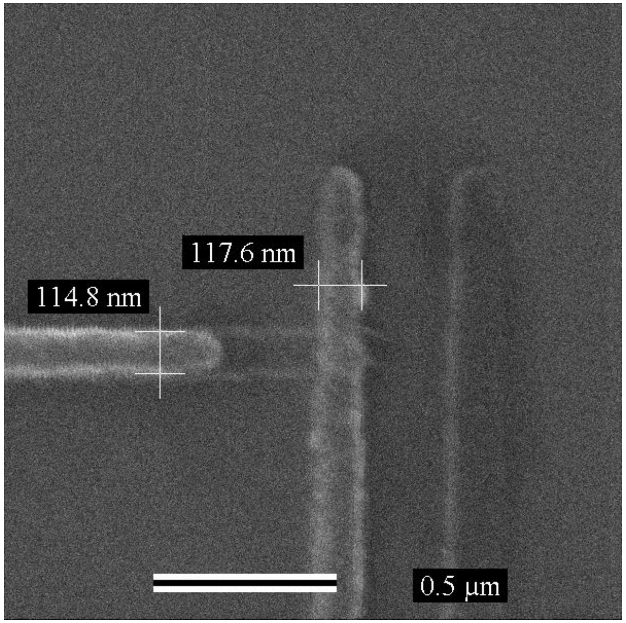
Results II

- Junction resistance measurements



Results III

- Control sample on silicon
- 3 samples on quartz
- 1/6 of the junctions on quartz worked
  - Electrical conductivity
  - Surface roughness



Conclusions

- Quality factors of 2,100 – 10,000 at 4 K temperature
- Working Josephson junction based circuitry on top of the resonator
- Quartz is a possible candidate for measurements in quantum regime

Future work

- Single electron transistor
- Sensitive displacement sensor
- Motion of the resonator changes the potential of the island changing the current

- Measure the resonator near its quantum ground state