The fabrication of 20,000 pixel kinetic inductance detector arrays for near-IR to visible astronomy

Mazin Lab

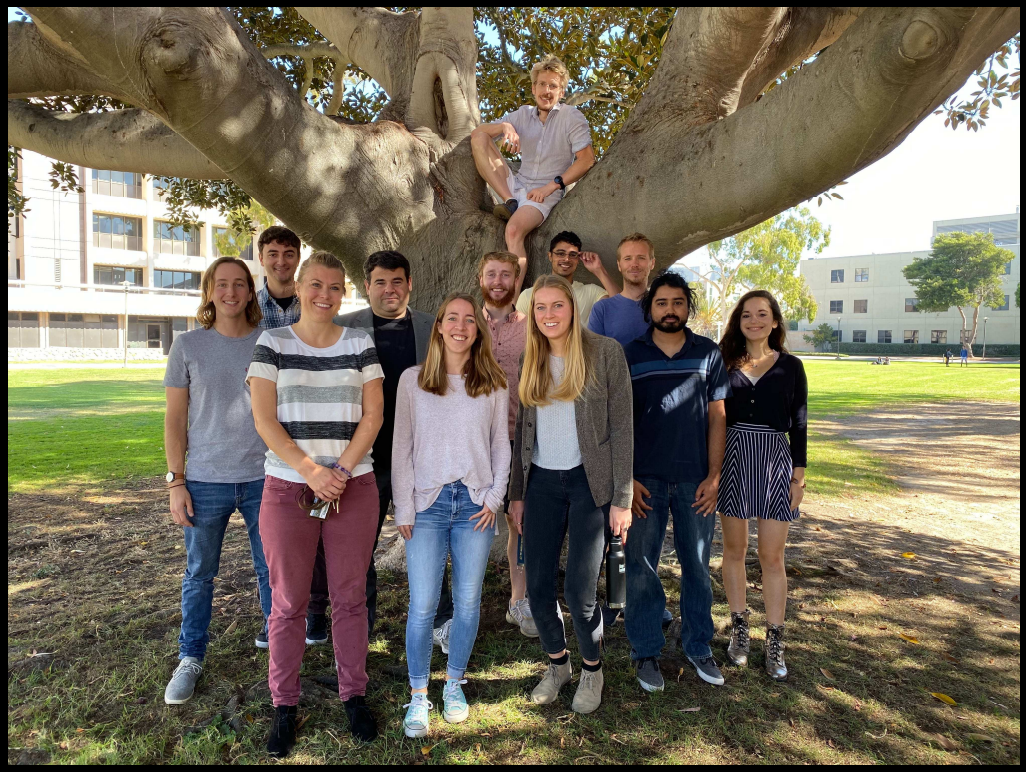
UNIVERSITY OF CALIFORNIA · SANTA BARBARA

LET THERE BE LIGHT

All of the wavelengths

All of the times

mazinlab.org

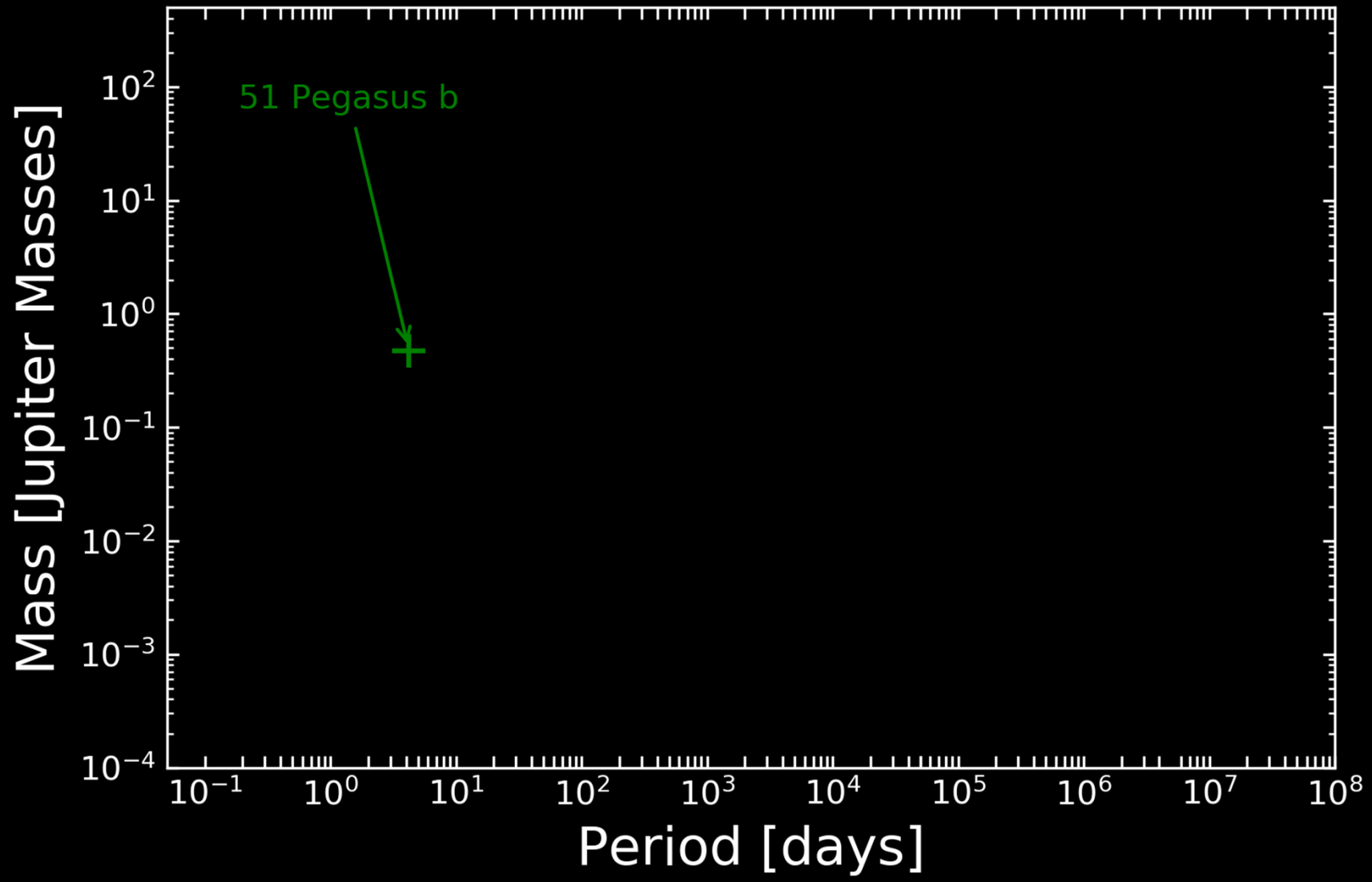


Grégoire Coiffard

Ben Mazin, Jeb Bailey, Clint Bocksteigel, Miguel Daal, Kristina Davis, Rupert Dodkins, Neelay Fruitwala, Isabel Lipartito, Jenny Smith, Sarah Steiger, Noah Swimmer, Alex Walter, Nicholas Zobrist and Bruce Bumble (NASA JPL)

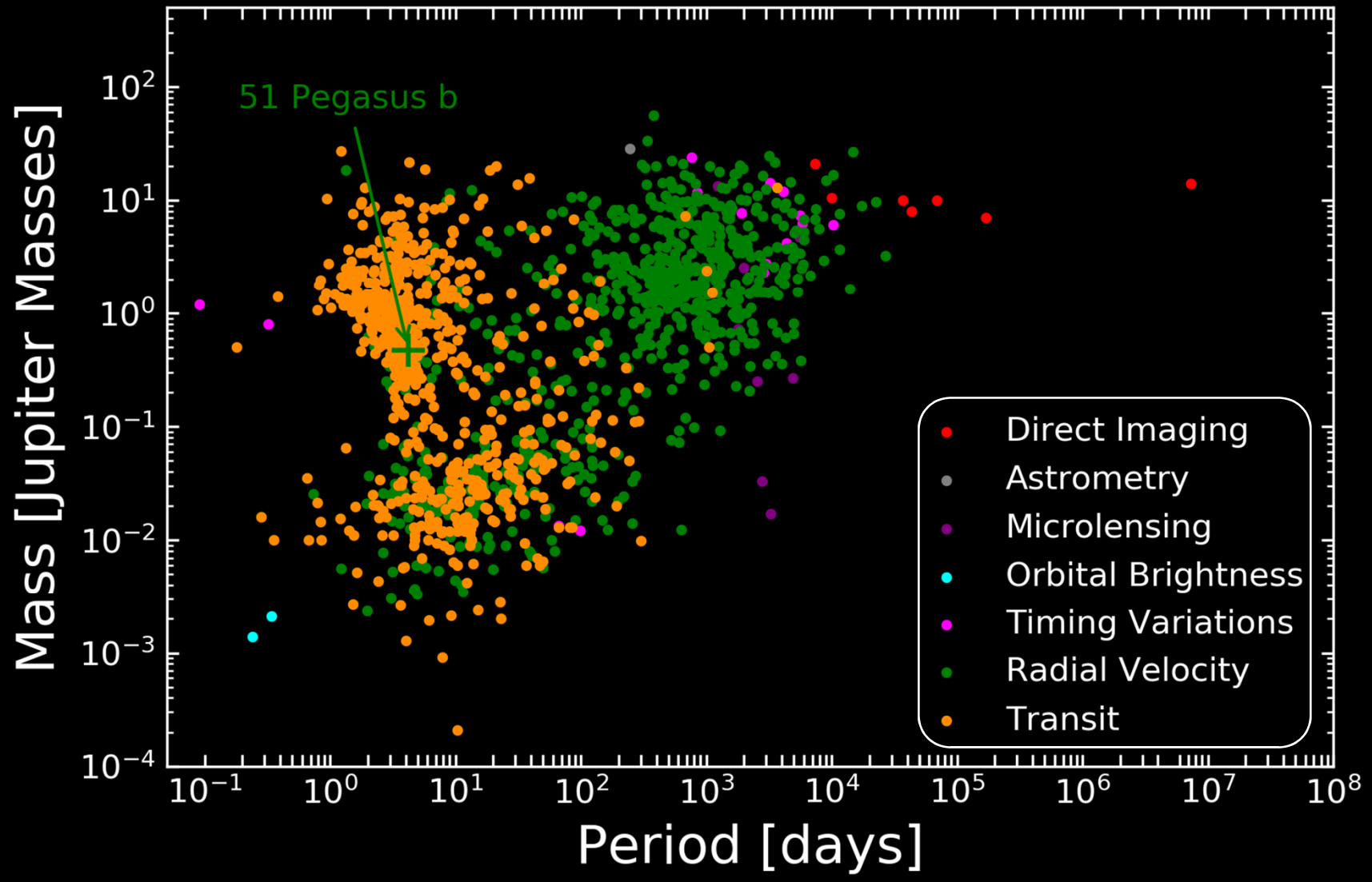
TechTalk UCSB, December 5

First exoplanet discovered: 51 Pegasus b in 1995 (Nobel Prize in Physics 2019)



Source: exoplanet.archive.caltech.edu

Looking for exoplanets – 4099 confirmed as of 11/21/2019



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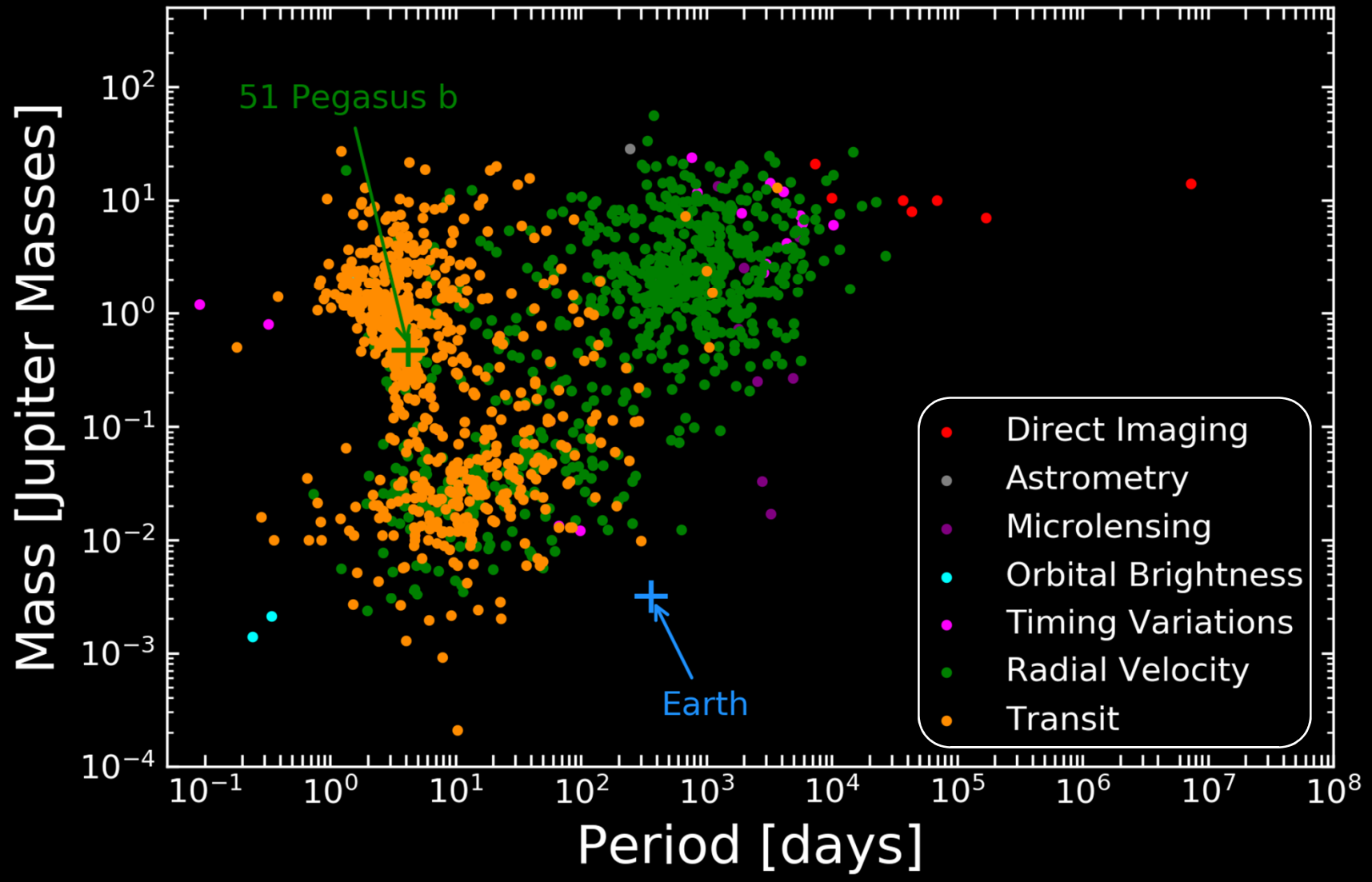

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Microwave Kinetic Inductance Detector: MKID

Superconductor: Below the transition temperature T_C , electrons are bond together in Cooper pairs (CPs) with a gap energy of 2Δ and they carry the current without DC resistance

$$2\Delta = 3.52\, k_B T_C$$

	Tc [K]	2Δ [meV]
PtSi	0.940	0.14
Hf	0.350	0.05
Nb	9.26	1.40

In semiconductor (CCD/CMOS technology), gap ~ 1eV (Si = 1.14eV)

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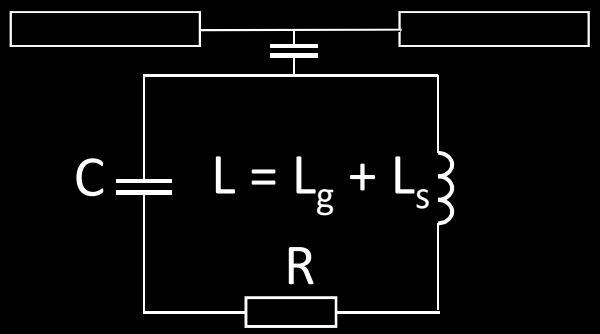
Under an AC electric field, the CPs change direction with a lag

→ Kinetic Inductance effect

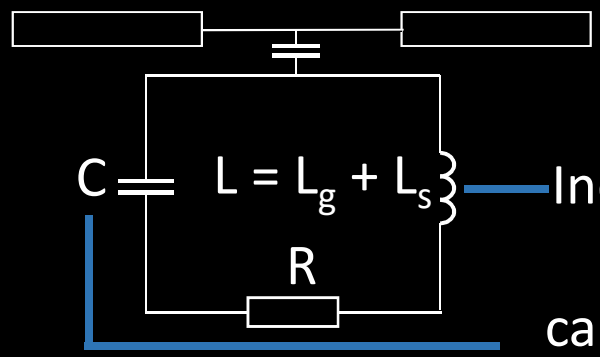
$$L_s = \frac{\hbar \rho}{\pi \Delta t} \propto \frac{1}{T_C}$$

MKID equivalent circuit → superconducting resonator



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

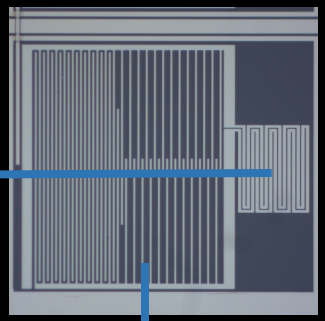
MKID equivalent circuit → superconducting resonator



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

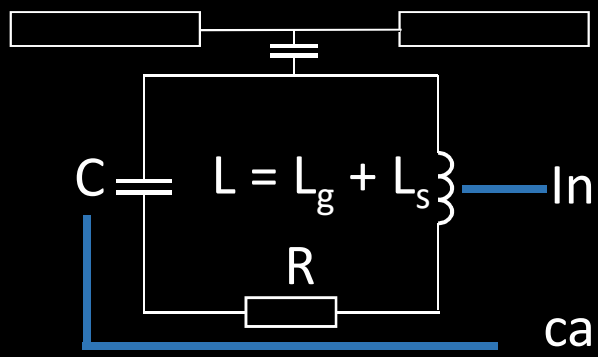
Inductor

capacitor



Resonator patterned on a superconducting thin film (e.g. PtSi, Hf)

Resonant frequency



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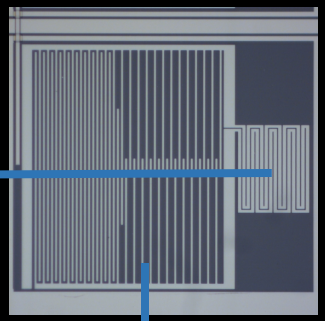
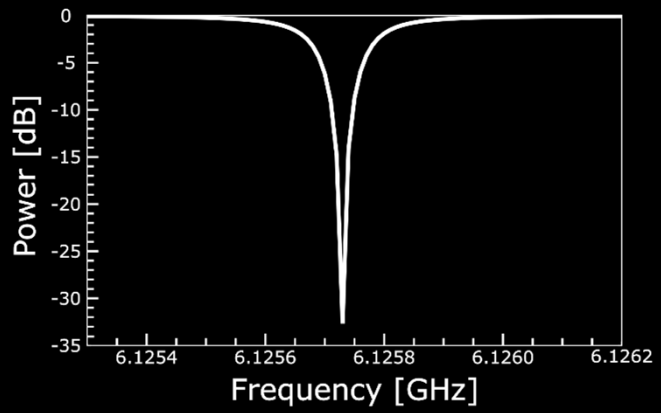
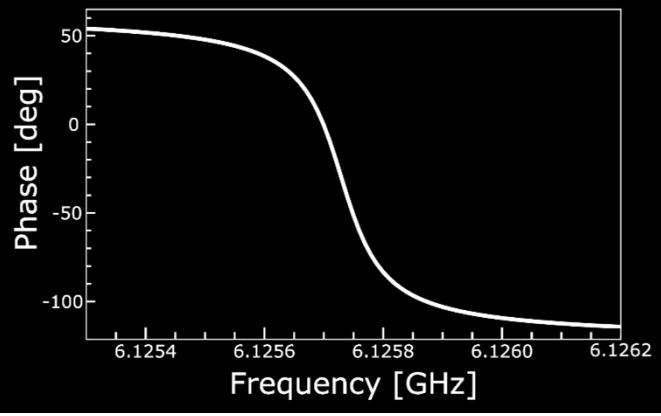
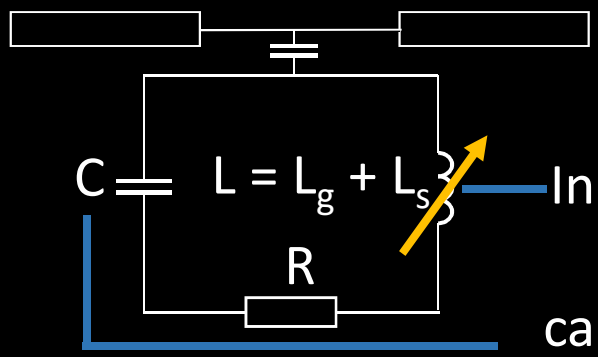


Resonator patterned on a superconducting thin film (e.g. PtSi, Hf)





Single photon detection



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Inductor

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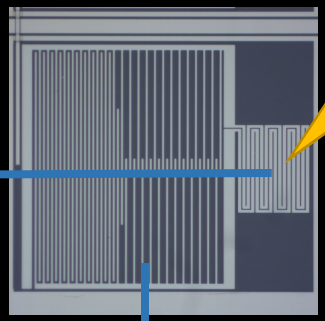
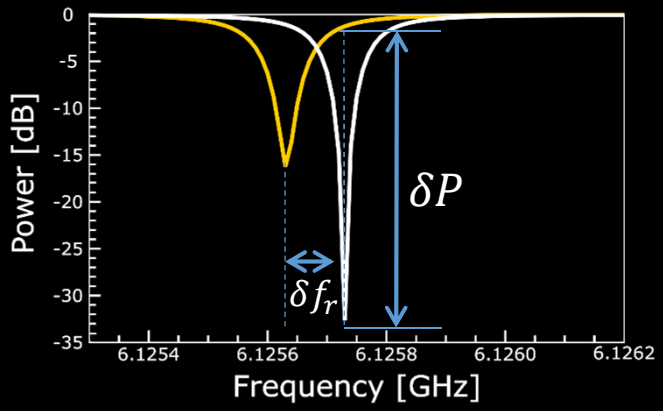


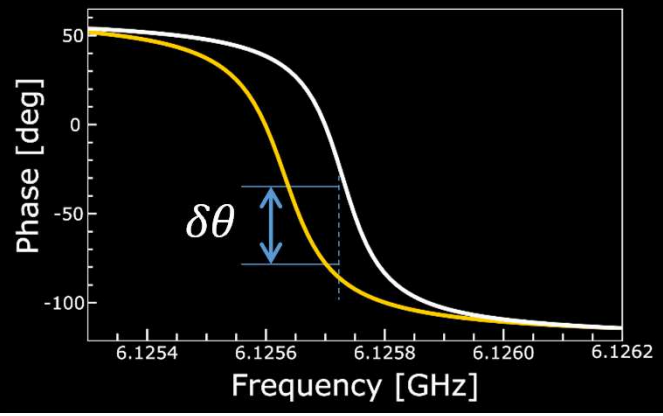
Photon E = hυ > Δ

Energy gap

PtSi – **0.00013** eV

(N.B. Si – 1.14 eV)





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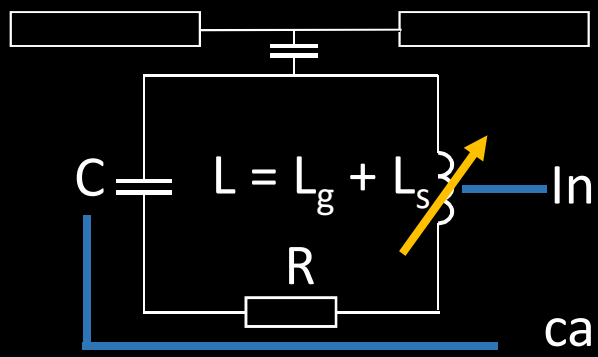
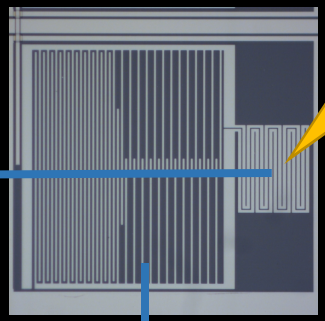


$$f_r \propto \frac{1}{\sqrt{LC}}$$



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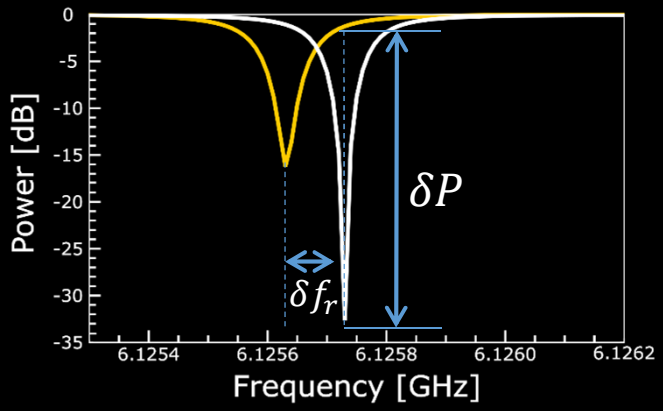
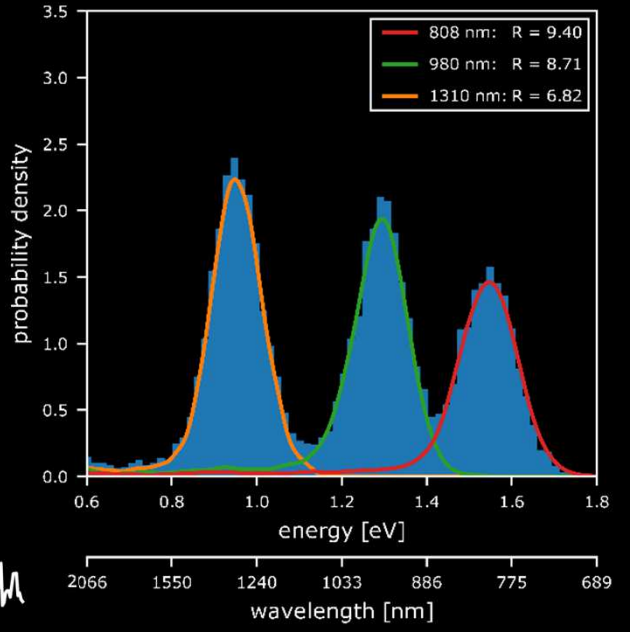
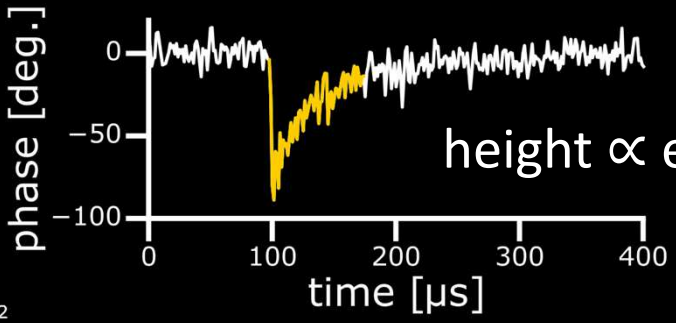


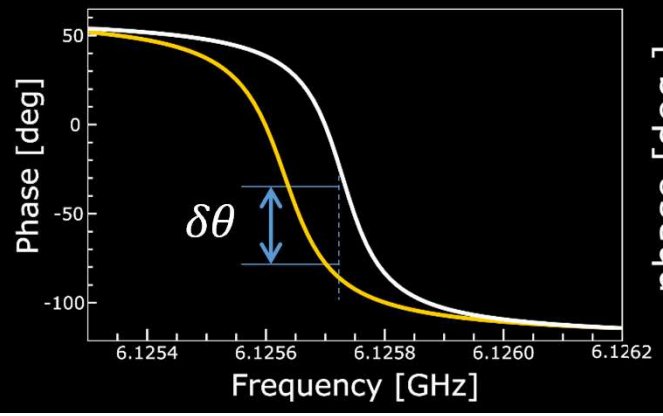


Typical photon event

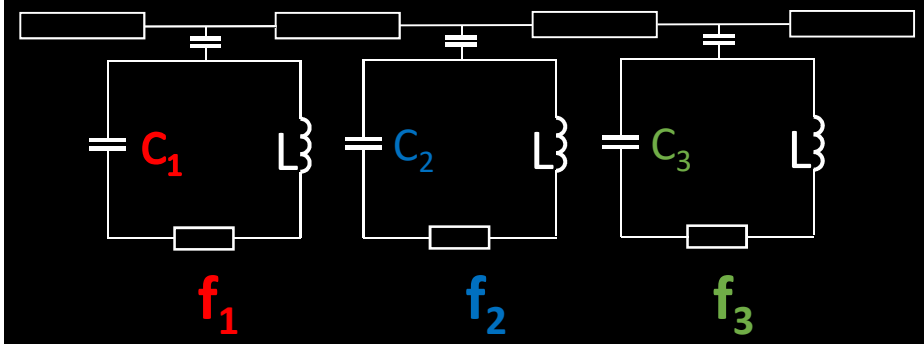


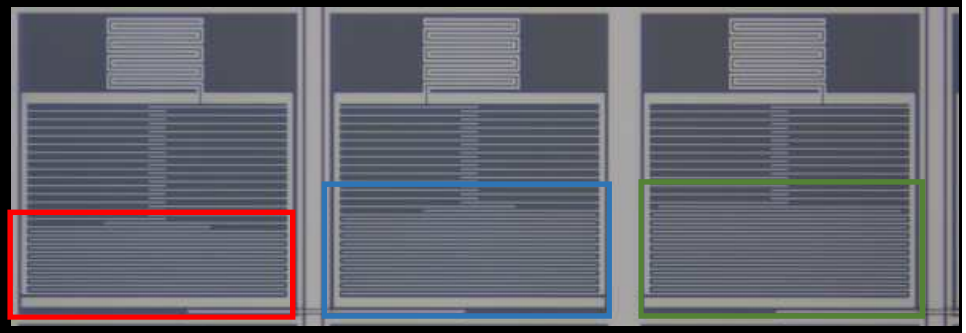
height ∝ energy

Spectral information



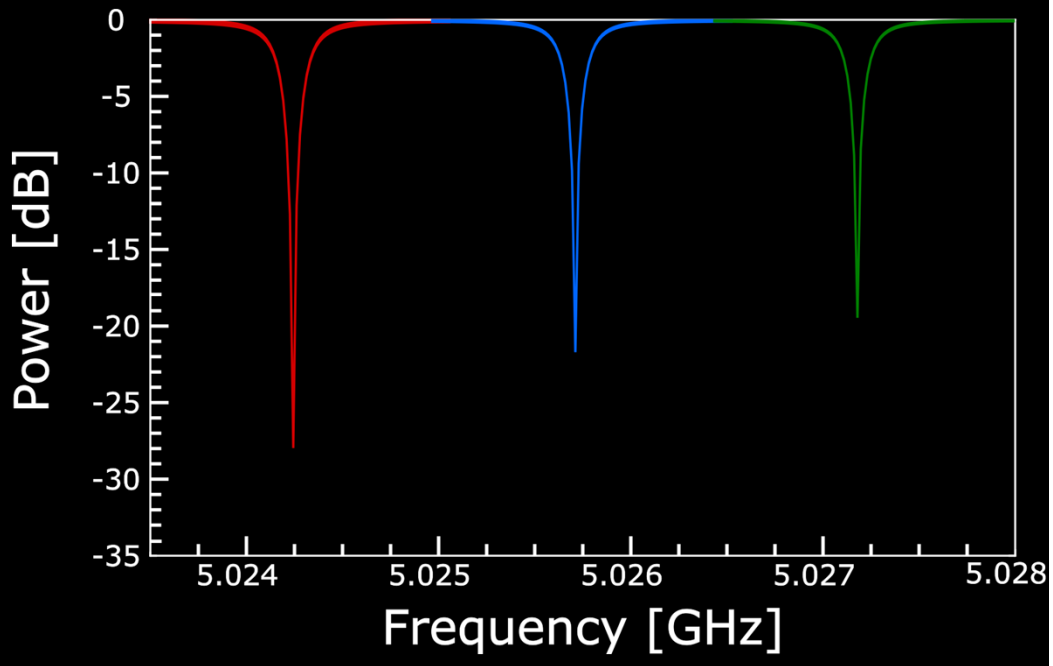
Frequency domain multiplexing

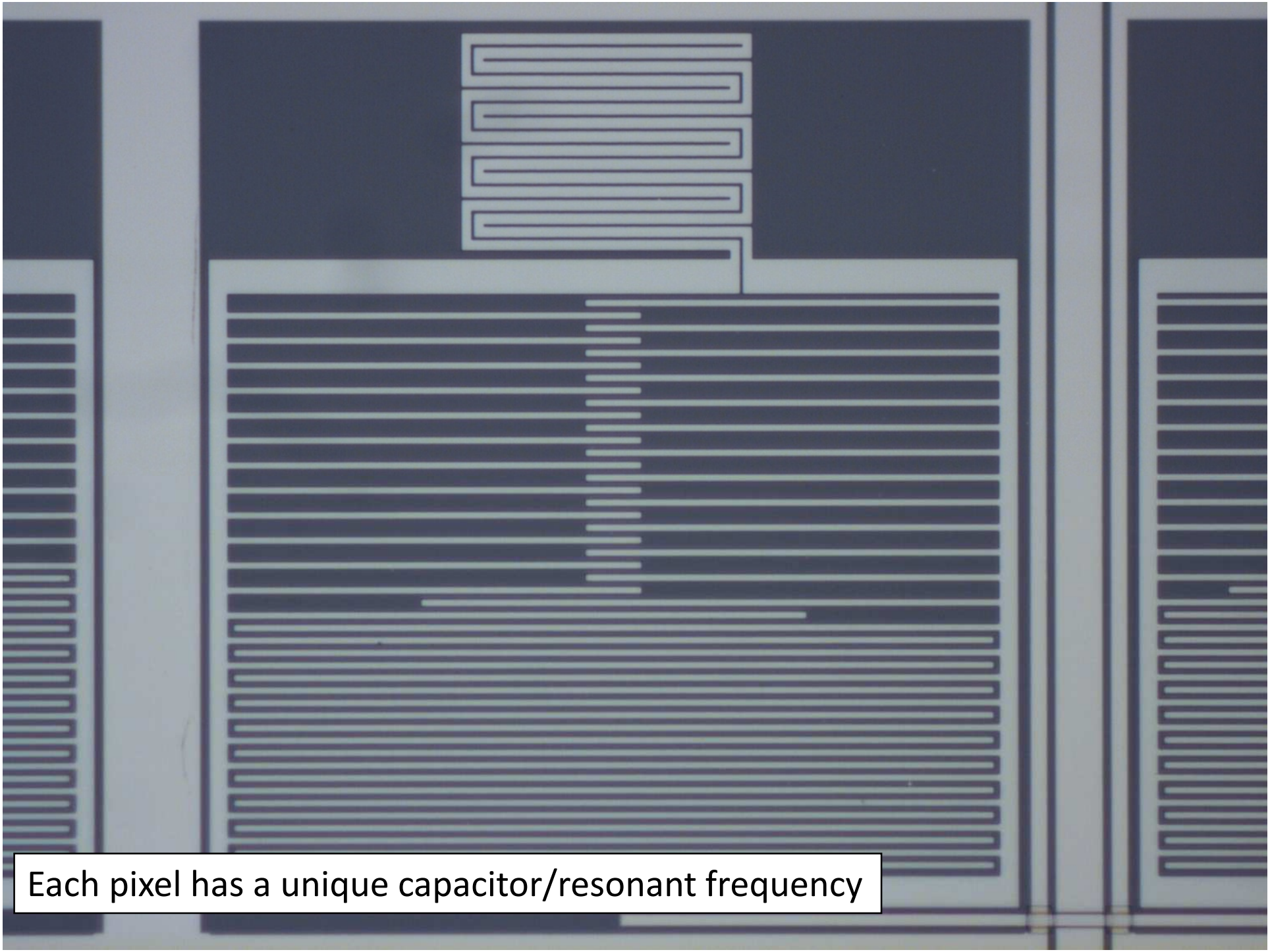


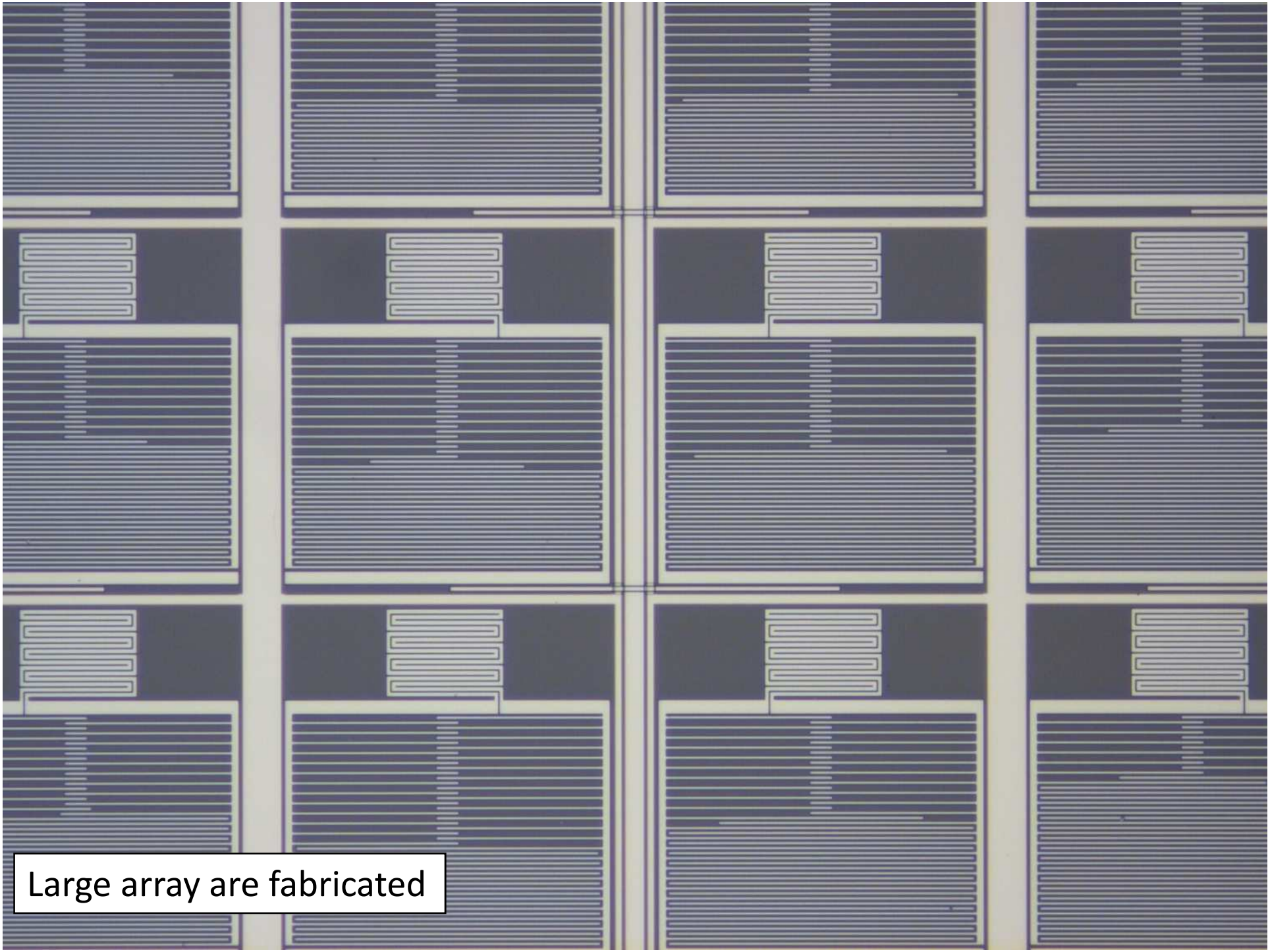


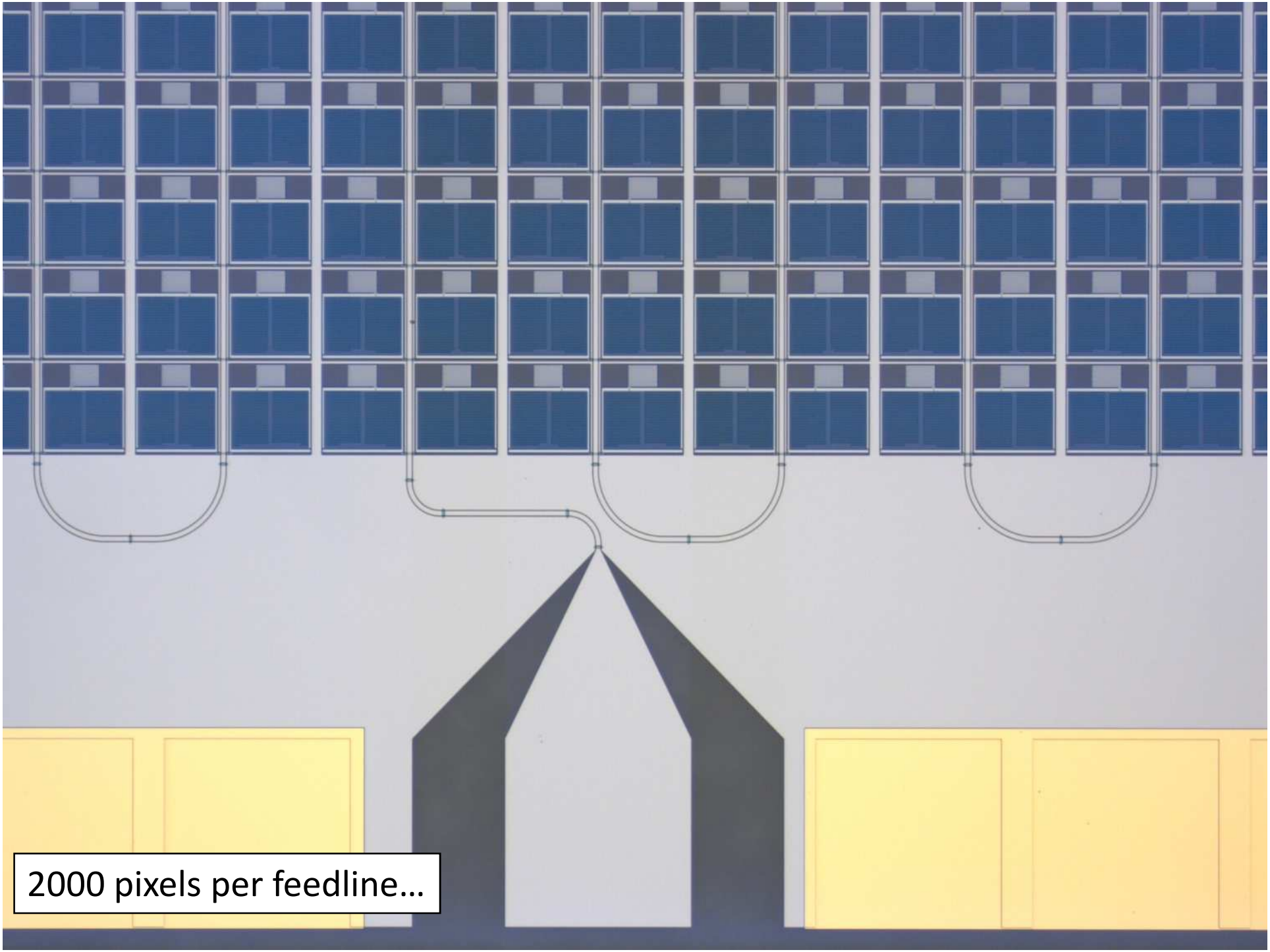
- Quality factor Q → gives the loss in the detector
  → Need highest Q possible to minimize noise/loss

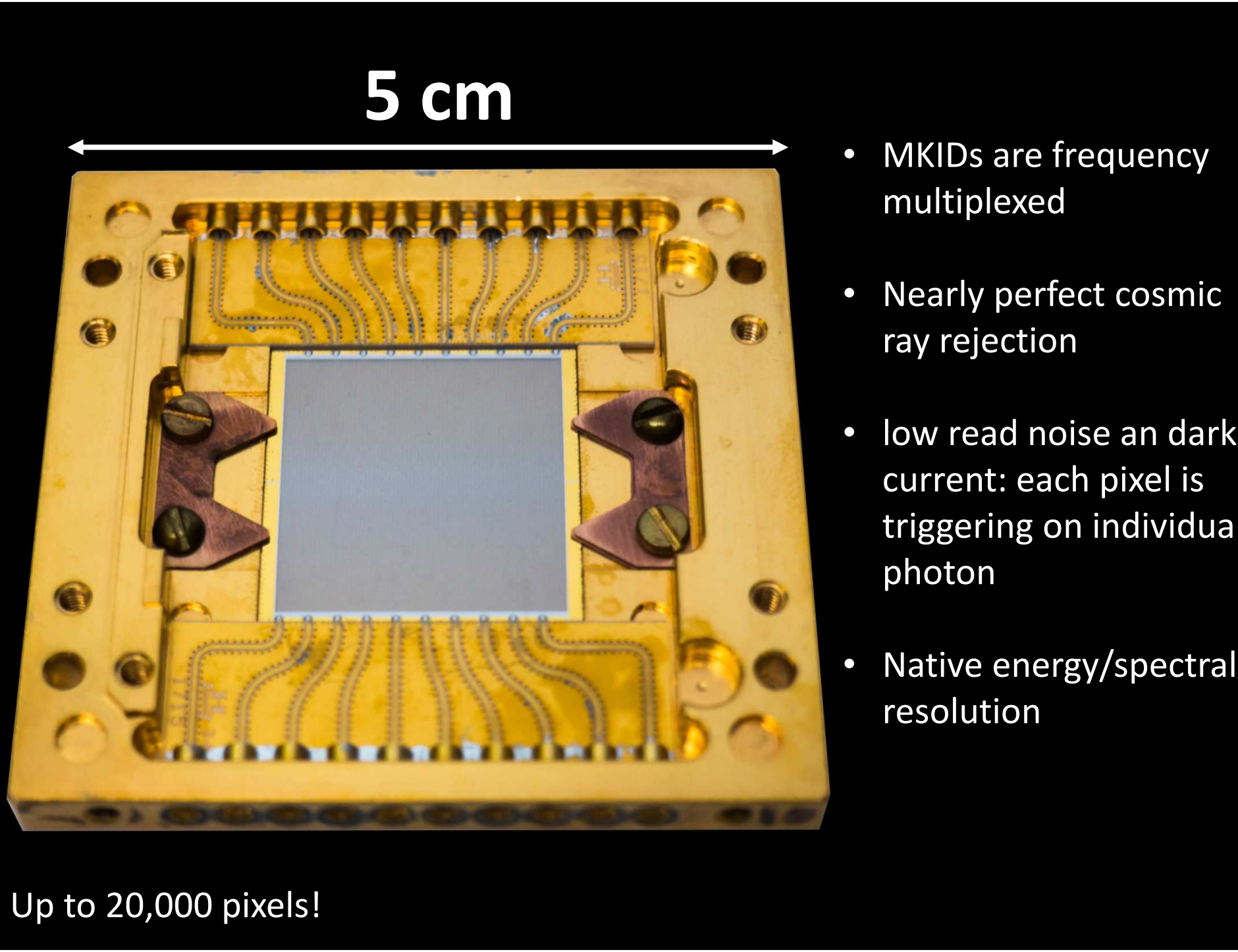
- High Q → sharp resonances
  → dense packaging



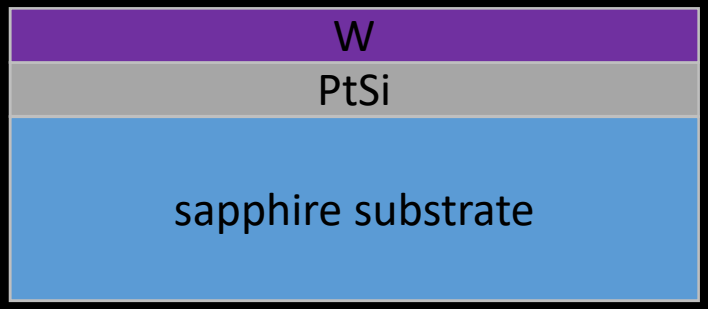

Each pixel has a unique capacitor/resonant frequency


Large array are fabricated


2000 pixels per feedline…


5 cm
• MKIDs are frequency multiplexed
• Nearly perfect cosmic ray rejection
• low read noise an dark current: each pixel is triggering on individual photon
• Native energy/spectral resolution
Up to 20,000 pixels!

MKIDs array fabrication at UCSB nanofab

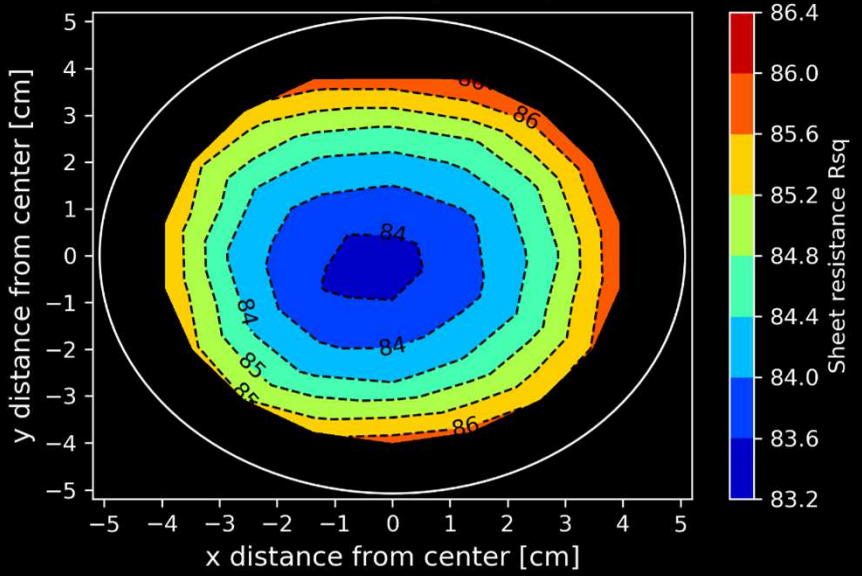


Pt (27 nm) and Si (43nm) sputtered on a sapphire substrate + annealing at 400C for 90 min in an UHV (7e-9 Torr) sputter system *(our own AJA system in Physics Building)*

→ 68 nm PtSi film

+ W cap layer (to protect the PtSi during the process)

Room temperature resistivity map

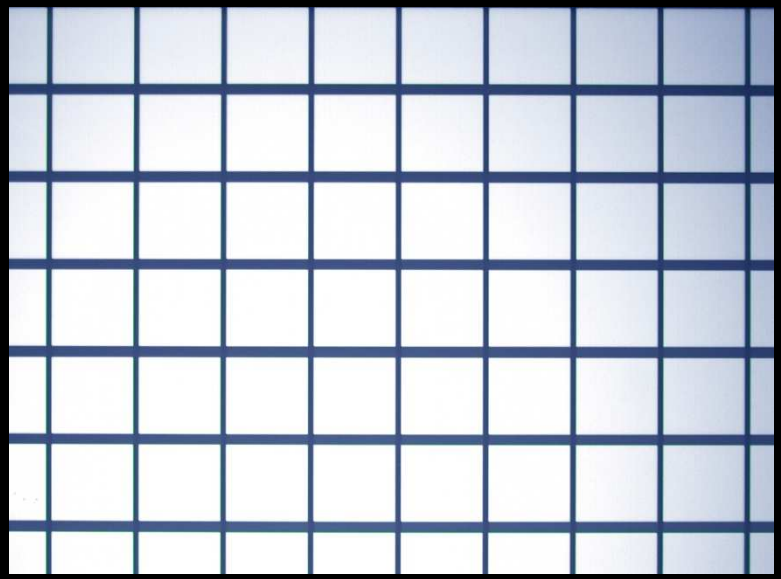


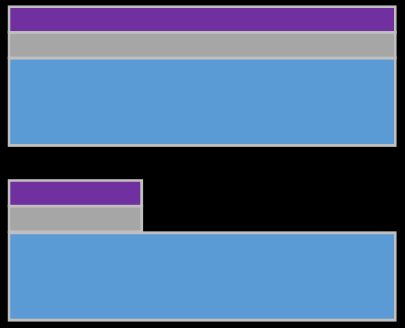
PtSi: 85 μΩ.cm, Tc ~ 940mK

resistivity / Tc / Lkin

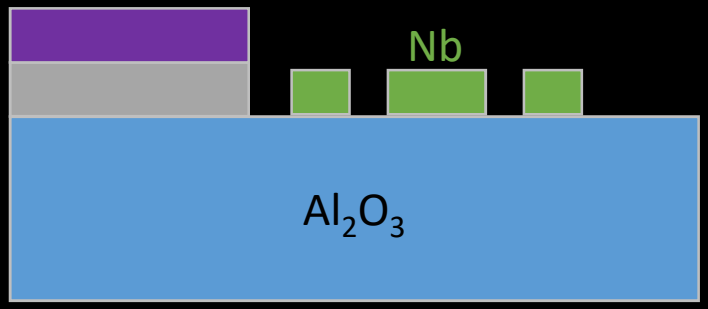
Resonator boxes

W and PtSi boxes are dry etched in ICP#2 with SF_6 and $CF_4/Cl_2/Ar$ respectively

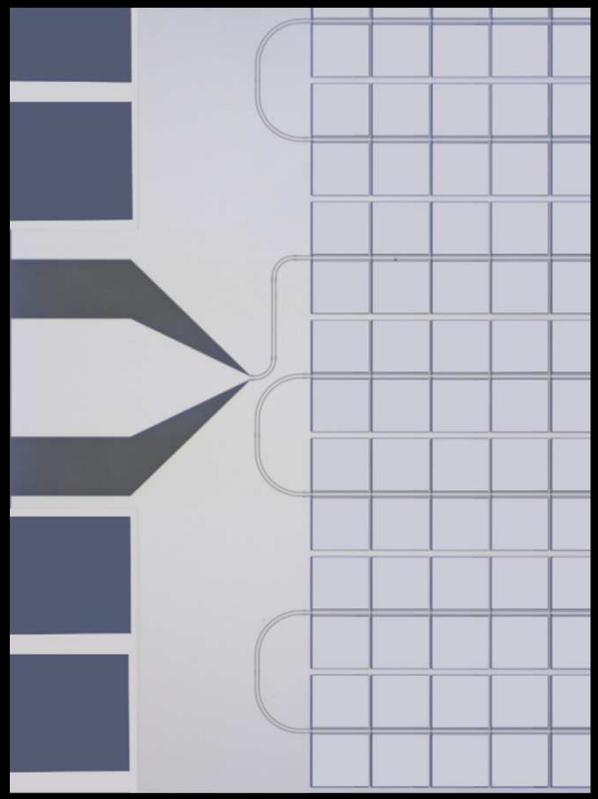


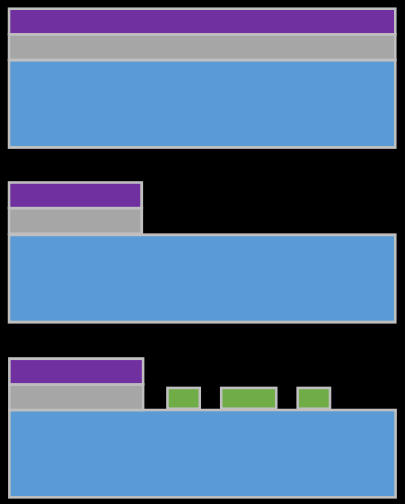


Superconducting transmission line

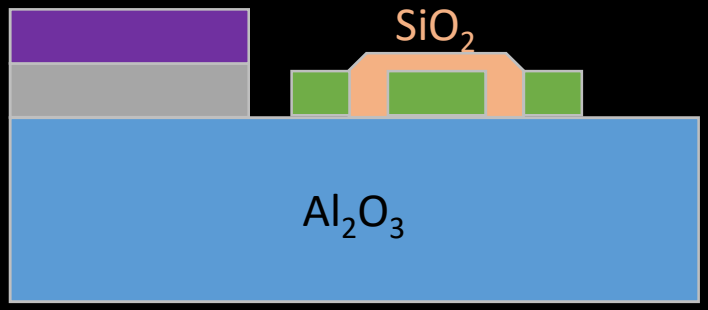


Deposition of the Nb (high Tc = 9.26K) transmission line *(in our own AJA sputter system)* and lift-off

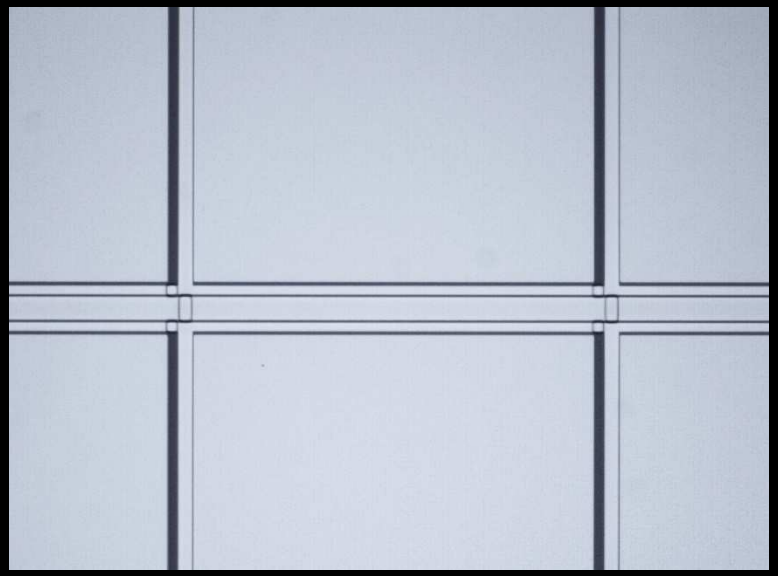


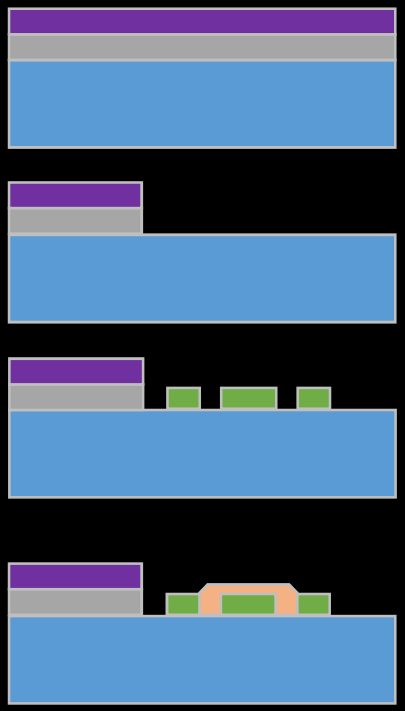


Insulating pads

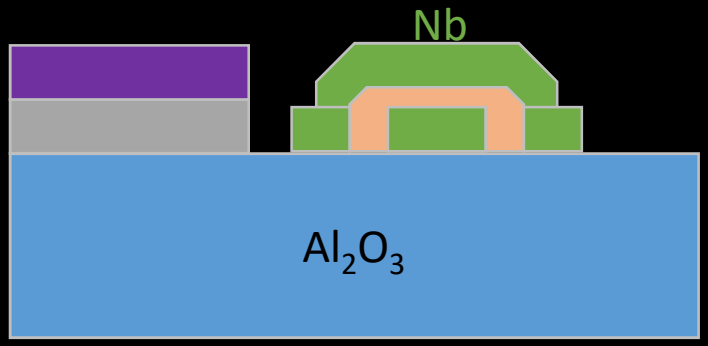


SiO2 insulating pads are deposited in sputter#3 (or a-Si:H in Unaxis PECVD) on top of the transmission line





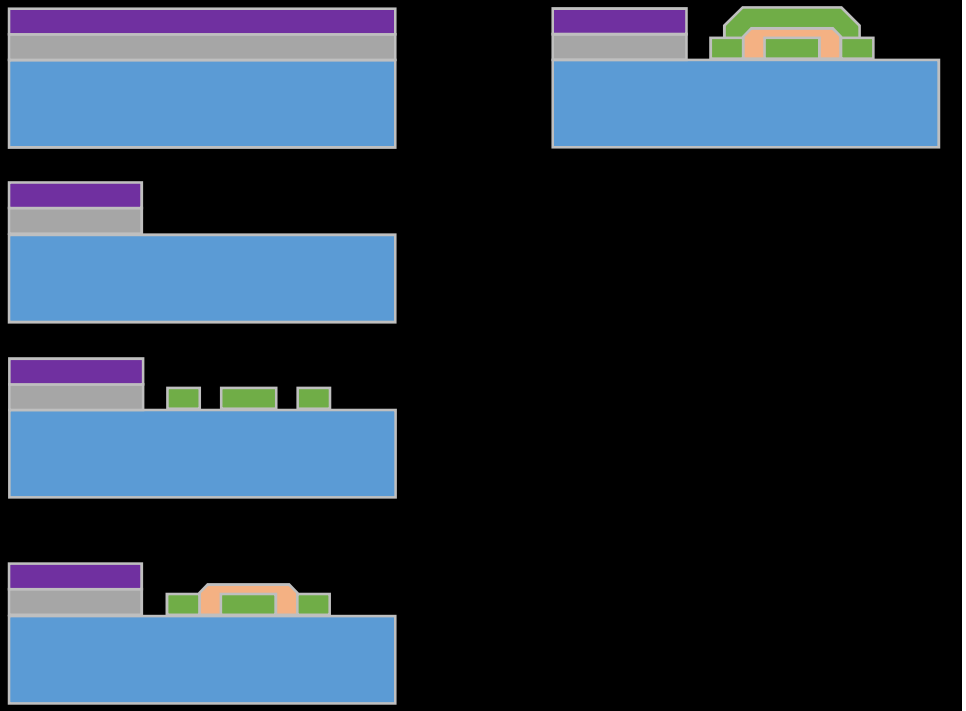
Bridges and coupling bars



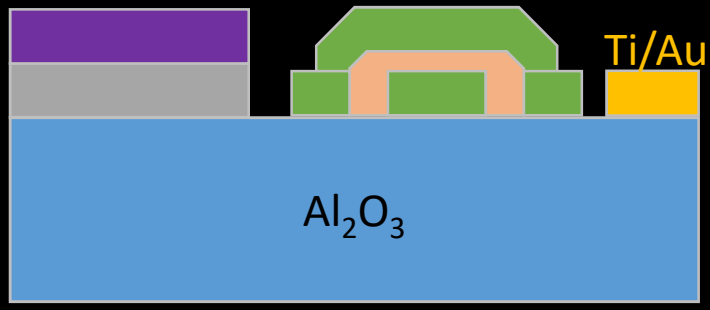
Nb bars deposited in our sputter system

→ connect the ground planes of the transmission line (bridges)

→ couple the resonators to the transmission line

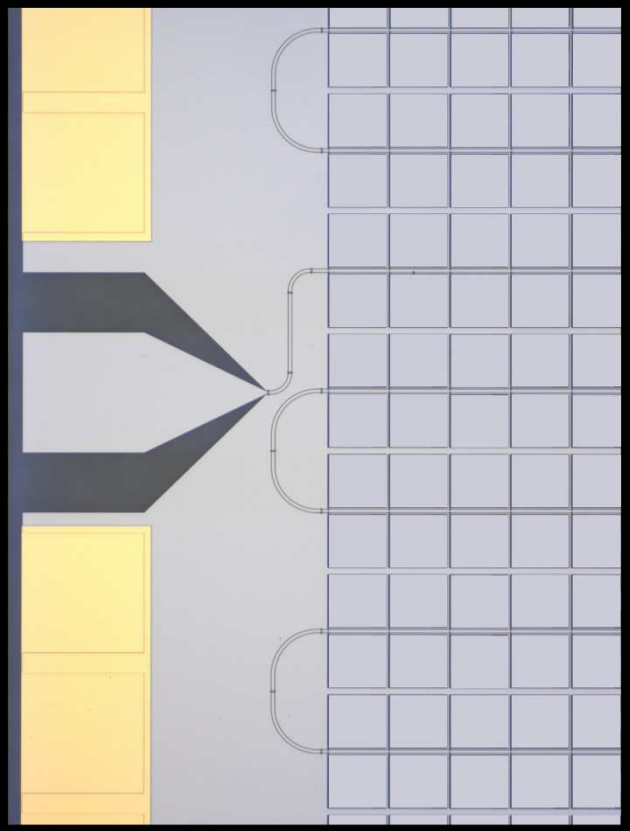


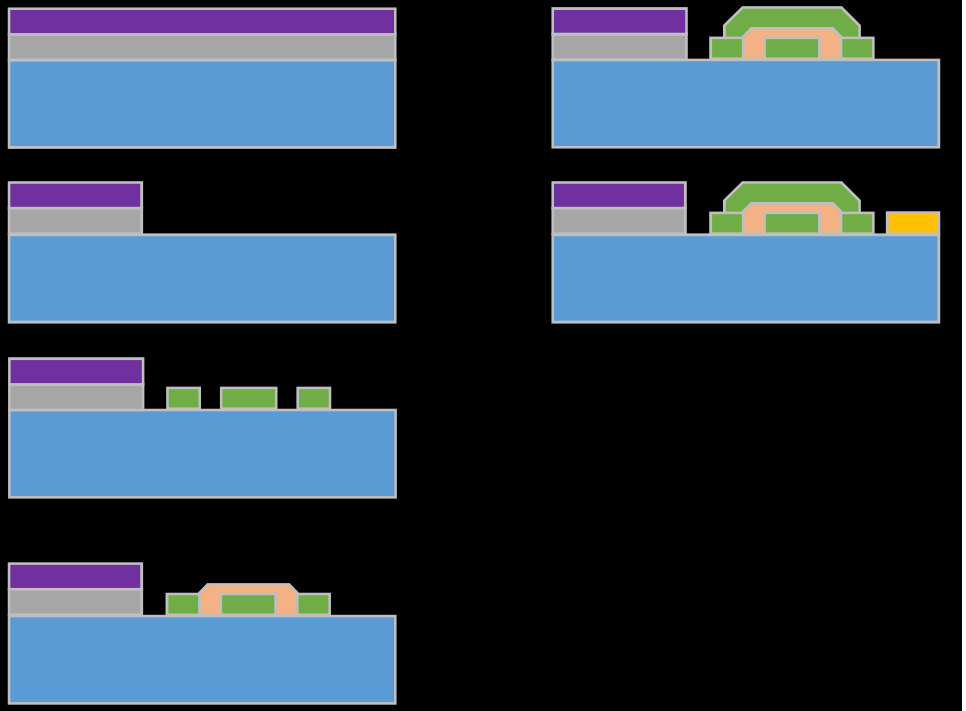
Gold bond pads



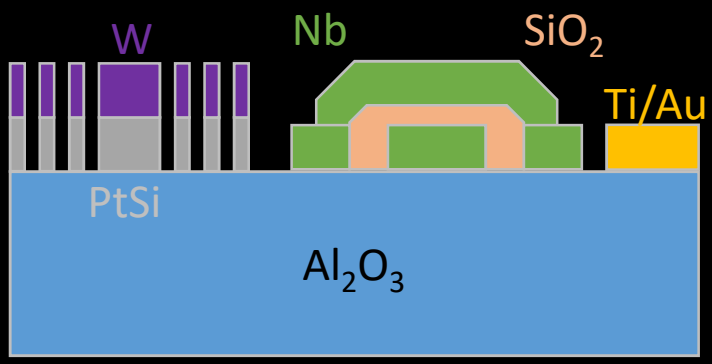
Ti/Au (5/200nm) bond pads evaporated in ebeam#3

→ enhance thermalization of the array

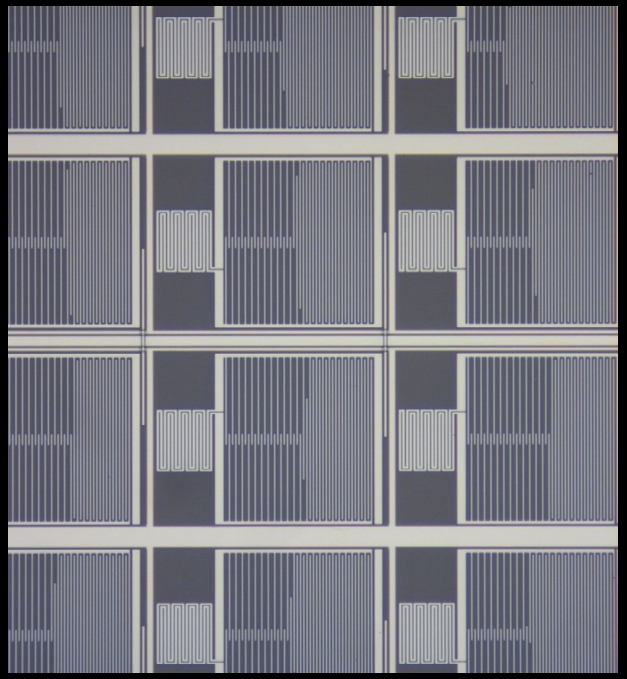


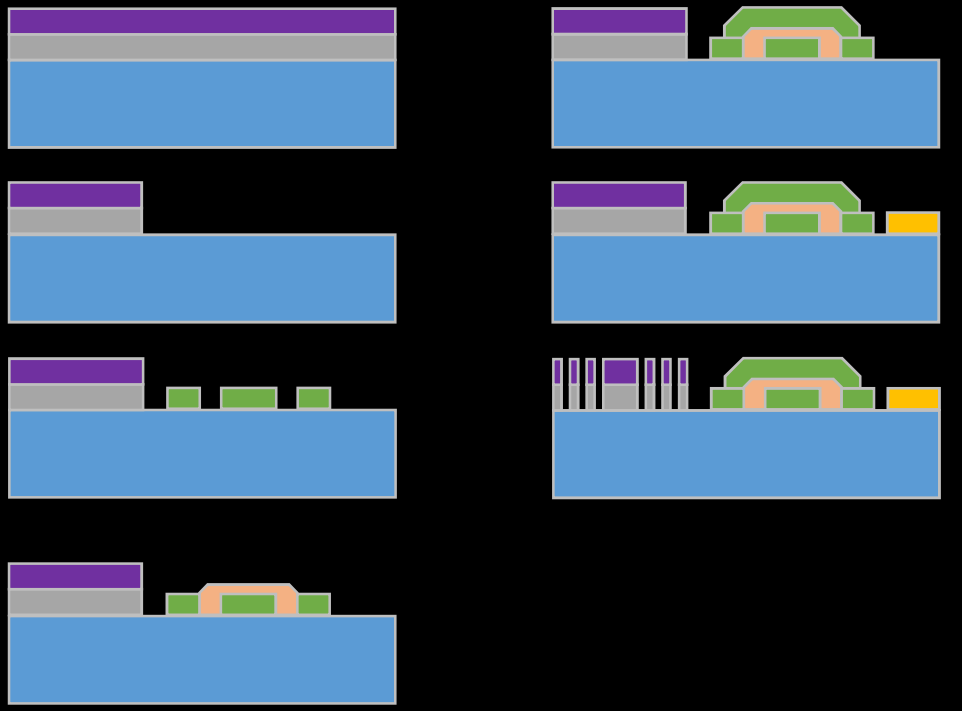


Etch of the resonators

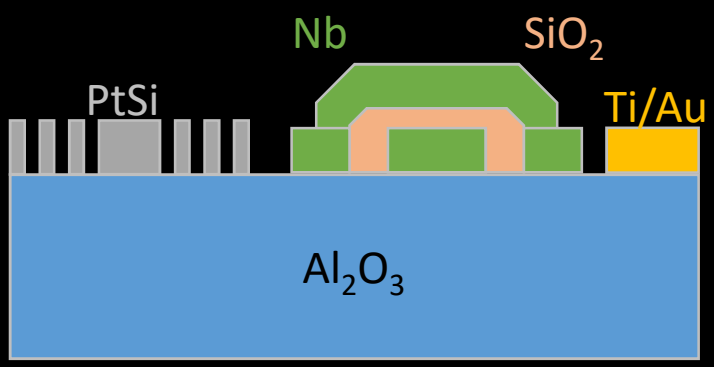


The resonators are patterned and etched in ICP#2 (SF_6 and $CF_4/Cl_2/Ar$)

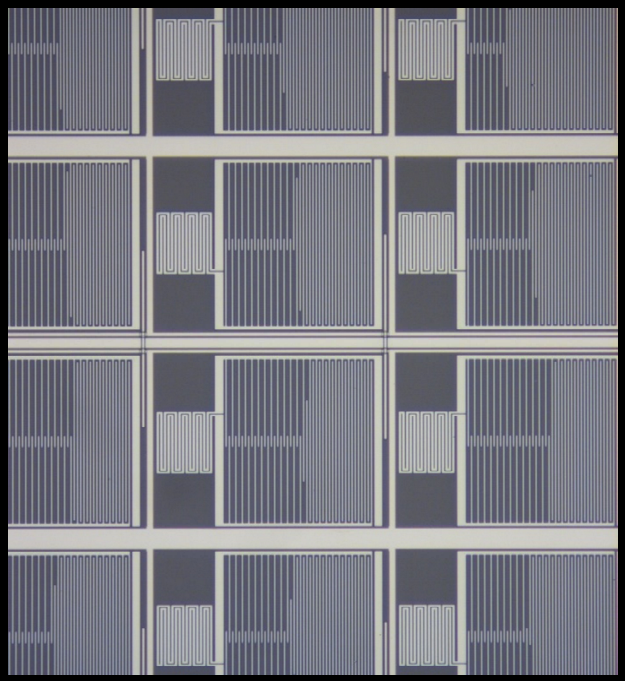




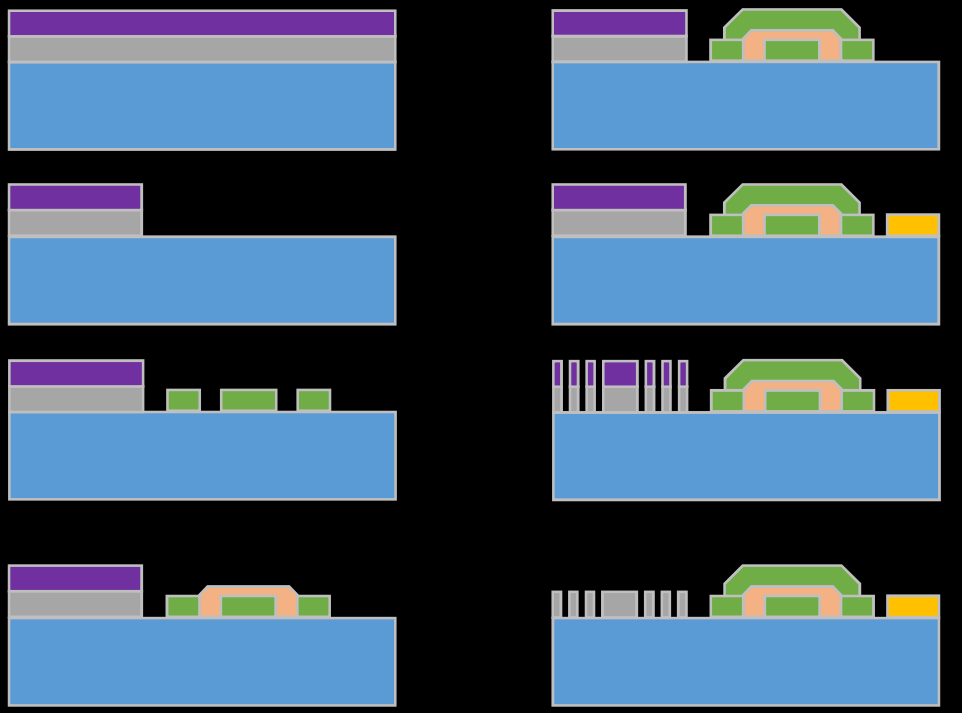
W removal



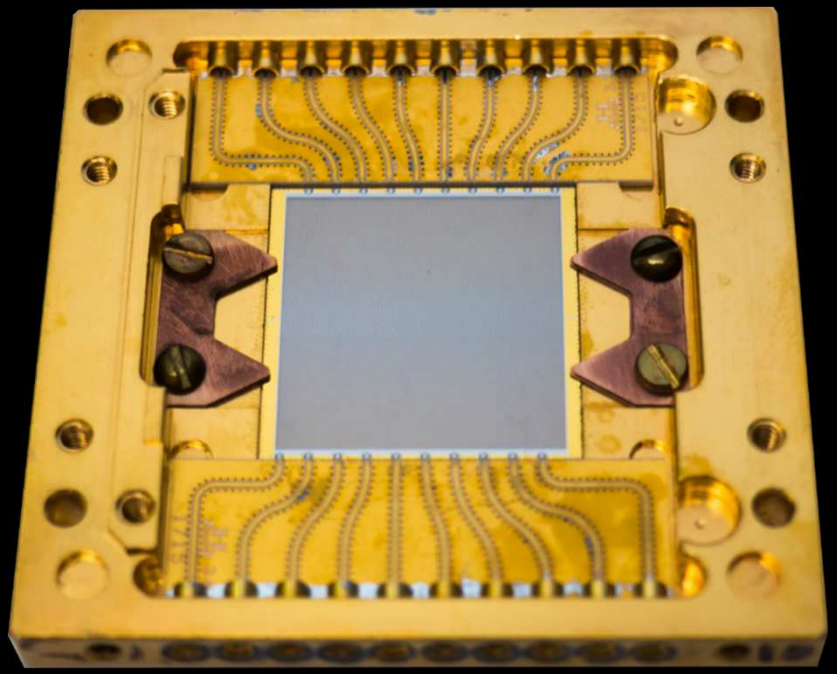
The W protect layer is wet etched in H_2O_2 @ 50°C



entire process takes only 2 days
(if everything goes well…)

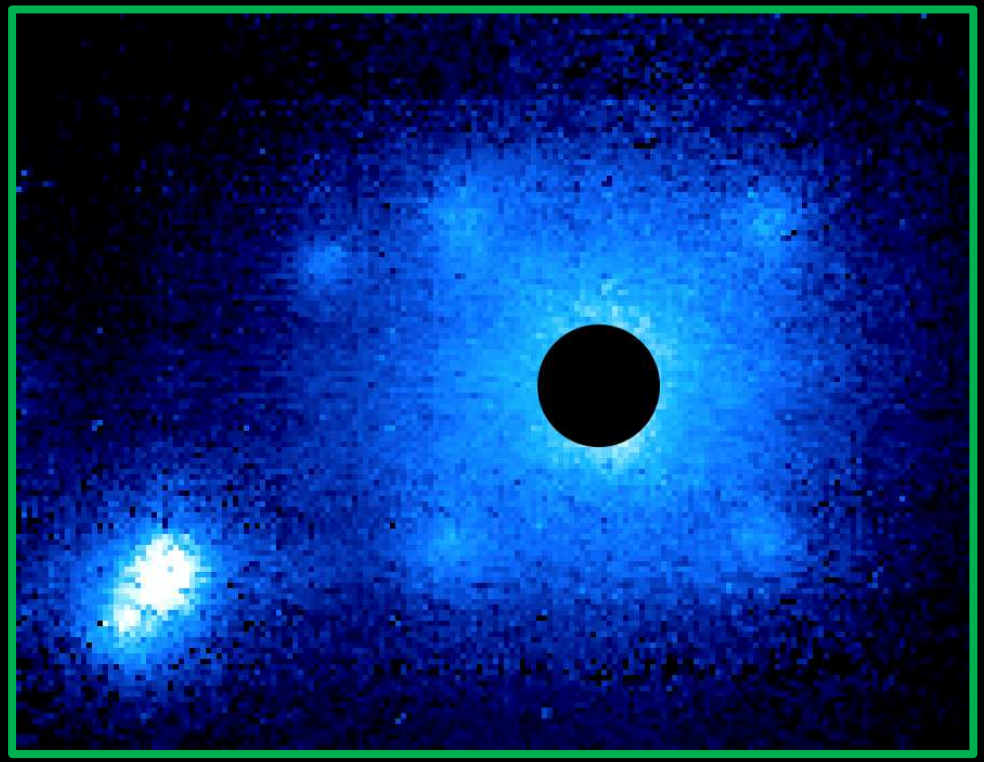


Detectors performances



- Array cooled down to ~ 80mK
- Instrument band : 500-1500 nm
- Pixel yield ~ 90%

Theta Ori B
Quadruple star system



infrared 900-1100 nm
exposure: 30 sec
(false color)

How can we improve our detectors?

- Yield : be cleaner
- Lower Tc material → sensitivity varies as 1/Tc (Hafnium Tc = 340 mK)
  - Materials studies → e.g. for hafnium performances is strongly related to crystal orientation
- Improve the design → most of the noise comes from the capacitor

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- Lower Tc material → sensitivity varies as 1/Tc (Hafnium Tc = 340 mK)
  - Materials studies → e.g. for hafnium performances is strongly related to crystal orientation
- Improve the design → most of the noise comes from the capacitor

What else are we doing in Mazin Lab?

- Other wavelength: Miguel Daal is working on X-ray thermal MKIDs and dark matter detector
- MKIDs spectrometer: Renan Moreira is building the photonic circuit with us
- Full cryostat fabrication
- Data reduction and analysis software