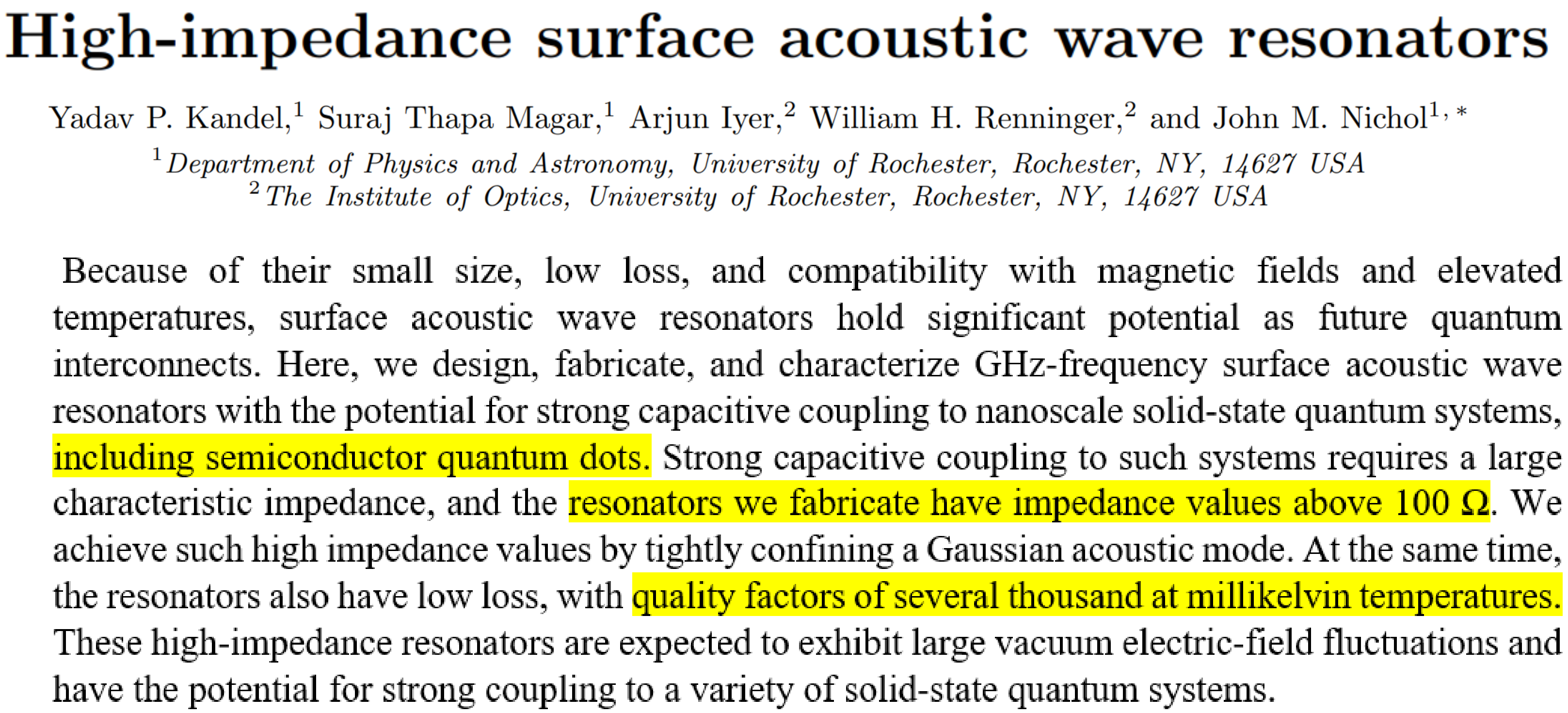
Crash course in resonators and…



High-impedance surface acoustic wave resonators

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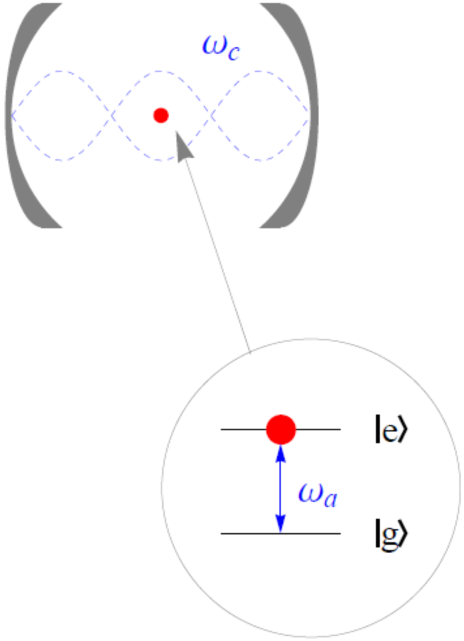
Because of their small size, low loss, and compatibility with magnetic fields and elevated temperatures, surface acoustic wave resonators hold significant potential as future quantum interconnects. Here, we design, fabricate, and characterize GHz-frequency surface acoustic wave resonators with the potential for strong capacitive coupling to nanoscale solid-state quantum systems, including semiconductor quantum dots. Strong capacitive coupling to such systems requires a large characteristic impedance, and the resonators we fabricate have impedance values above 100 Ω. We achieve such high impedance values by tightly confining a Gaussian acoustic mode. At the same time, the resonators also have low loss, with quality factors of several thousand at millikelvin temperatures. These high-impedance resonators are expected to exhibit large vacuum electric-field fluctuations and have the potential for strong coupling to a variety of solid-state quantum systems.

Aldo Tarascio – Journal Club 08/12/2023

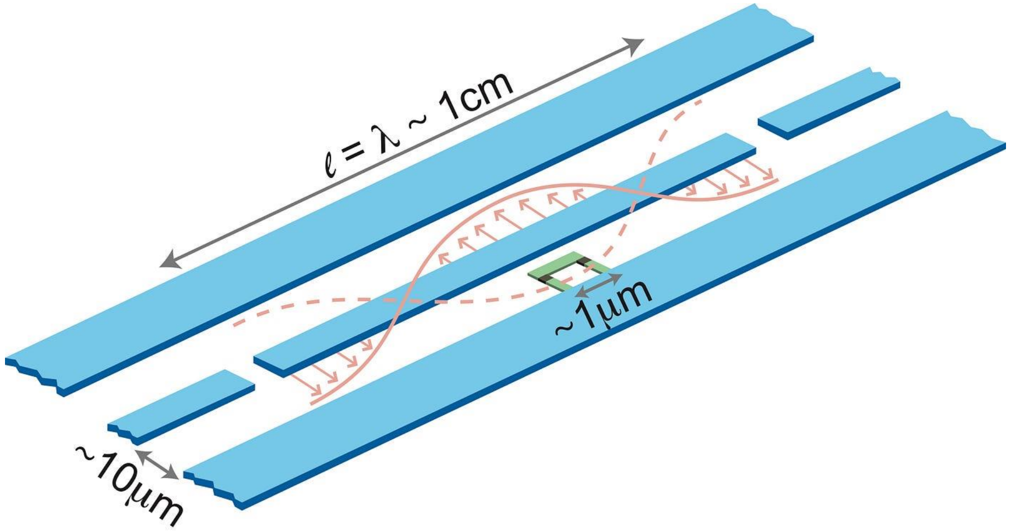
Cavity QED

$$H_{JC} = \hbar\omega_{cavity} a^{+}a + \hbar\omega_{atom}\frac{\sigma_z}{2} + \hbar g(a^{+}\sigma_{-} + a\sigma_{+})$$



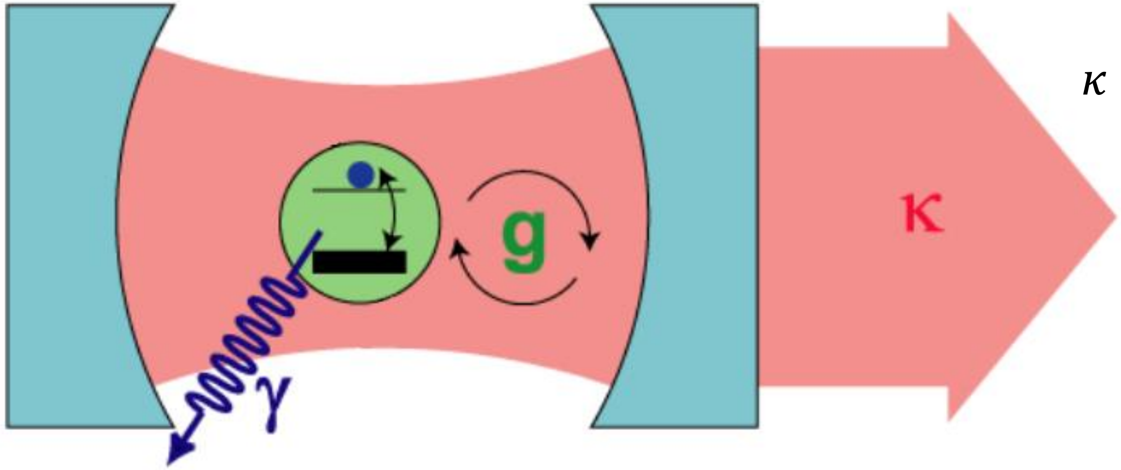
circuit QED

$$H_{JC} = \hbar\omega_{resonator} a^{+}a + \hbar\omega_{qubit}\frac{\sigma_z}{2} + \hbar g(a^{+}\sigma_{-} + a\sigma_{+})$$



A. Blais, R.-S. Huang, A. Wallraff, S. M. Girvin, and R. J. Schoelkopf, Physical Review A **69**, 062320 (2004).

What are the relevant parameters?



$$\kappa = \frac{2\pi}{Q}$$

$$\gamma = \frac{2\pi}{T_2}$$

$$\mathrm{g} \sim Z_r = \sqrt{L_r/C_r}$$
$$\mathrm{g} \sim A^{-1/2}$$

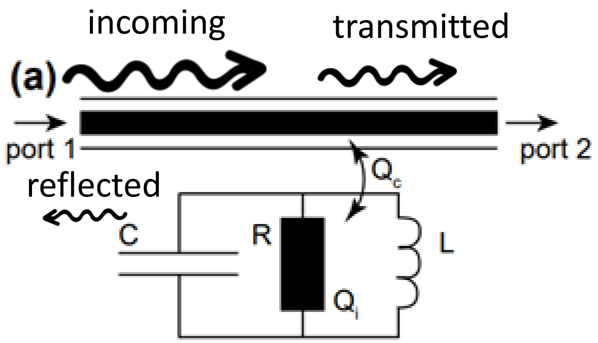
γ is determined by the coherence of your 2 level system

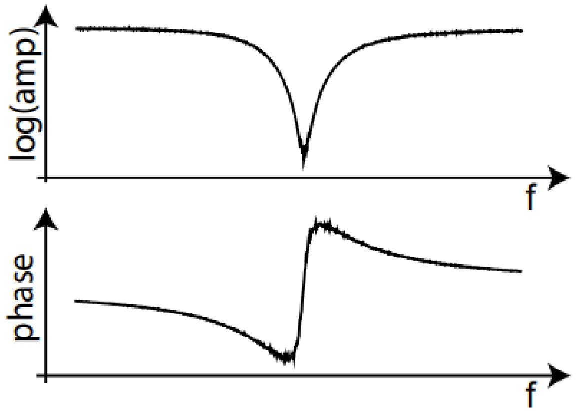
κ is determined by the confinement of your cavity

g is determined by the nature of the interaction and the resonator circuit parameters

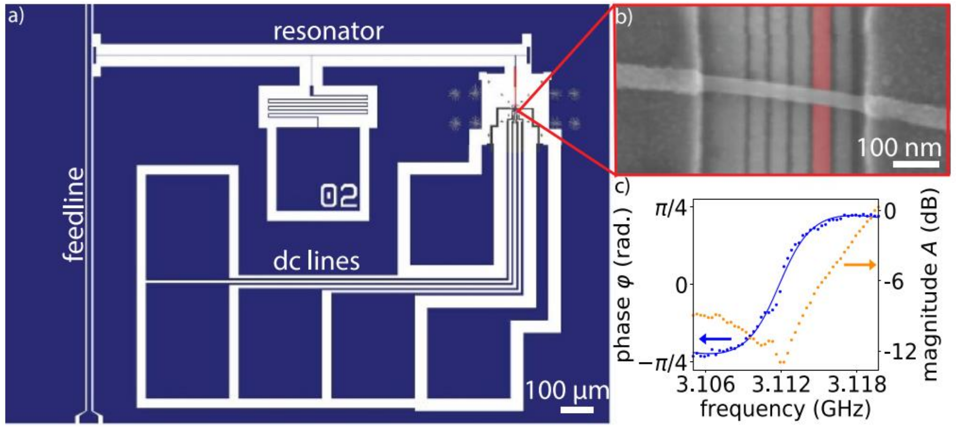
When g $\gg \kappa, \gamma$ then you are in the strong coupling regime and the JC Hamiltonian describes the model

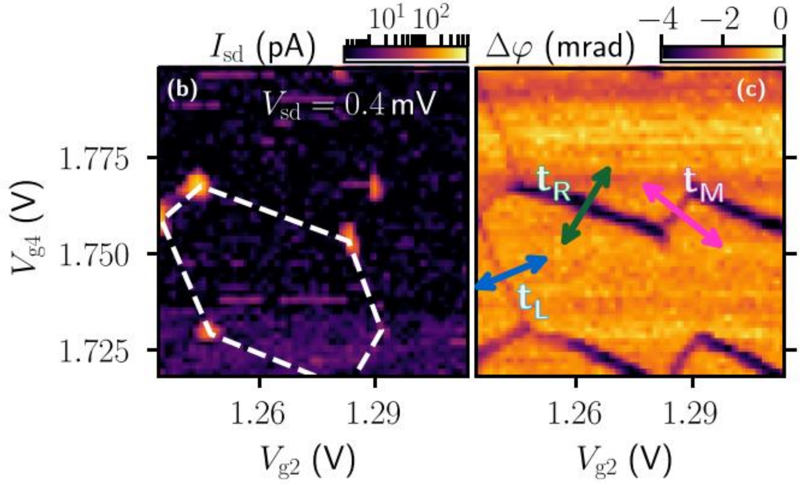
How do we measure a resonator?





Efficient and robust analysis of complex scattering data under noise in microwave resonators
S. Probst et al Rev. Sci. Instrum. 86, 024706 (2015)

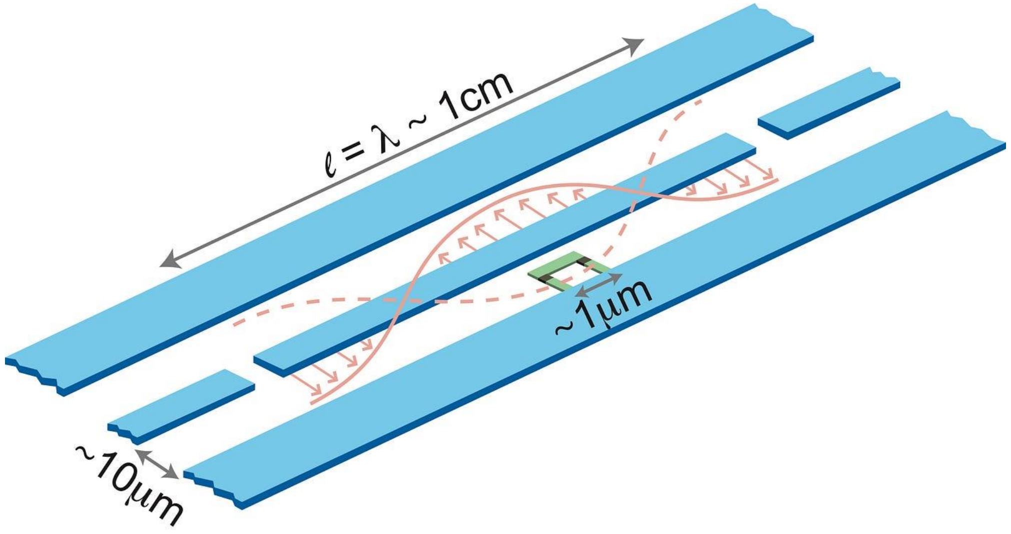




Charge-sensing of a Ge/Si core/shell nanowire double quantum dot using a high-impedance superconducting resonatorJ. H. Ungerer, P. Chevalier Kwon et al Mater. Quantum. Technol. 3 031001 (2023)

Circuit QED

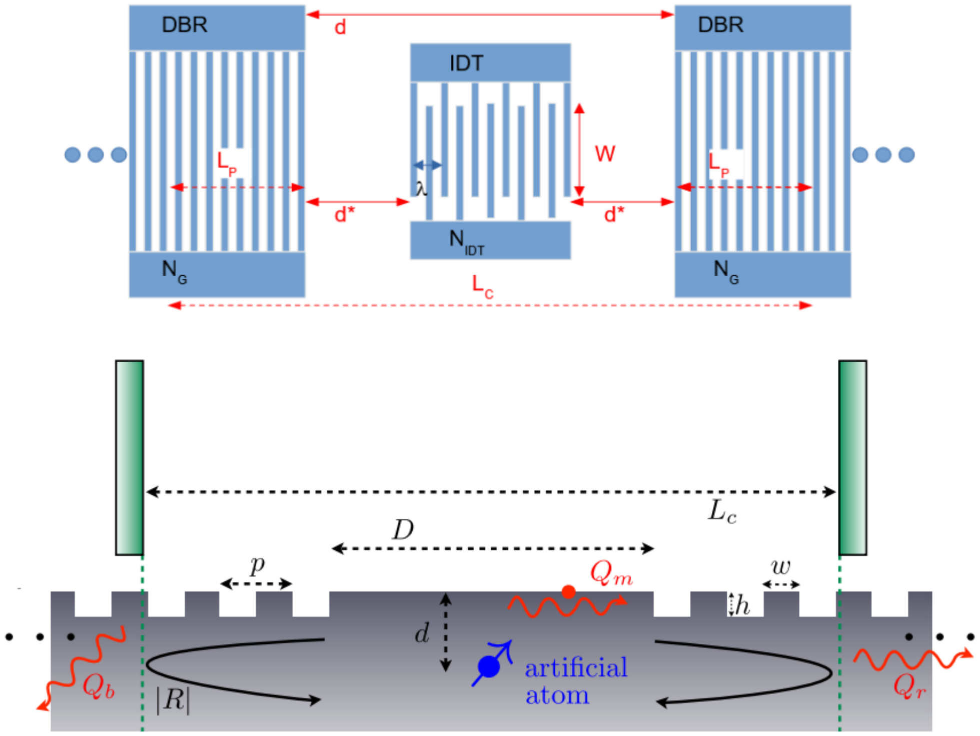
$$H_{JC} = \hbar\omega_r a^+ a + \hbar\omega_q \frac{\sigma_z}{2} + \hbar g(a^+\sigma_- + a\sigma_+)$$



Cavity quantum electrodynamics for superconducting electrical circuits: An architecture for quantum computation
A. Blais et al Physical Review A **69**, 062320 (2004).

Circuit QED with phonons (QAD?)

$$H_{JC} = \hbar\omega_r a^+ a + \hbar\omega_q \frac{\sigma_z}{2} + \hbar g(a^+\sigma_- + a\sigma_+)$$



Universal Quantum Transducers Based on Surface Acoustic Waves
M. J. A. Schuetz et al Phys. Rev. X **5**, 031031

The 1 port Saw resonator

$$Q_0 = \frac{\pi(\underline{d} + 2\underline{L_p})}{\underline{\lambda_0}(1 - \tanh(|\underline{r_S}|\,\underline{N_G}))}$$

$$Q_{\text{Diffraction}} = \frac{5\pi}{|1+\underline{\gamma}|}\left(\frac{W}{\underline{\lambda_0}}\right)^2$$

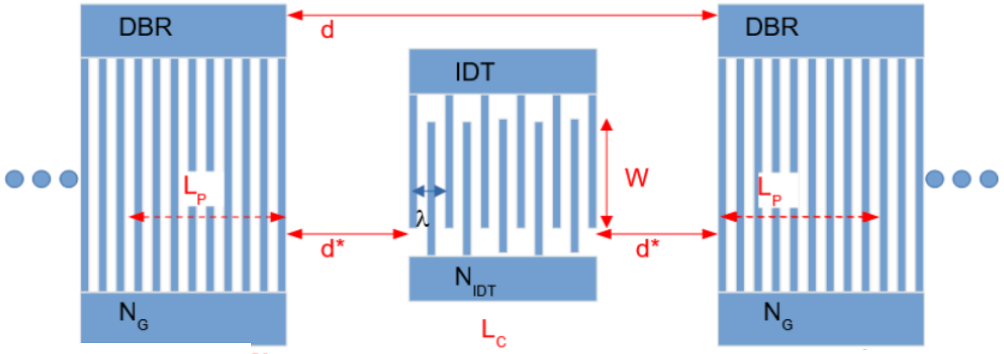
$$Q_{ext} = \frac{1}{5.74\,\underline{v_{SAW}}\,\underline{Z_C}\,\underline{C_S}\,\underline{W}\,\underline{K^2}\,(0.5\underline{N_{IDT}})^2} \cdot \underline{L_c}$$

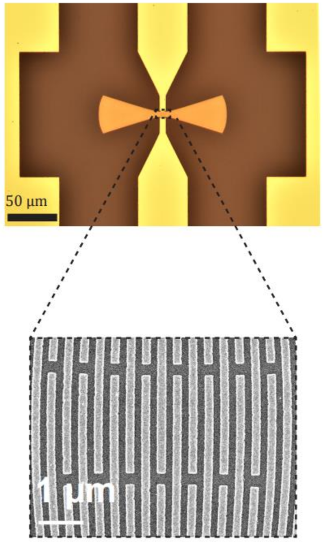
$$Q_{\text{bk}} = 2\pi \underline{N_{\text{eff}}}/[\underline{C_b}(\underline{h/\lambda_c})^2]$$

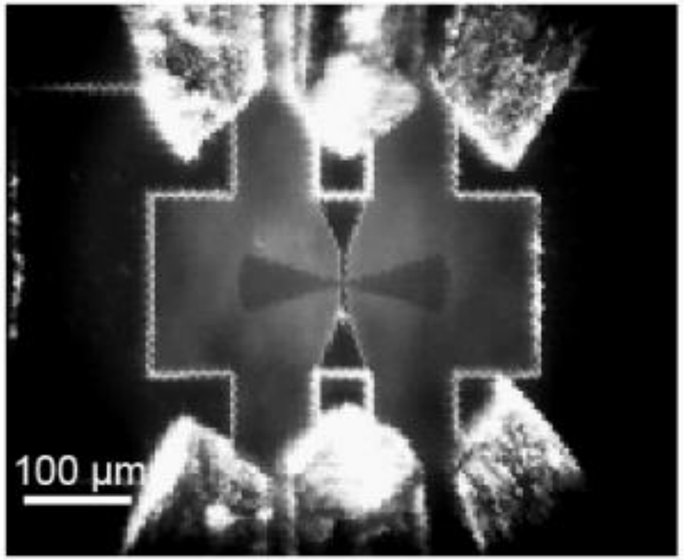
	GaAs	LiNbO3
V_saw	**2864 m/s**	**3488 m/s**
C_s	**1.2 pF/cm**	**4.6 pF/cm**
K^2	**0.07**	**4.8**
gamma	**-0.537**	**-1.08**

Fabrication Parameters

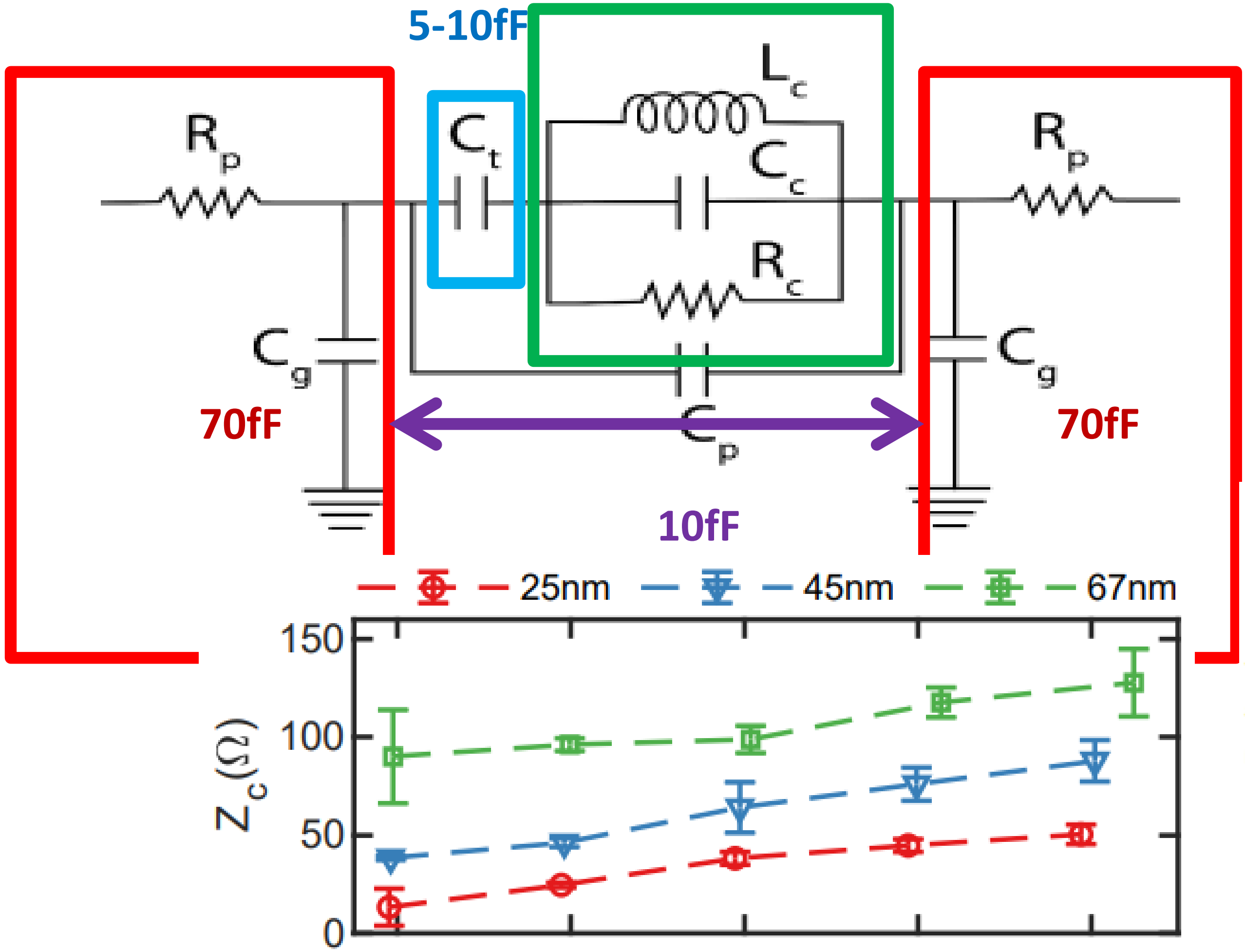
Material Parameters

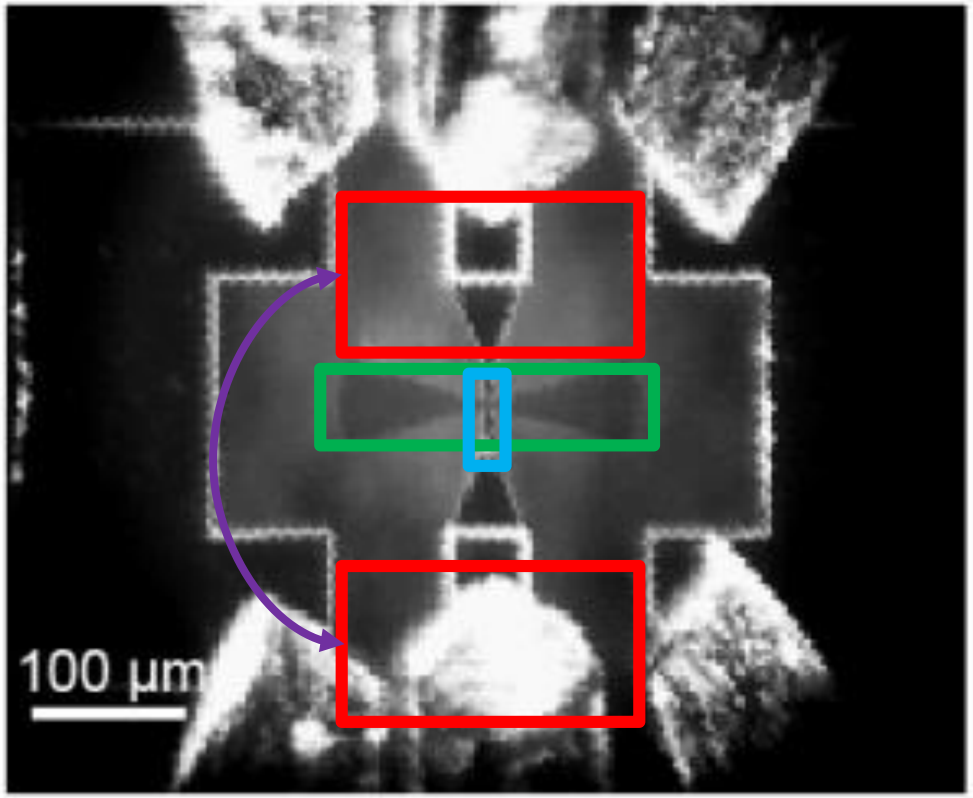






Modeling the resonator





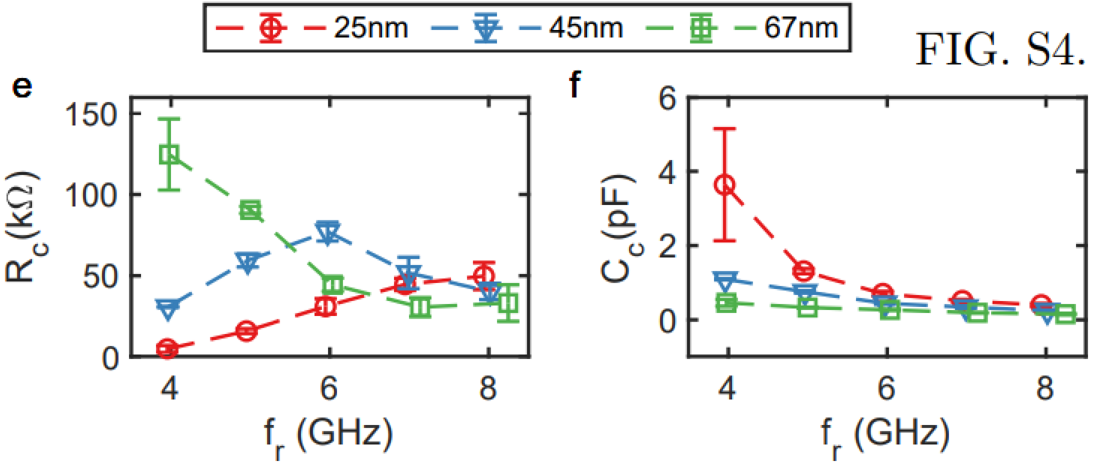


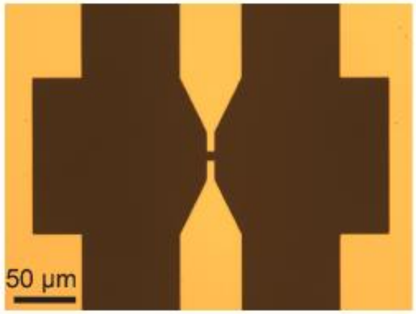
FIG. S4.

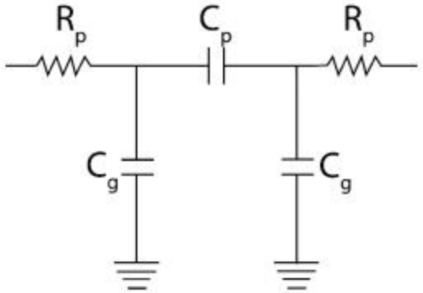
Fitting the parameters

Calibrate the VNA

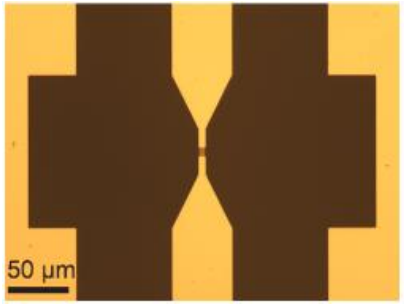
Simulate Cp Cg with a pad only device

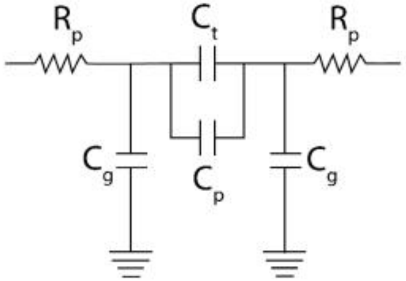
Use the sim-Cg and fit Rp and Cp from a pad only device



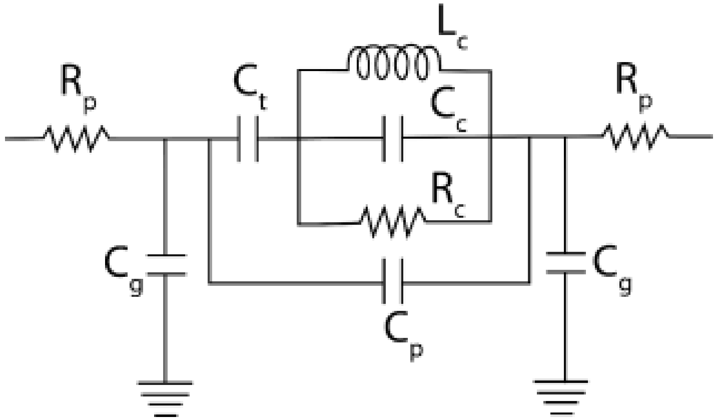


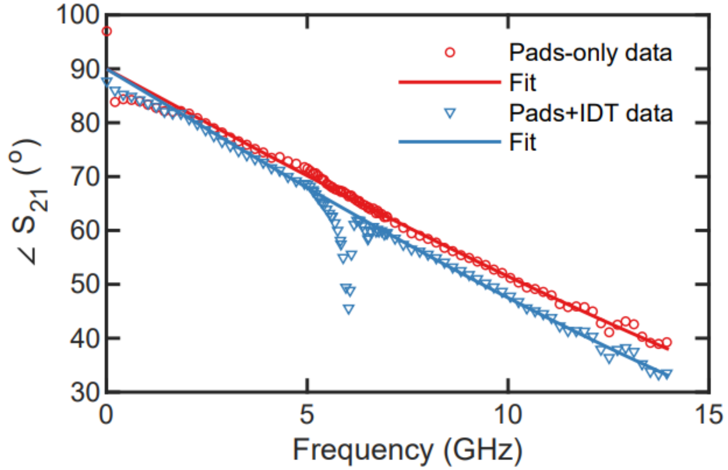
fit Ct and update Rp in a IDT device, ignoring the resonance



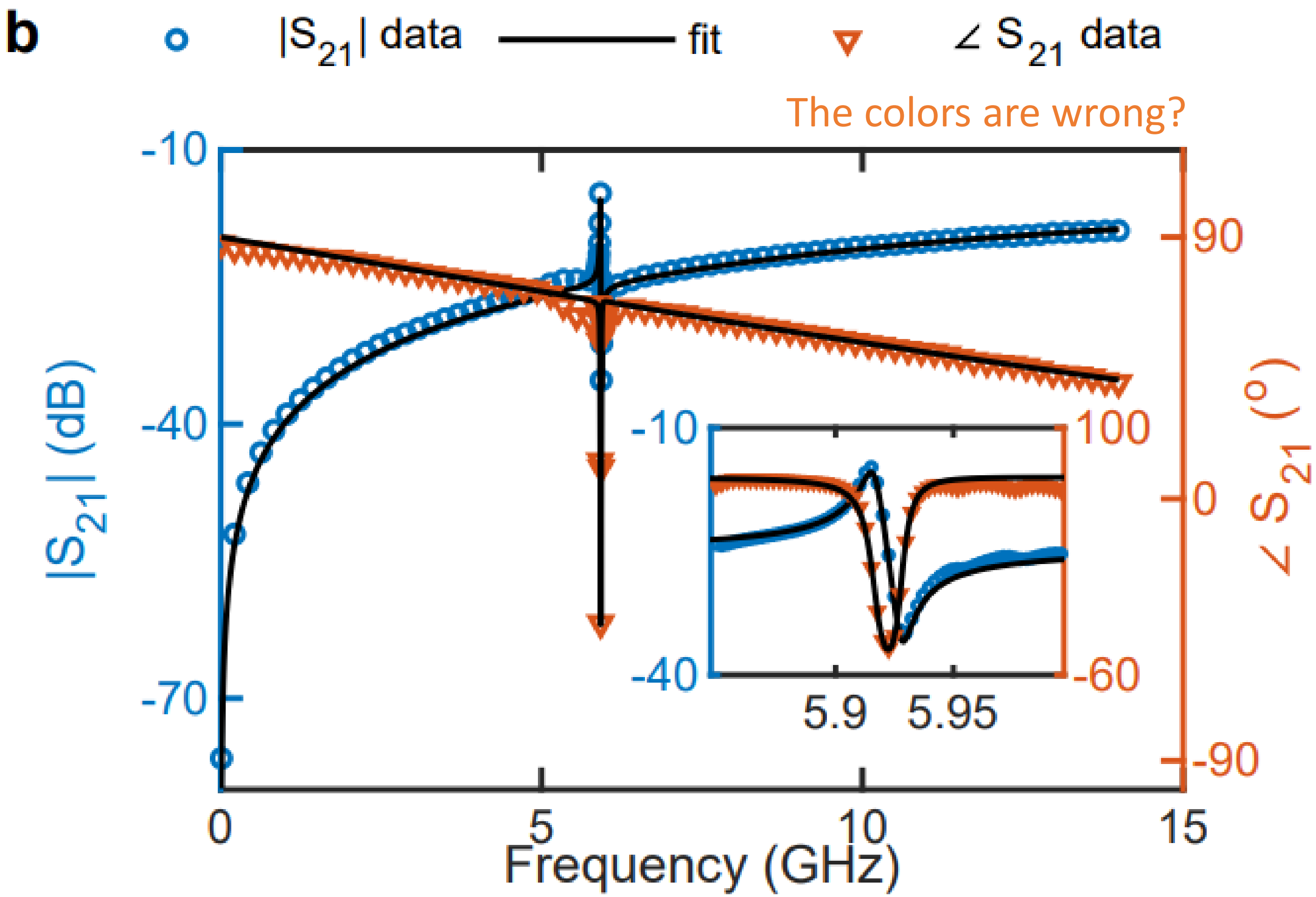


Fit Cc Rc fitting near the resonance

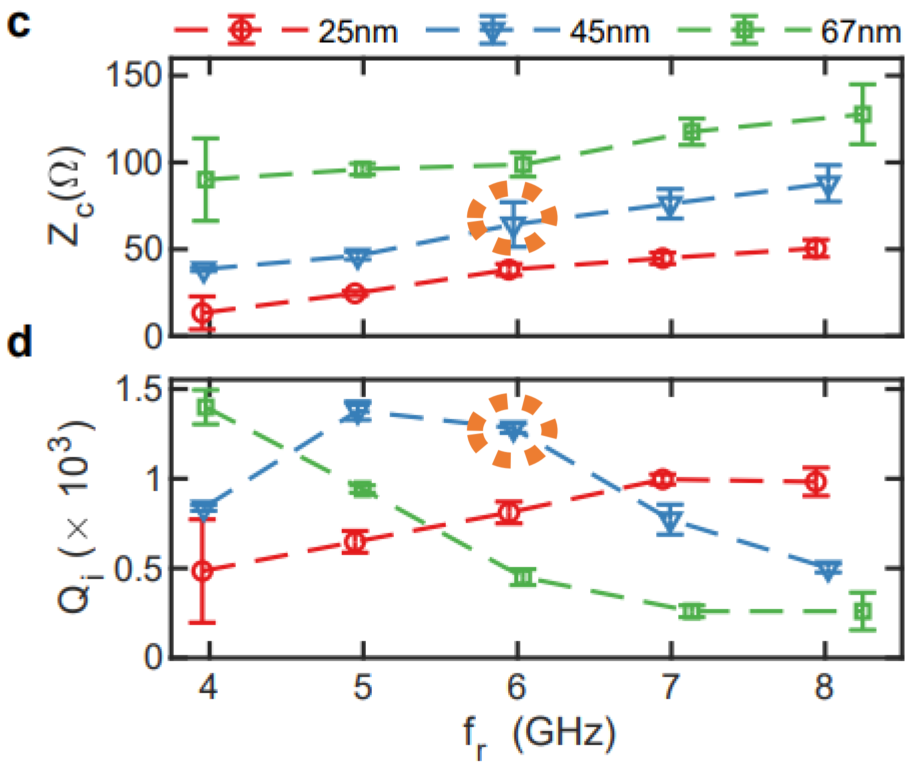




Characterization at RT



The colors are wrong?



QRAP resonators

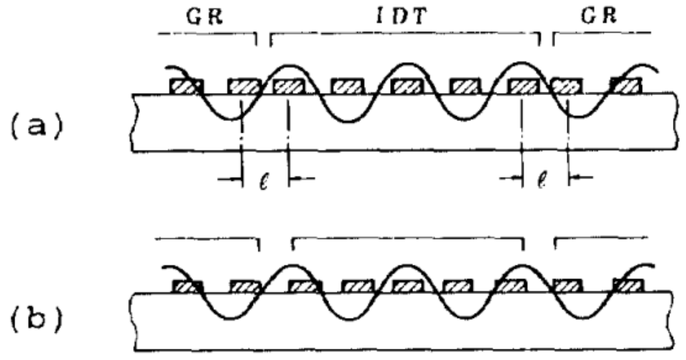
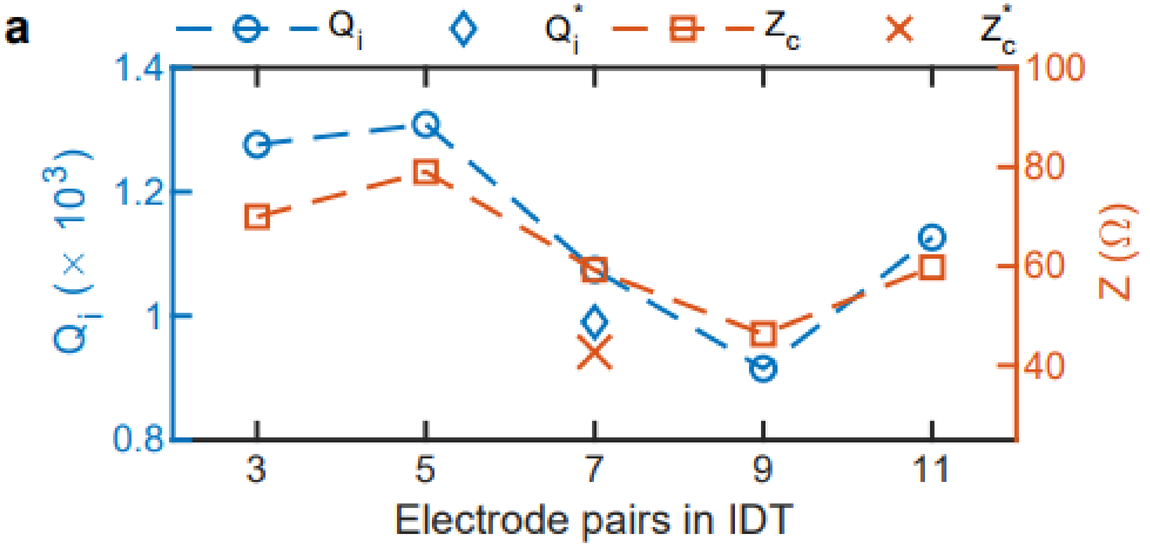


Figure-1 Schematic of SAW Resonators
(a) Conventinal (b) QARP Structure

Fig 3



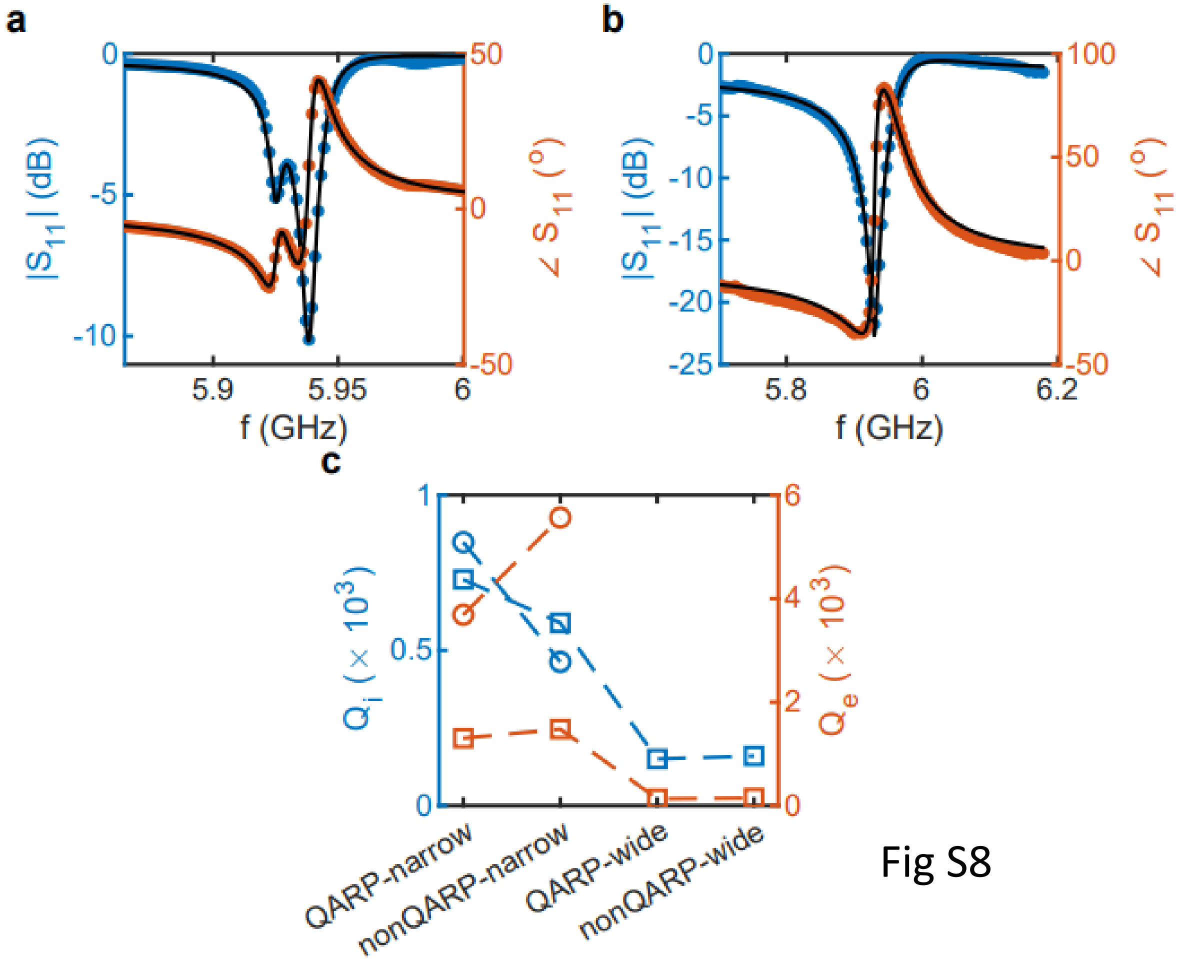
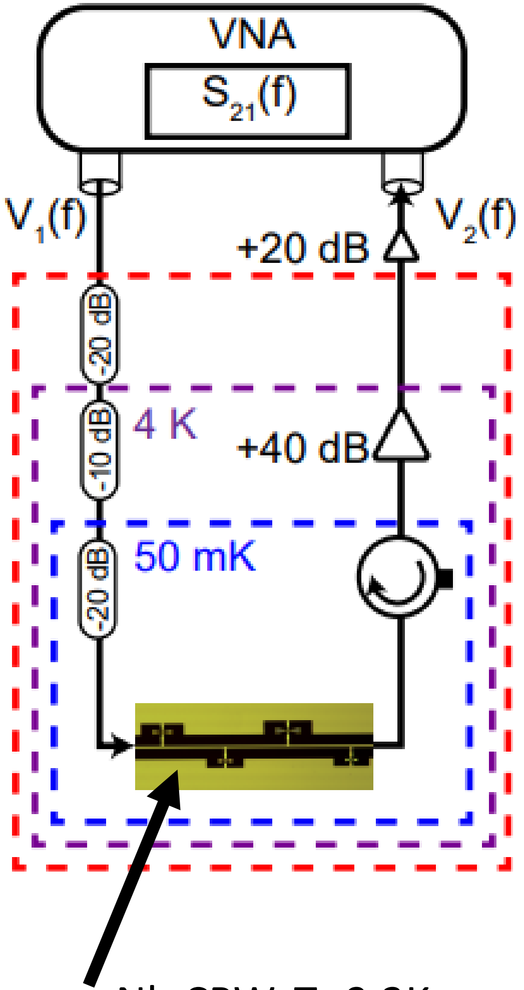


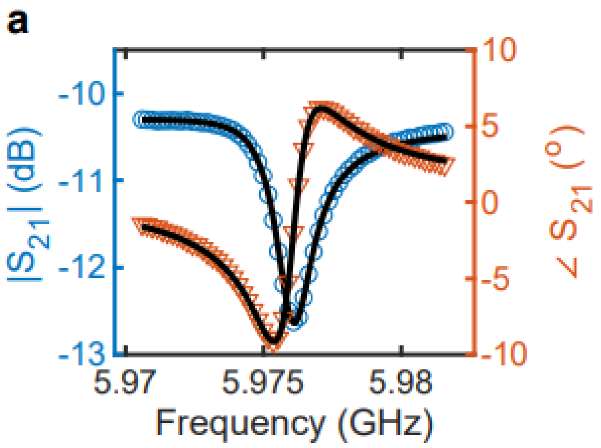
Fig S8

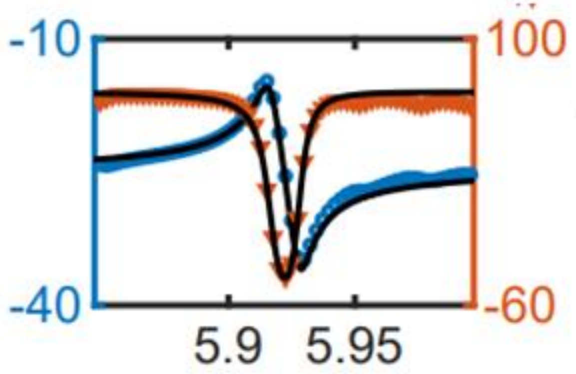
Y. Ebata 10.1109/ULTSYM.1988.49348

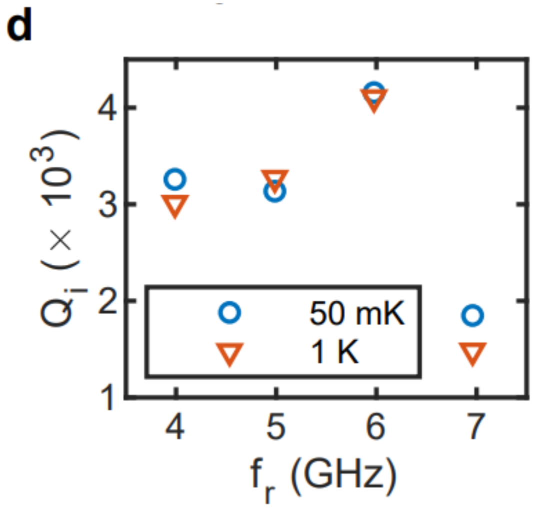
Cryogenic characterization

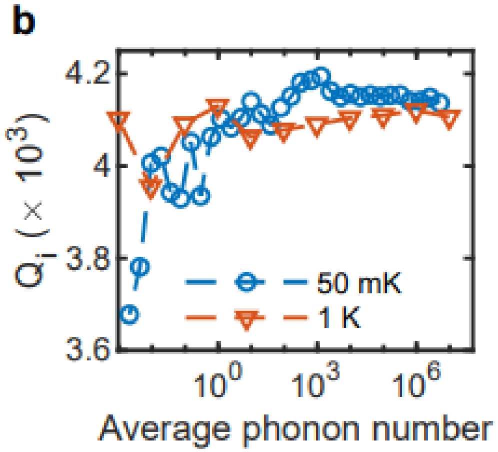


Nb CPW, Tc 9.3K

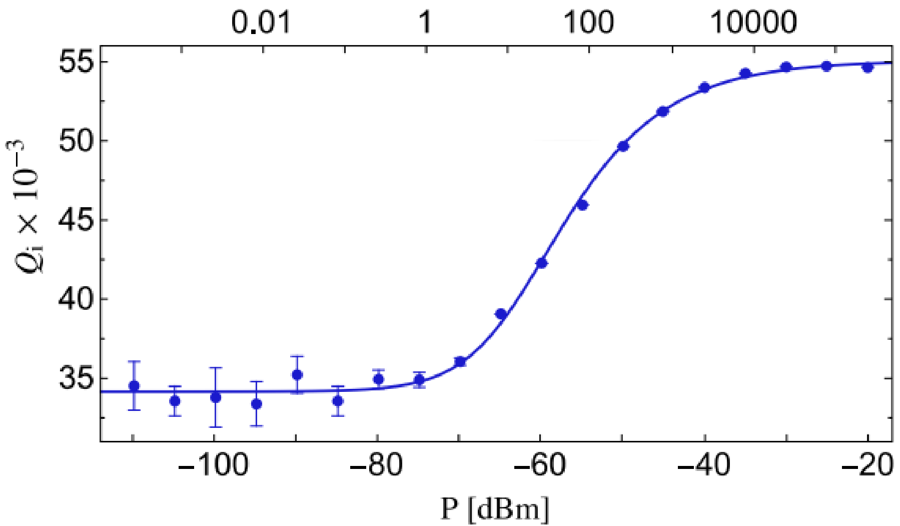








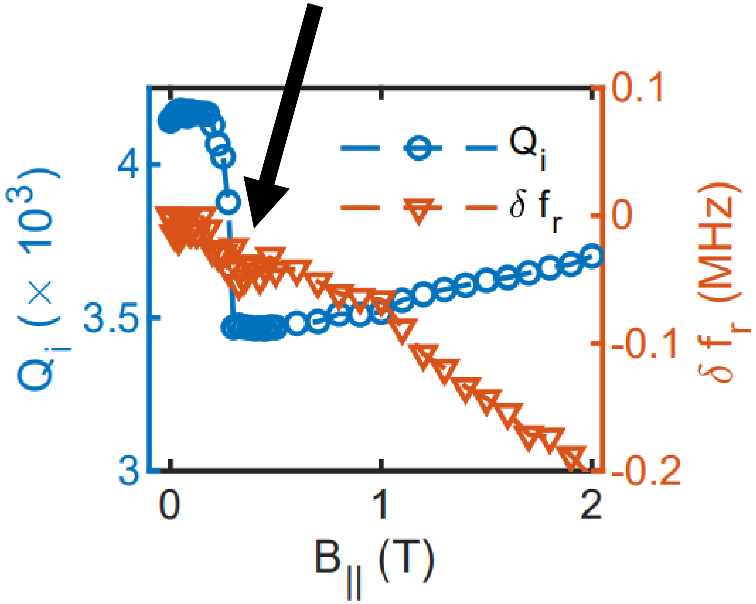
$$\langle n \rangle = \frac{Q_c}{\omega_r}\left(\frac{Q_i}{Q_i + Q_c}\right)^2 \frac{P_{in}}{\hbar\omega_r}$$

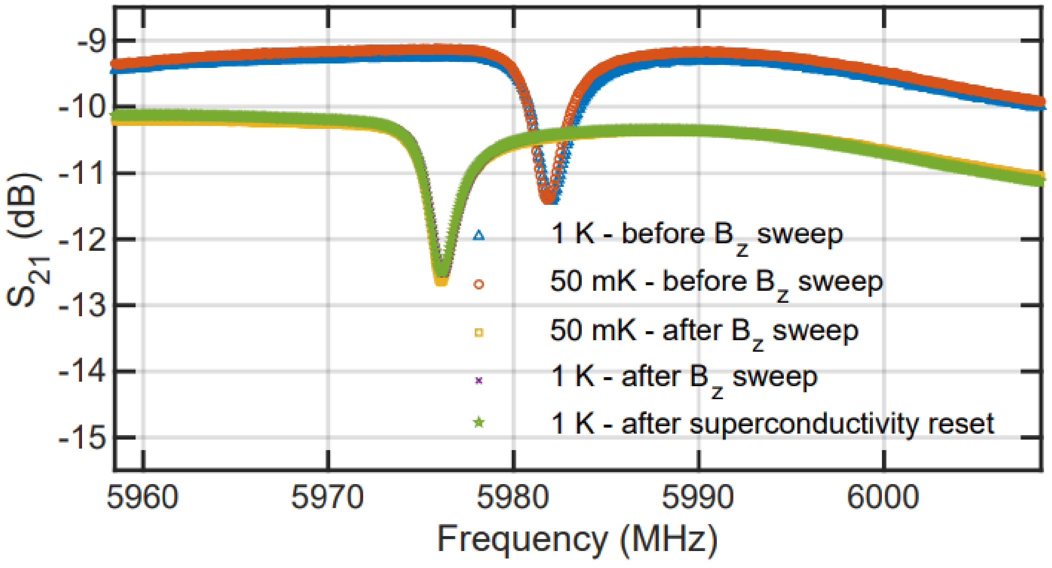


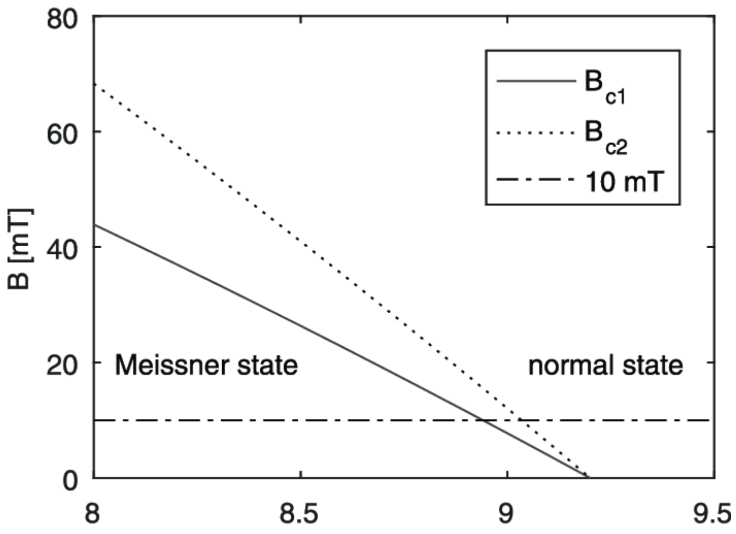
Surface acoustic wave resonators in the quantum regime PRB 93, 041411(R) R. Manenti et al

Magnetic field dependence

Loss of SC of the electrodes





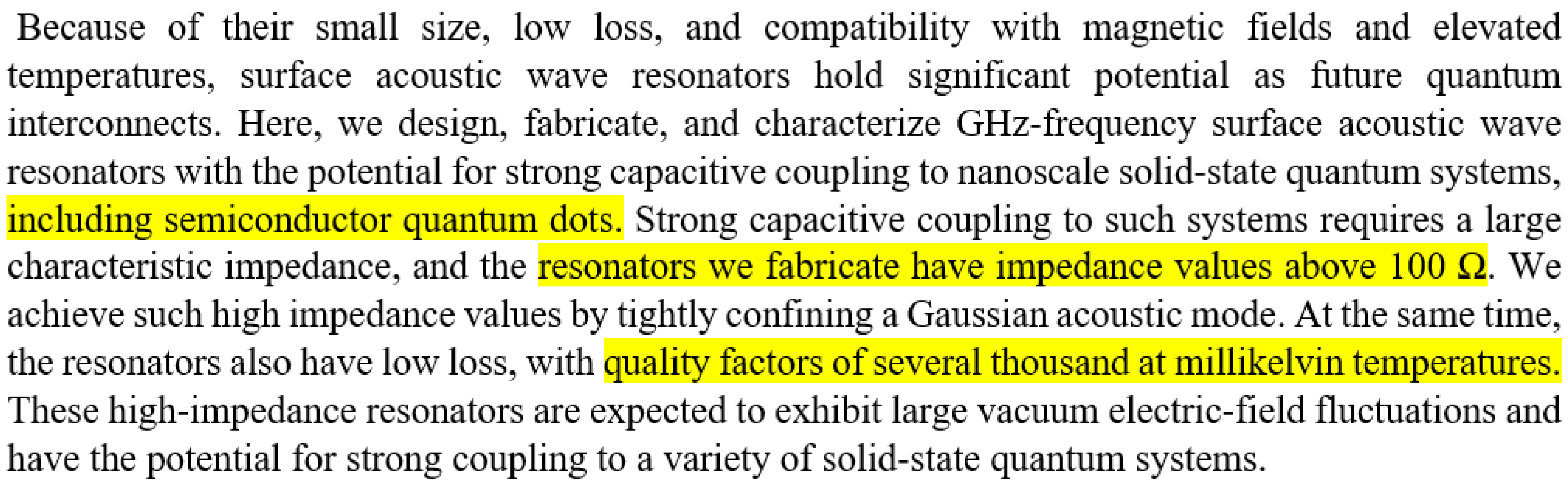


Journal of Applied Physics 122(17):173901
DOI:10.1063/1.4996113

In conclusion

- It’s possible to have high Z at RT
- Loss of SC is not changing Q in a large way

- Do they really show high Z at low temperature?
- The substrate used does not allow for semiconductor dots



Because of their small size, low loss, and compatibility with magnetic fields and elevated temperatures, surface acoustic wave resonators hold significant potential as future quantum interconnects. Here, we design, fabricate, and characterize GHz-frequency surface acoustic wave resonators with the potential for strong capacitive coupling to nanoscale solid-state quantum systems, including semiconductor quantum dots. Strong capacitive coupling to such systems requires a large characteristic impedance, and the resonators we fabricate have impedance values above 100 Ω. We achieve such high impedance values by tightly confining a Gaussian acoustic mode. At the same time, the resonators also have low loss, with quality factors of several thousand at millikelvin temperatures. These high-impedance resonators are expected to exhibit large vacuum electric-field fluctuations and have the potential for strong coupling to a variety of solid-state quantum systems.