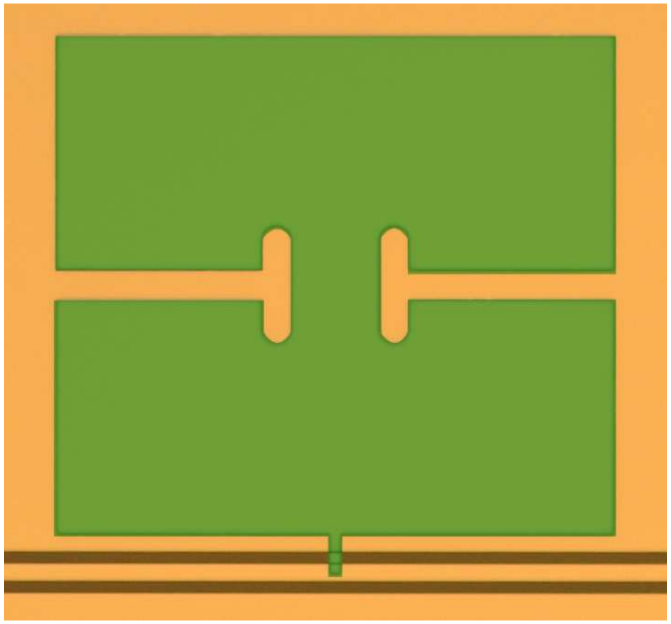
Parallel plate microwave kinetic inductance detectors



Grégoire Coiffard, Ben Mazin, Paul Szypryt, Gerhard Ulbricht (now in Dublin), Miguel Daal and Nicholas Zobrist

Mazin Lab
All of the wavelengths
All of the times
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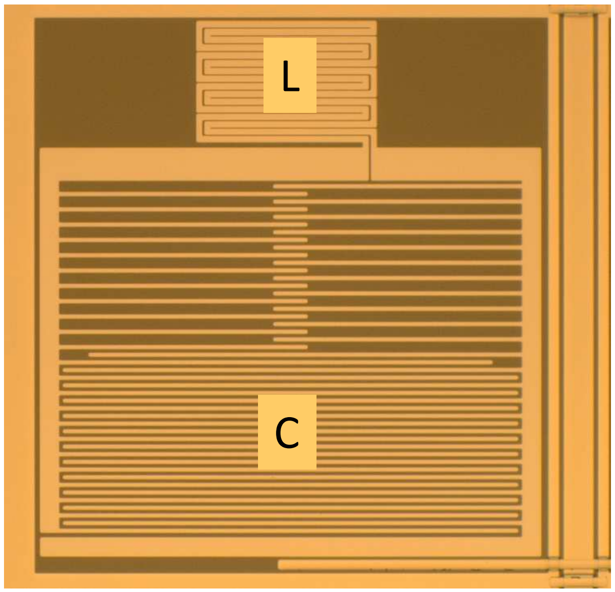
17th International Workshop on Low Temperature Detectors
July 17th – 21th 2017, Kurume (Japan)

Parallel Plate Capacitor MKIDs

Classical LEKID design

High meandered inductance



Small interdigitated capacitance

f_0 dominated by L

$$f_0 \propto \frac{1}{\sqrt{LC}}$$

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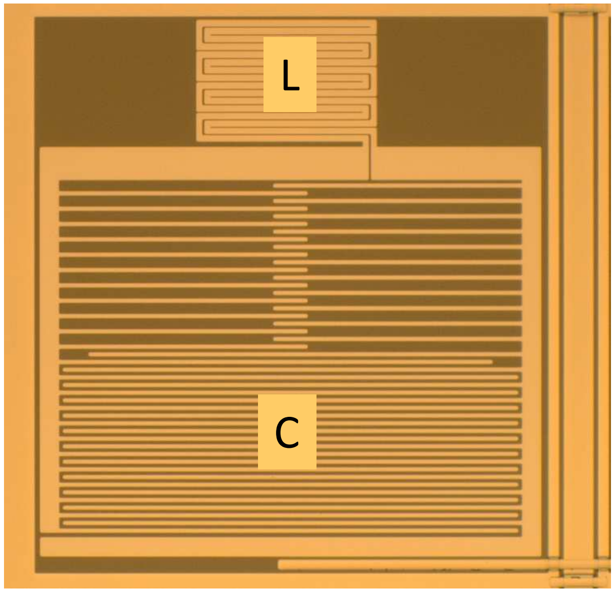

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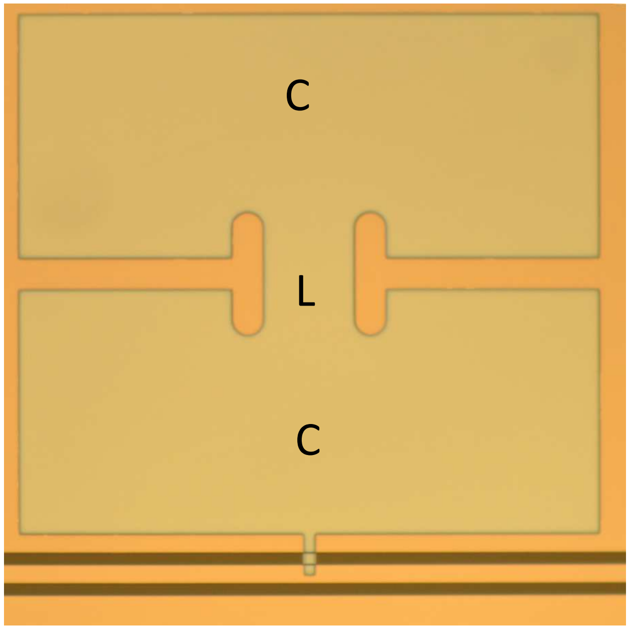
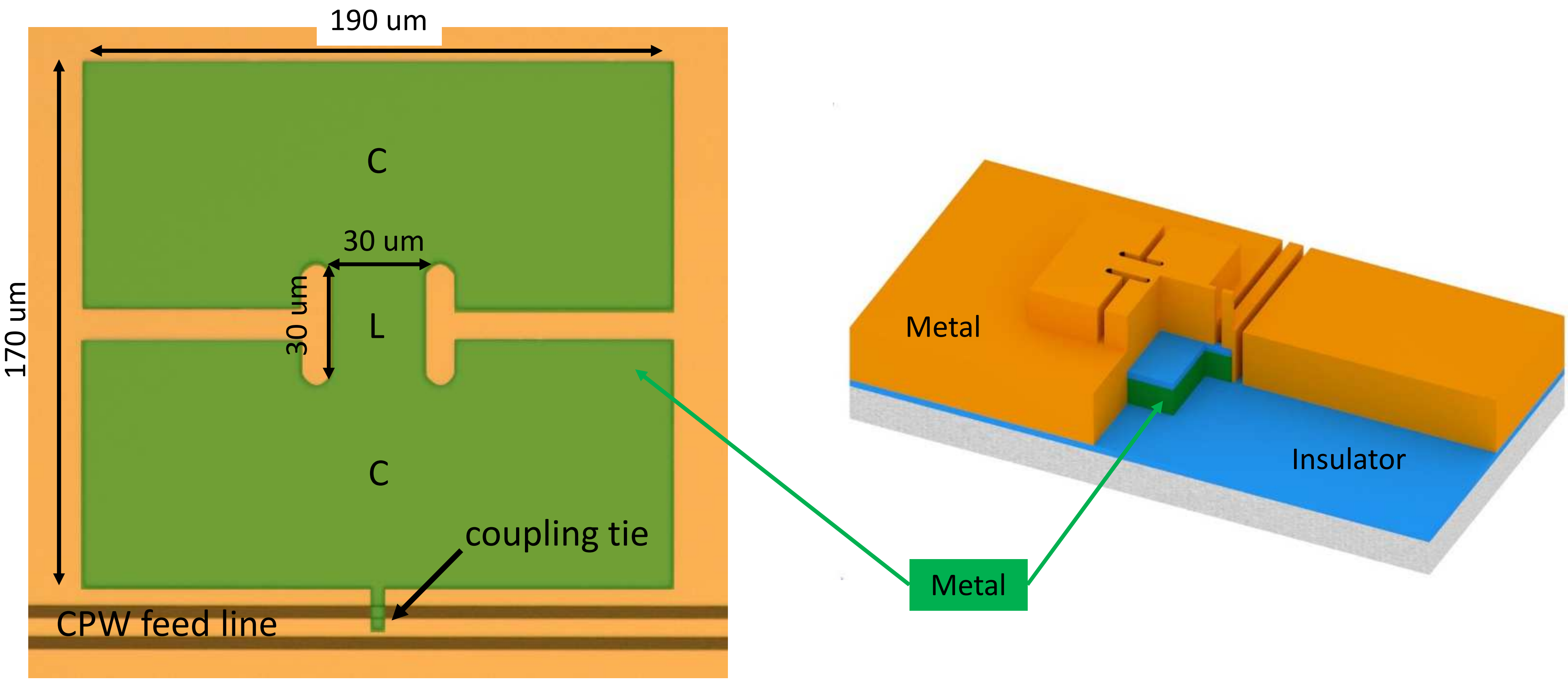
Parallel plate design



Major change = two large parallel plate capacitors and small square inductance

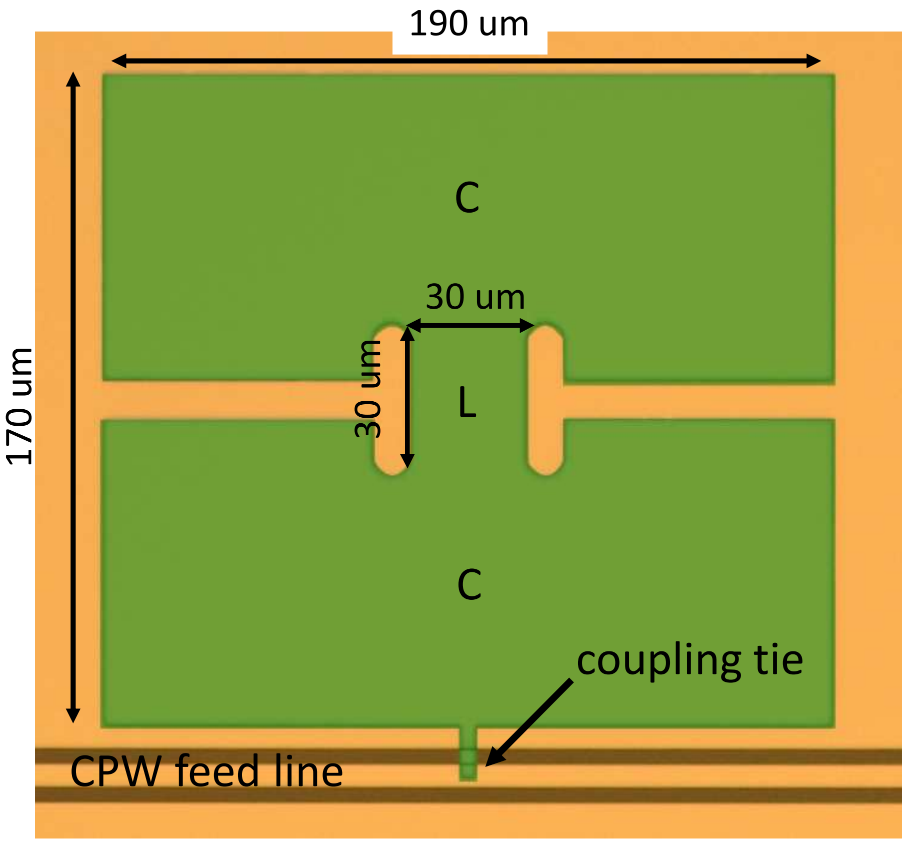
f_0 dominated by C

Parallel Plate Capacitor MKIDs



(color added for clarity – Insulator not shown)

Parallel Plate Capacitor MKIDs



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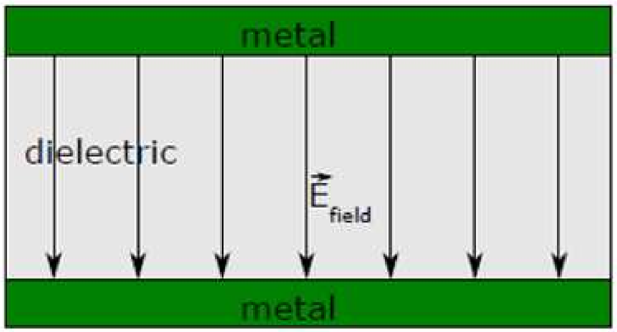
- Maximize the readout power before nonlinear effects thanks to the low current density in the wide inductor (30umx30um)
- Improvement in signal-to-noise ratio due to the saturation of TLS (drive at high power)
- Inductor geometrically more uniform than a classical meandered inductor → increase energy resolution

Parallel Plate Capacitor MKIDs

$$S_{TLS}(\nu) = \kappa(\nu,\omega,T) \times \frac{\int_{V_{TLS}} |\vec{E}(\vec{r})|^3 d^3\vec{r}}{4\left(\int_V |\varepsilon(\vec{r})\vec{E}(\vec{r})|^2 d^3\vec{r}\right)^2}$$

J. Gao et al. Applied Physics Letters 92, 212504 (2008)



For a parallel plate capacitor: $V_{TLS} = V$

$$S_{TLS} \propto \frac{E^3 V}{4\varepsilon^2 E^4 V^2} \propto \frac{1}{\varepsilon^2 E V}$$

Lower TLS noise by:

- Using a high ε material
- Maximizing the electric field in the capacitor (driving the MKID at high power)
- Making the volume of the capacitor as large as possible

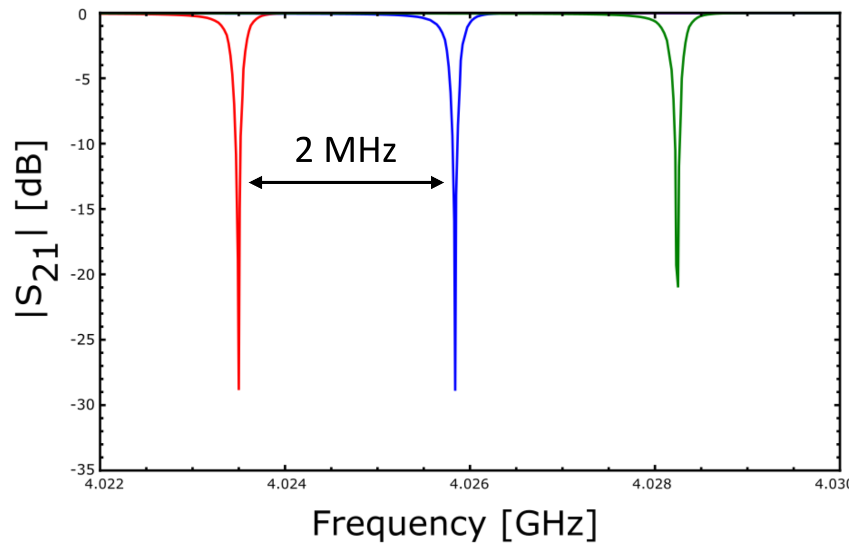
EM simulations

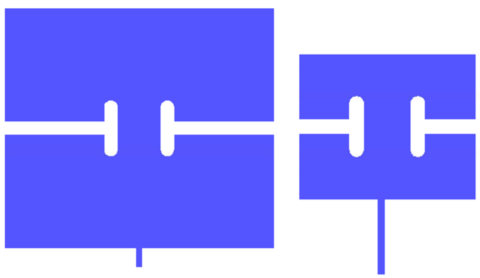
- Resonant frequencies between 4-8GHz
- Pixel pitch ~ 150umx150um
- Use PtSi L_{kin} ~ 10pH/sq

$$f_0 \propto \frac{1}{\sqrt{LC}} \qquad C \propto \frac{\varepsilon A}{t}$$

Dielectric : Al_2O_3 ε = 10 → 10 nm

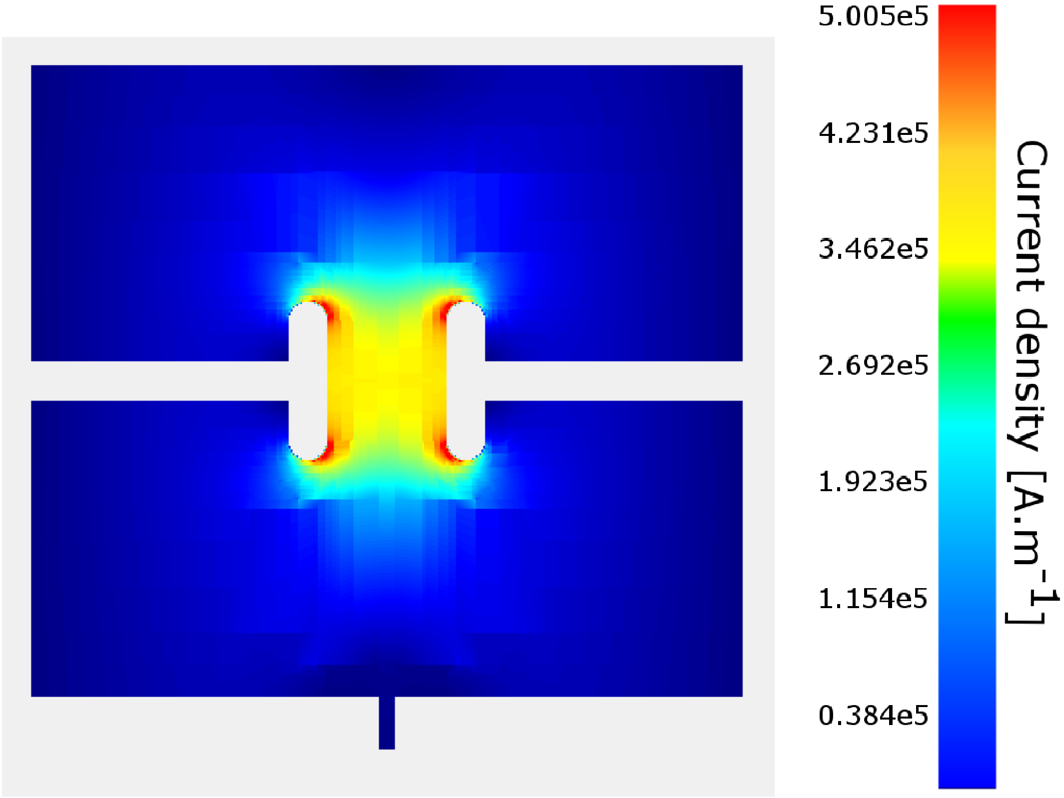
Resonances positions mainly depends on the thickness of the Al_2O_3 layer
→ Has to be very uniform to avoid collisions





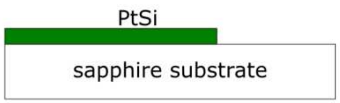
Resonances tuning by shrinking the capacitor size step-by-step

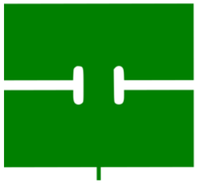
EM simulations



Inductor = high current density area
→ Sensitive part of the MKID

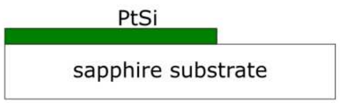
Micro-fabrication process

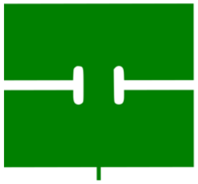




Sputtering of Pt and Si + annealing at 300C = 55nm thick PtSi film
→ Patterning of the inductor, the coupling tie and the first side of the parallel plate capacitor

Micro-fabrication process





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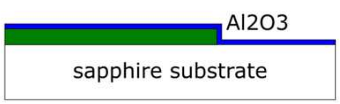

Atomic layer deposition of 10 nm of Al_2O_3 over the entire wafer (thickness uniformity of 98% over a 4inch wafer)

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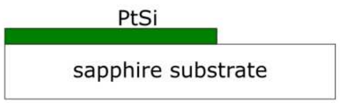

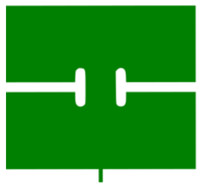

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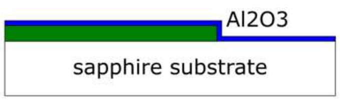

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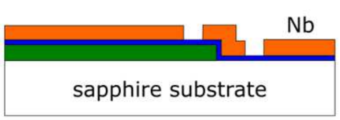
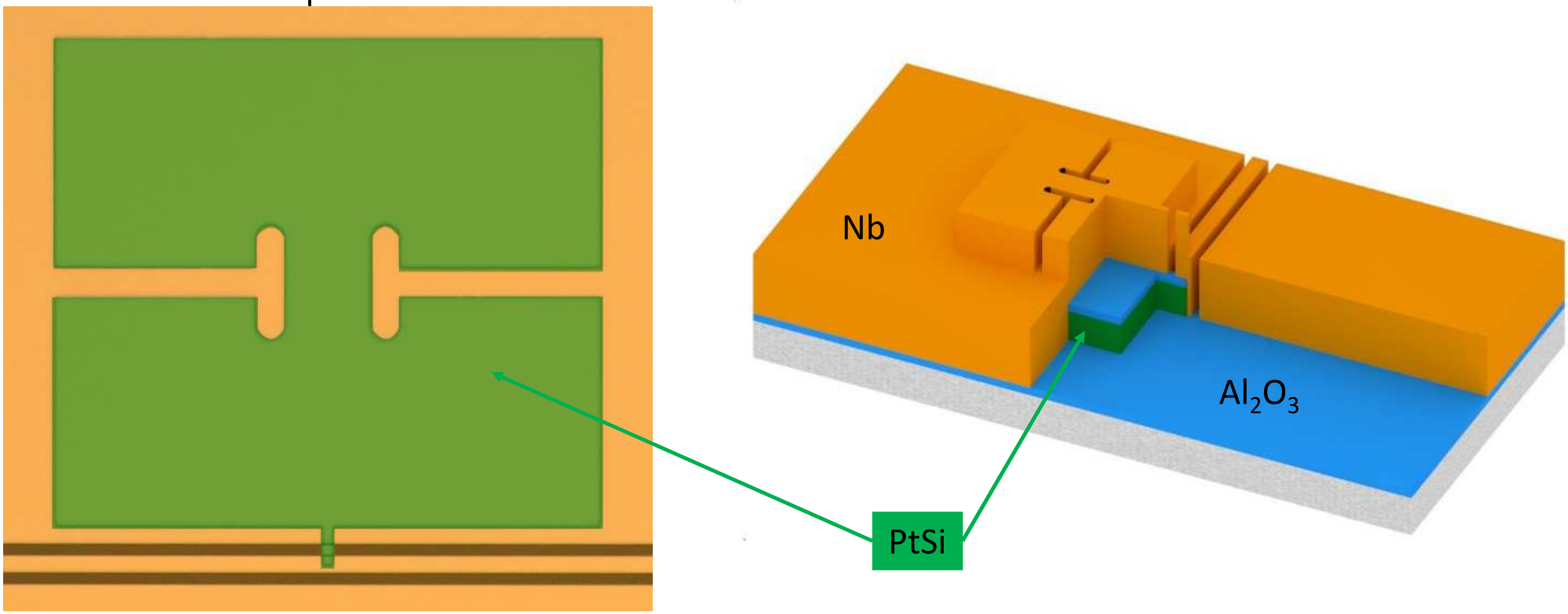


Sputtering of 80 nm of Nb
→ CPW feedline and second side of the capacitor

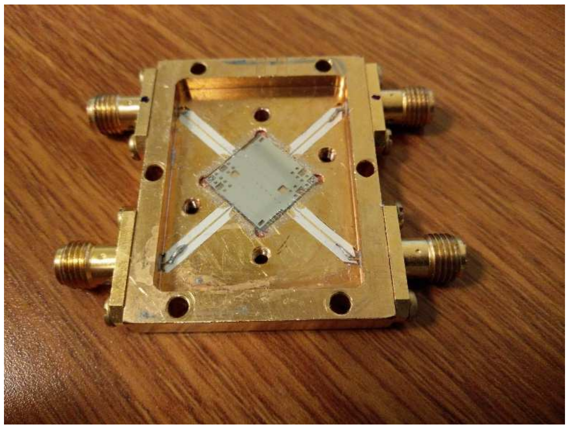
Micro-fabrication process

Top view



(color added for clarity – Al_2O_3 not shown)

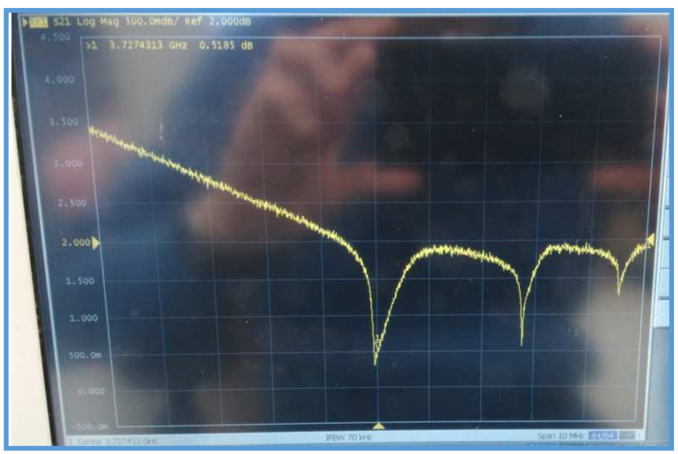
Characterization



Test device:

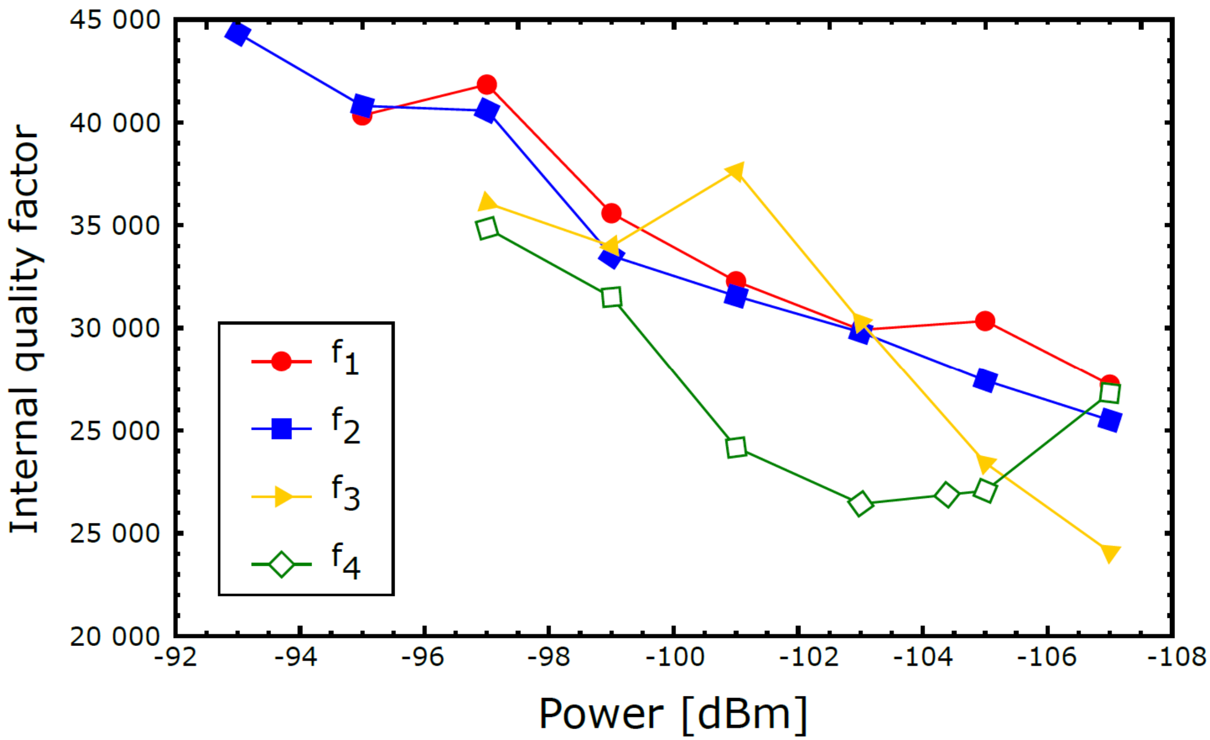
- 2 feedlines (different inductor dimensions)
- 18 resonators, 3x6 centered on 4 GHz, 6 GHz and 8 GHz

Parallel plate MKIDs resonate



- Resonances located around their design frequencies
- 13 resonances out of 18 were identified
- Few dB deep, best resonances Qi ≈ 35 000 – 40 000

Characterization



Qi increases as the power is increased
→ We tend to saturate TLS loss

Parallel plate MKIDs become nonlinear at high power: A factor of 4 compared to lumped element design

Parallel plate microwave kinetic inductance detectors, submitted to Applied Physics Letters last week

Conclusions & Perspectives

- Fabricated working parallel plate resonators

- Higher readout power (a factor of 4) before nonlinearity compared to classical LEKID geometry ≈ -92dBm

- Work on dielectric loss to reduce the noise, improve Q_i and increase saturation power

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- Fabricated working parallel plate resonators
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More tests are being done with alternative dielectric materials (e.g. HfO_2 , $\varepsilon = 25$)

Our process requires a backside illumination : test on double side polished wafer / mushroom absorber on top of the inductor

An amplitude readout approach can be used if the phase noise remains too high in these devices