Development of Kinetic Inductance Detectors for astronomical applications

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Outline

- Near Infrared and visible MKIDs (GEPI)
- mm Coupled Antenna MKIDs (APC)

Near Infrared and visible MKIDs

Motivation

- At GEPI, all the science is done at NIR and visible wavelengths.
- Very promising technology for many astronomical applications.
- Possible application: MOSAIC-like projects.

Near Infrared and visible MKIDs

MOSAIC : **Multi-Object Spectrograph of the Extremely Large Telescope (ELT)**

PI : François Hammer (GEPI) Paris Observatory

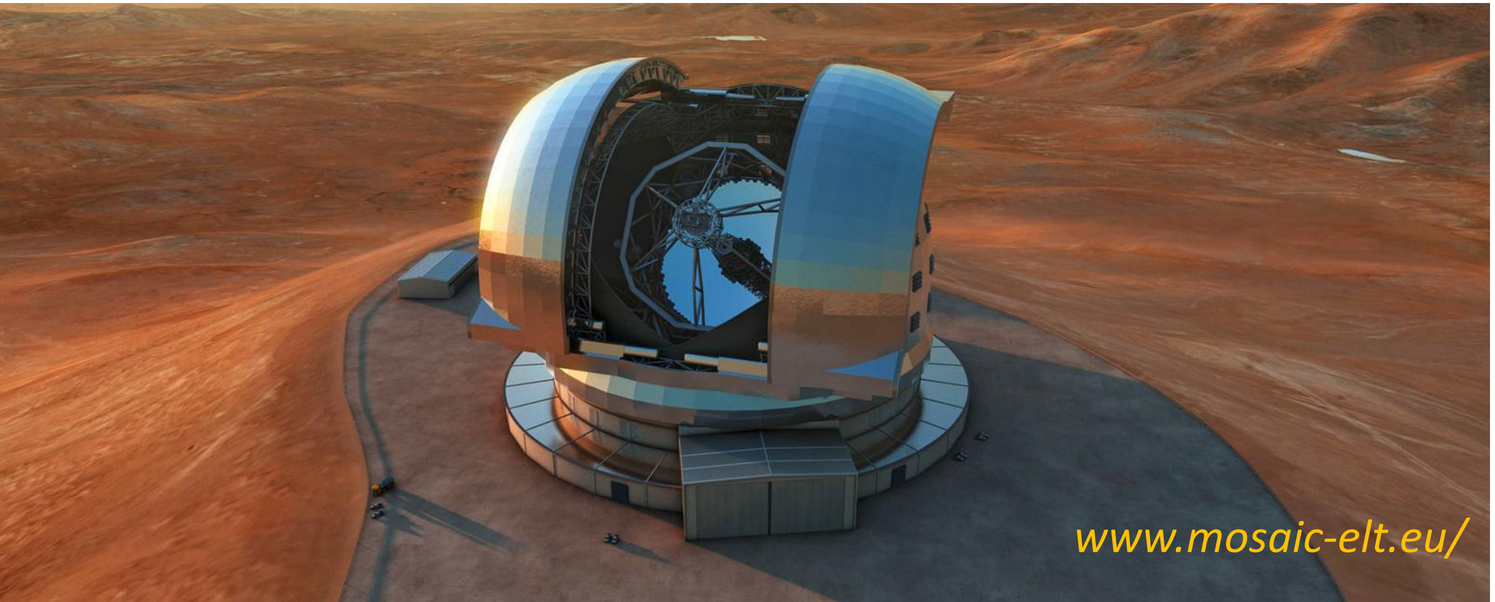
BREAKTHROUGH SCIENCE

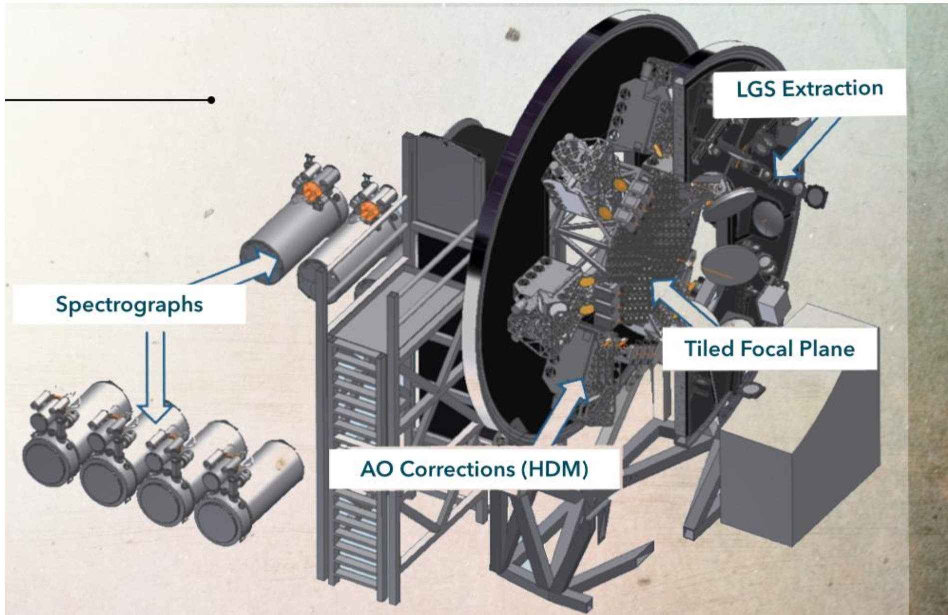
First galaxies

Resolved stellar population beyond the local group

Evolution of large-scale structures

Formation of exo-planets in different environments





Near Infrared and visible MKIDs

MOSAIC : **Multi-Object Spectrograph of the Extremely Large Telescope (ELT)**

A unique range of observations!

- ✓ ***SC1: 'FIRST LIGHT' – SPECTROSCOPY OF THE MOST DISTANT GALAXIES***
- ✓ ***SC2: EVOLUTION OF LARGE-SCALE STRUCTURES***
- ✓ ***SC3: MASS ASSEMBLY OF GALAXIES THROUGH COSMIC TIMES***
- ✓ ***SC4: AGN/GALAXY CO-EVOLUTION & AGN FEEDBACK***
- ✓ ***SC5: RESOLVED STELLAR POPULATIONS BEYOND THE LOCAL GROUP***
- ✓ ***SC6: GALAXY ARCHAEOLOGY***
- ✓ ***SC7: GALACTIC CENTRE SCIENCE***
- ✓ ***SC8: PLANET FORMATION IN DIFFERENT ENVIRONMENTS***

ELT-MOS White Paper: Science Overview & Requirements, Evans et al., ArXiv:1501.04726V1

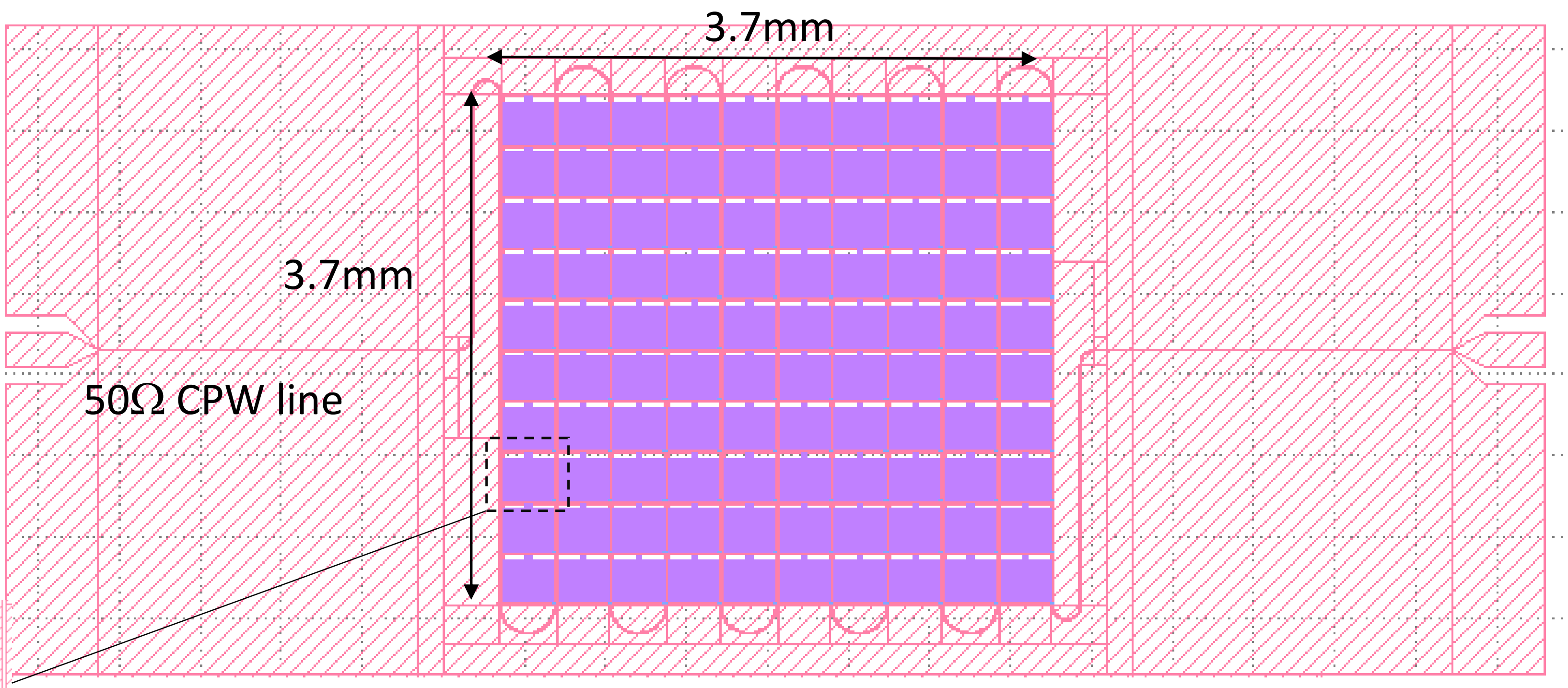
Near Infrared and visible MKIDs

MOSAIC requirements

HMM Visible	
Operating bandwidth	0.45 - 0.8 µm
Number of objects observed simultaneously	200
Diameter of the aperture on sky	0.8”
Spectral Resolution (λ/Δλ)	5000 & 15000
Limiting magnitude	RAB = 26

HMM Near-infrared	
Operating bandwidth	0.8 - 1.8 µm
Number of object observed simultaneously	100
Diameter of the aperture on sky	0.6”
Spectral Resolution (λ/Δλ)	5000 & 15000
Limiting magnitude	HAB = 28

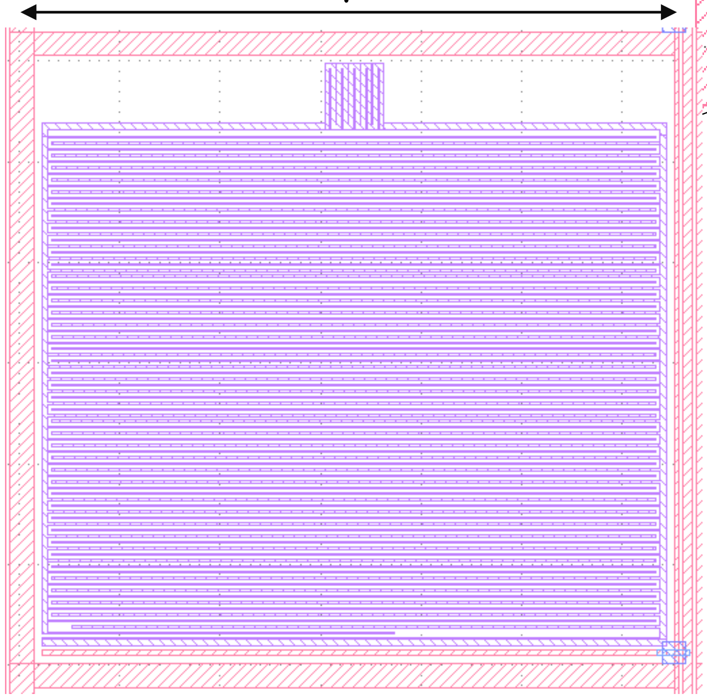
Near Infrared and visible MKIDs

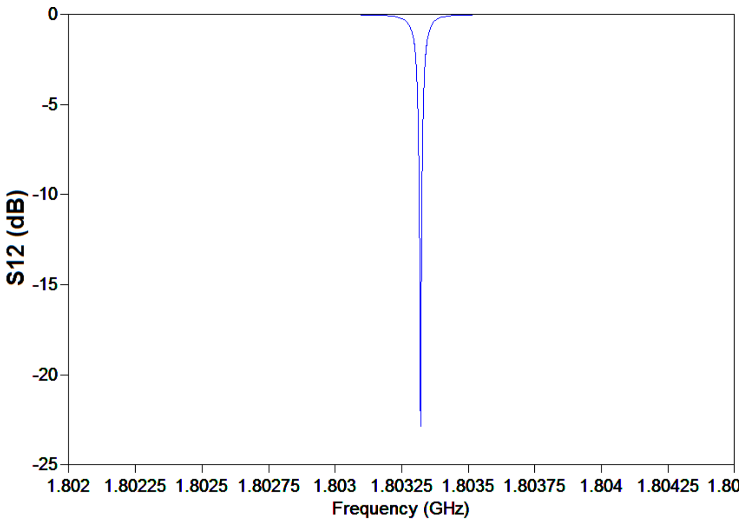


- As a start point, design inspired by the University of California work (B. Mazin et al).

$1GHz<f_0<2GHz$

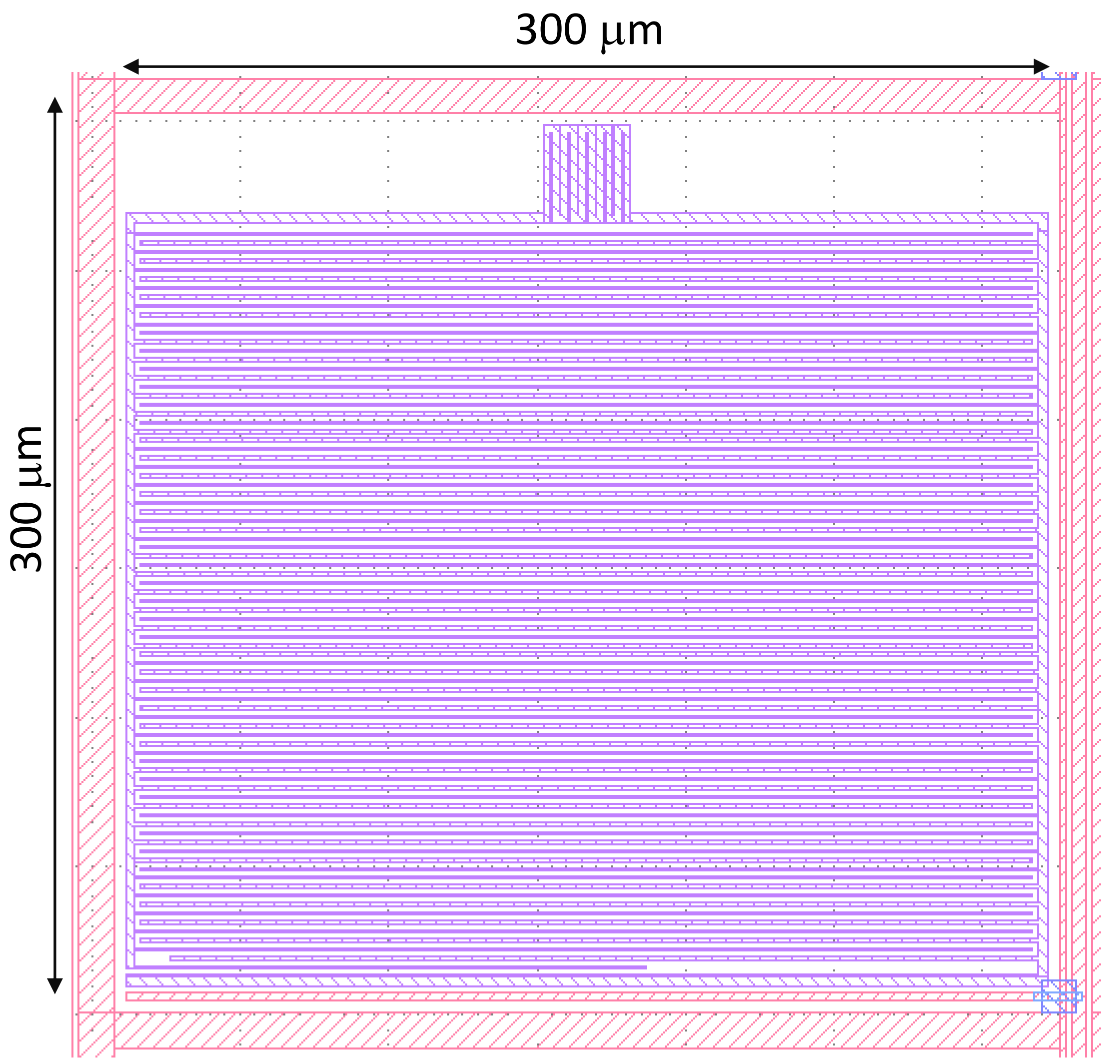
300 μm





- Simulation of a TiN-based LEKID resonating within 1-2 GHz, using typical TiN parameters of :
  - 60 nm-thick and $T_c \sim 1K$
  - L_{kin}=24 pH/□
  - ρ_n =110 μΩ cm

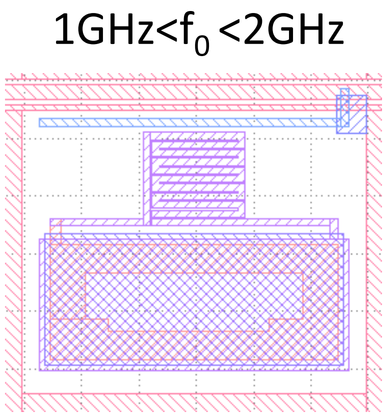
Near Infrared and visible MKIDs



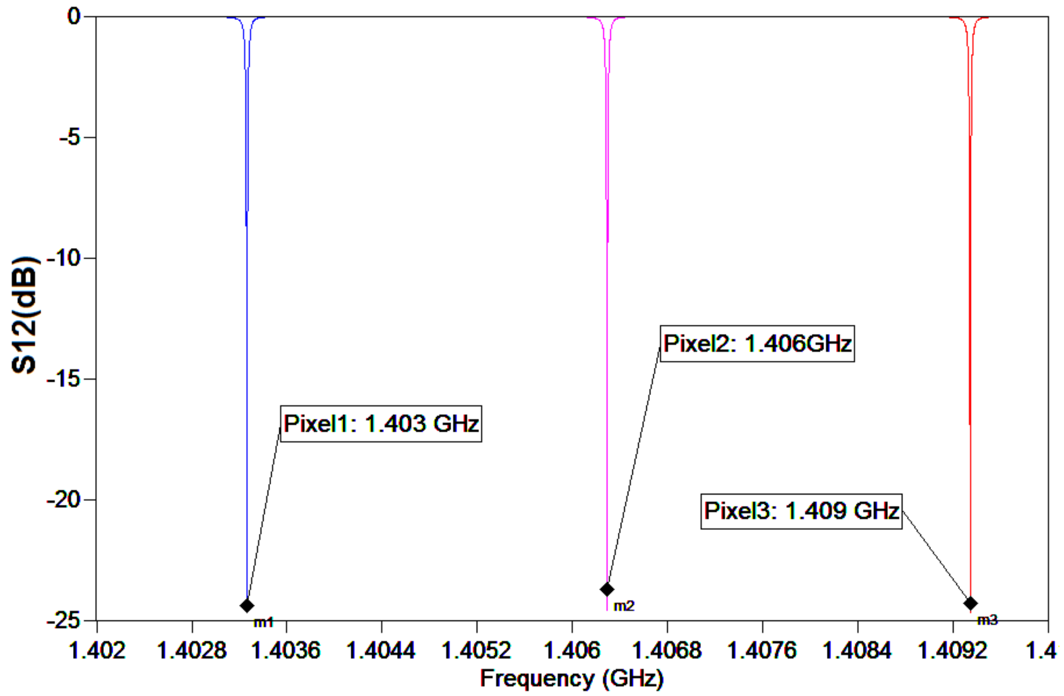
- In order to efficiently meet with the requirements of some astronomical applications (high spatial resolution), the KID size should be diminished typically from hundreds to a few tens of μm.

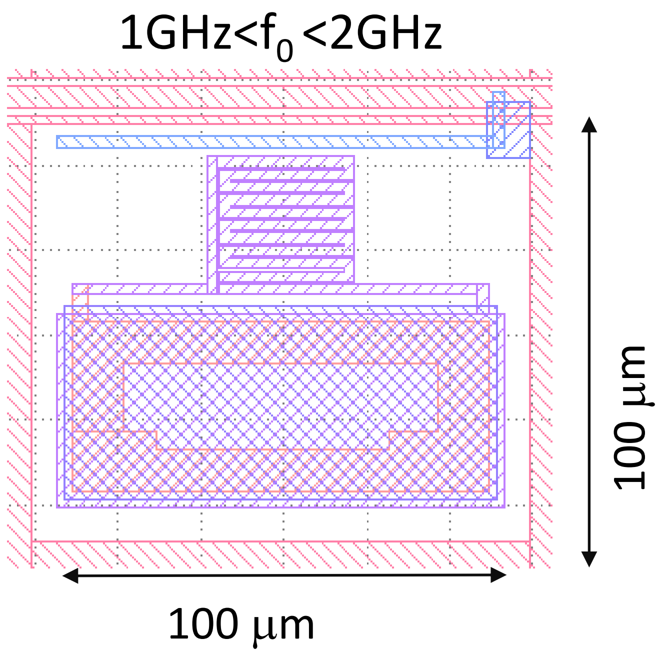
- Increasing the fill factor.

Replace the interdigitated Capacitor by a parallel plate (MIM) capacitor .



Near Infrared and visible MKIDs

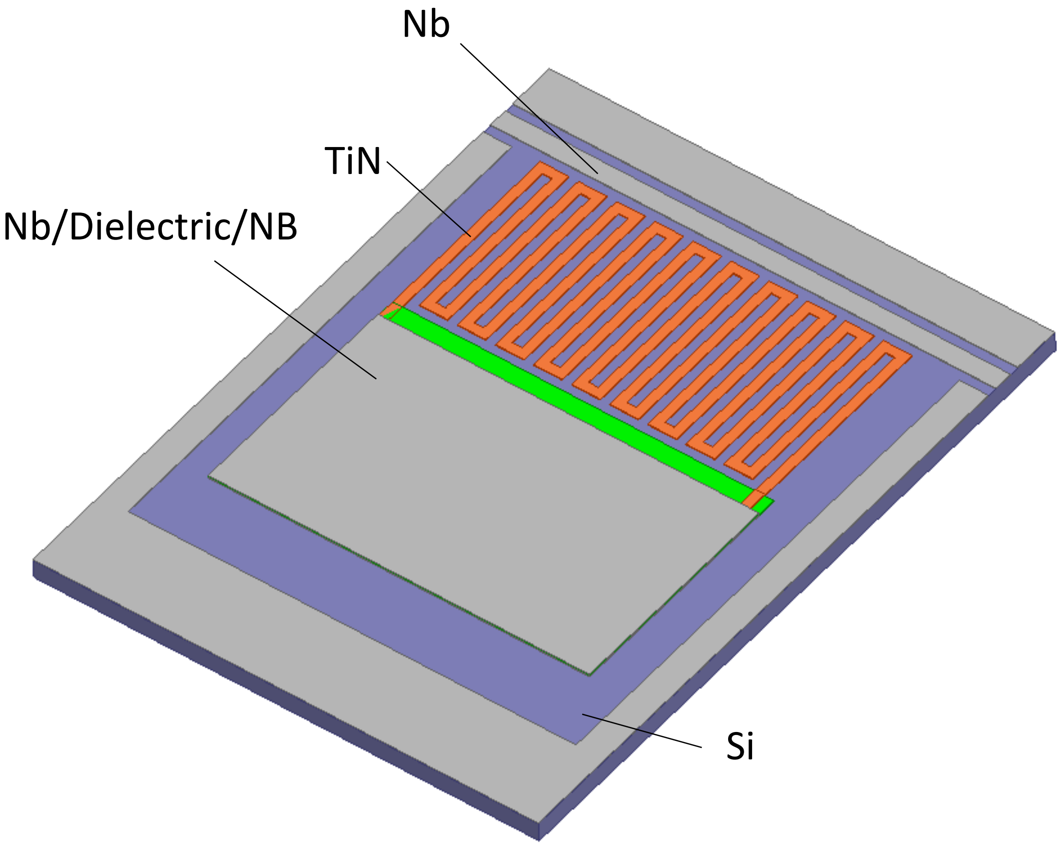


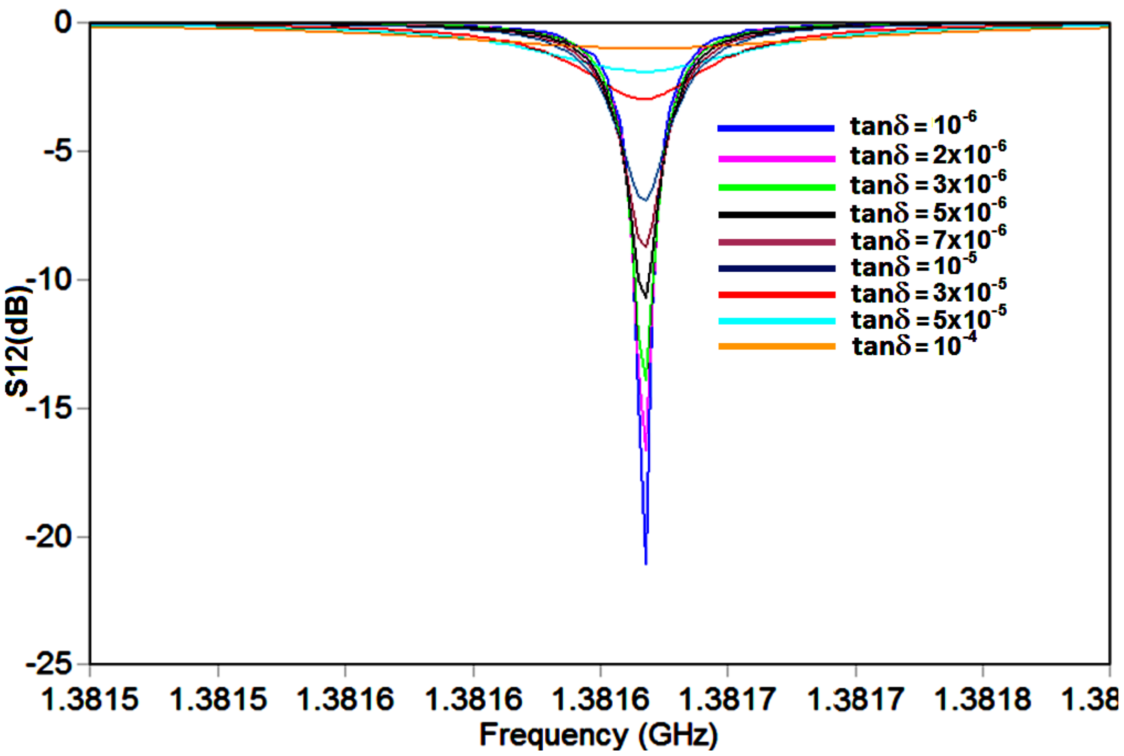


- Simulations of a parallel plate capacitor-based KID with ε_r=8 (AlN) and $t_{insolator}$ =100 nm using TiN parameters of :
  - 60 nm-thick and $T_c \sim$ 1K
  - L_{kin}=24 pH/□
  - ρ_n =110 $\mu\Omega$ cm
  - Dielectric loss factor Tan(δ)=0

- The frequency is tuned by removing nx4×4 µm square from the upper electrode or the bottom electrode.

Near Infrared and visible MKIDs

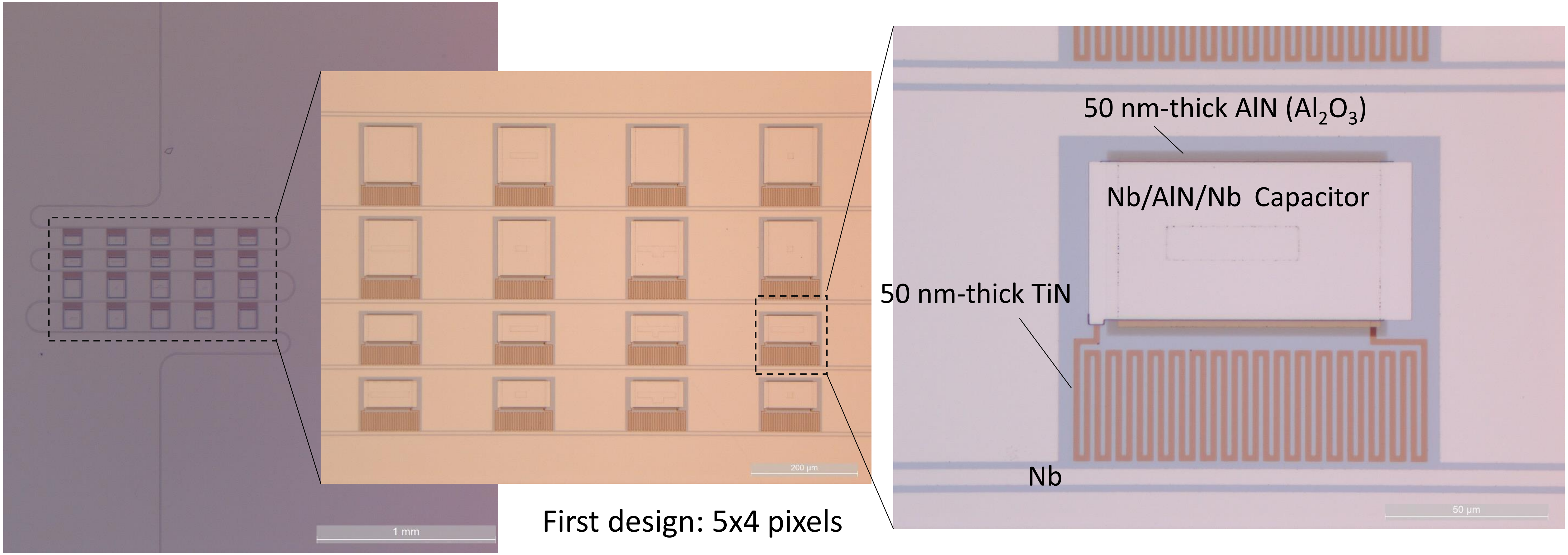




S. Beldi et al., LTD 2017

- Simulations with ε_r =8 (AlN) and t=100 nm.
- Dielectric loss factor tan(δ) < 10^{-5}.

Near Infrared and visible MKIDs

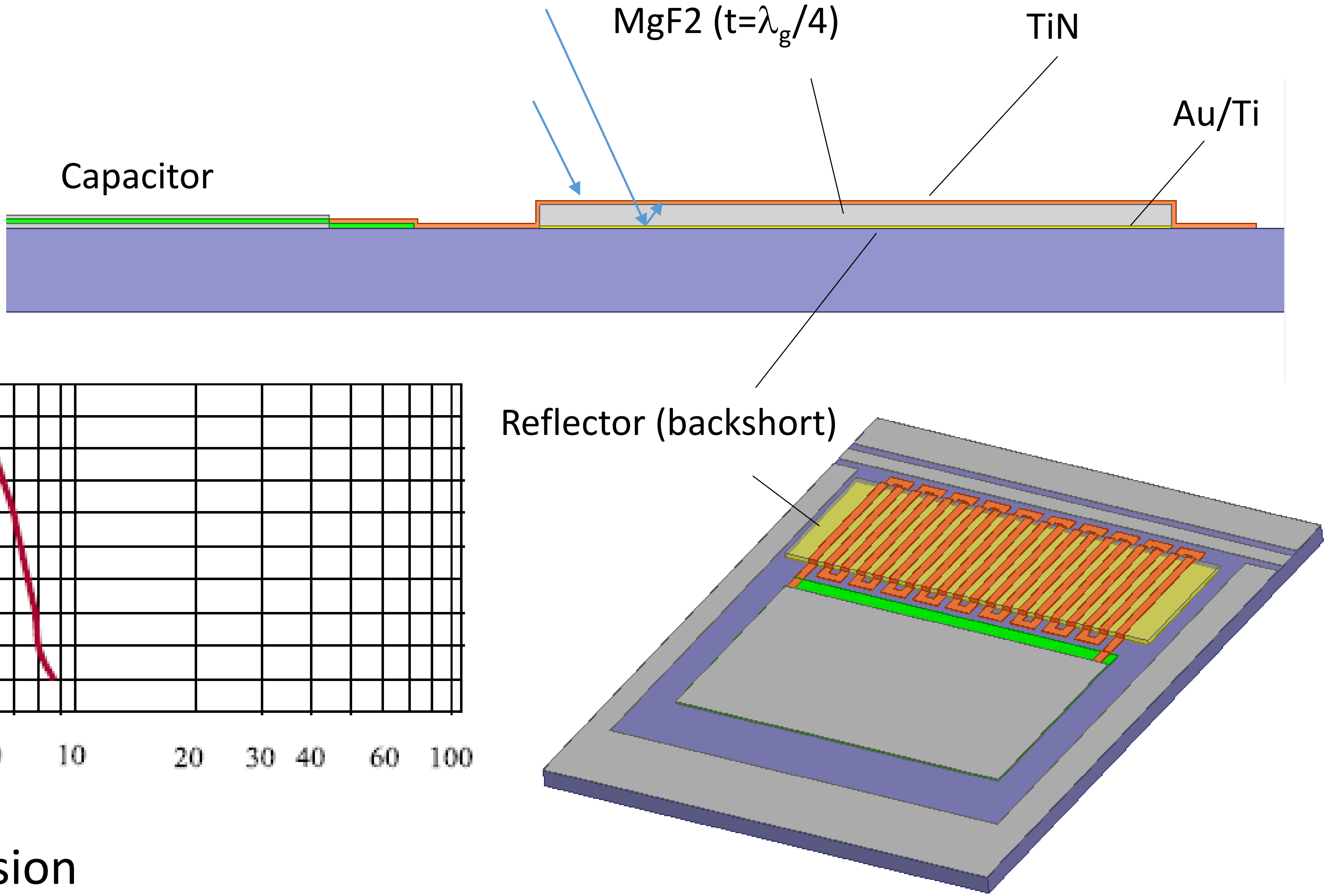


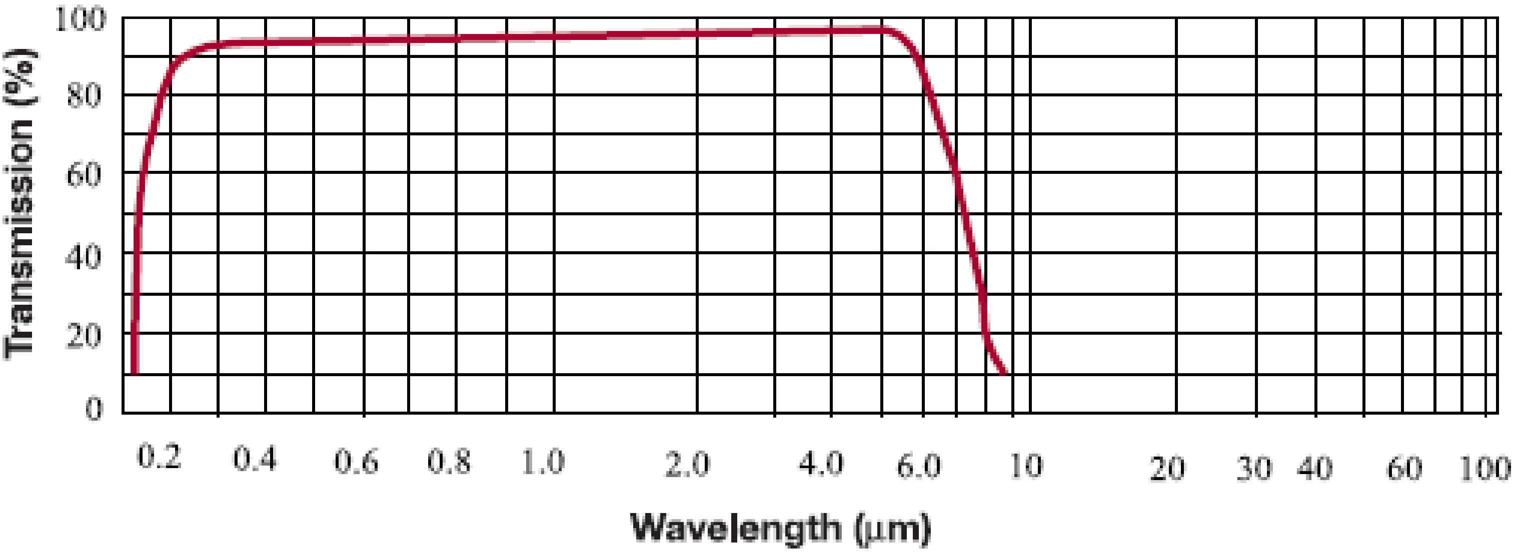
- Next step: the use of Al_2O_3 deposited by Atomic Layer Deposition (ALD) process (G. Coiffard et al, LTD 2017)

Near Infrared and visible MKIDs

New concept to increase the detection efficiency ?

- Magnesium Fluoride (MgF_2) is widely used as an antireflection layer.

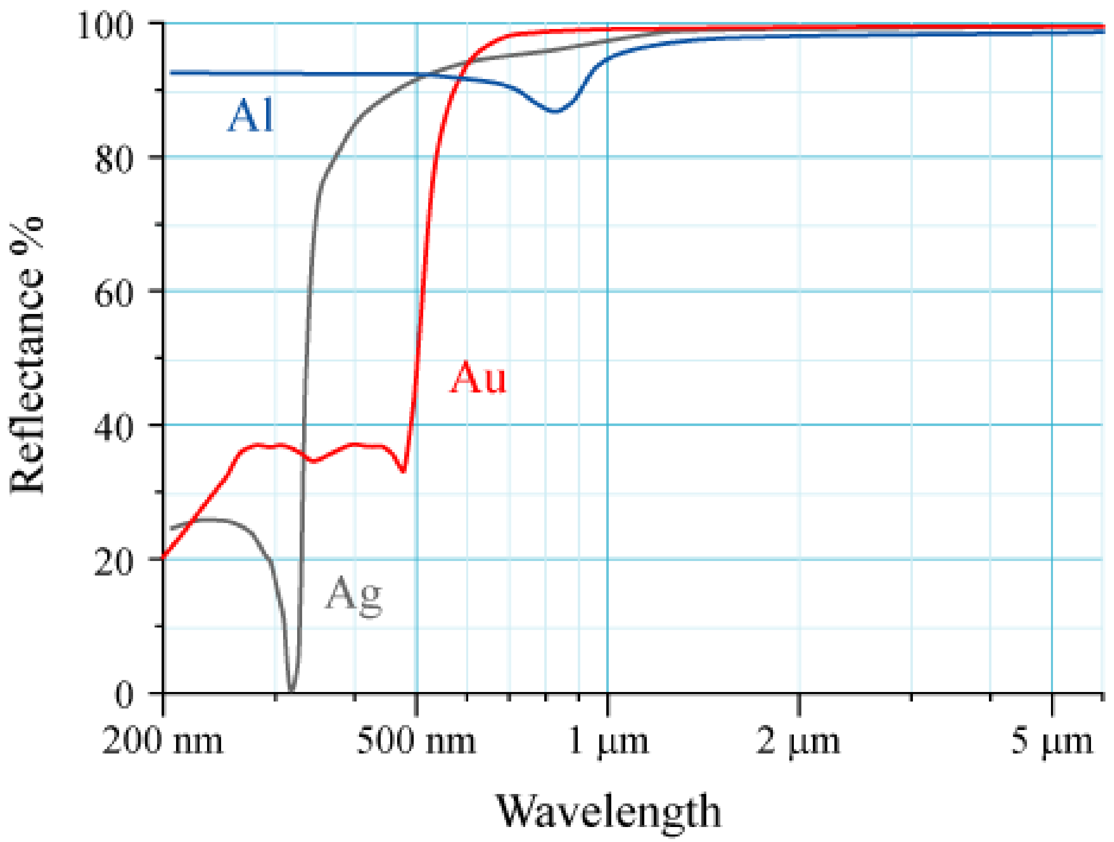




MgF_2 Transmission

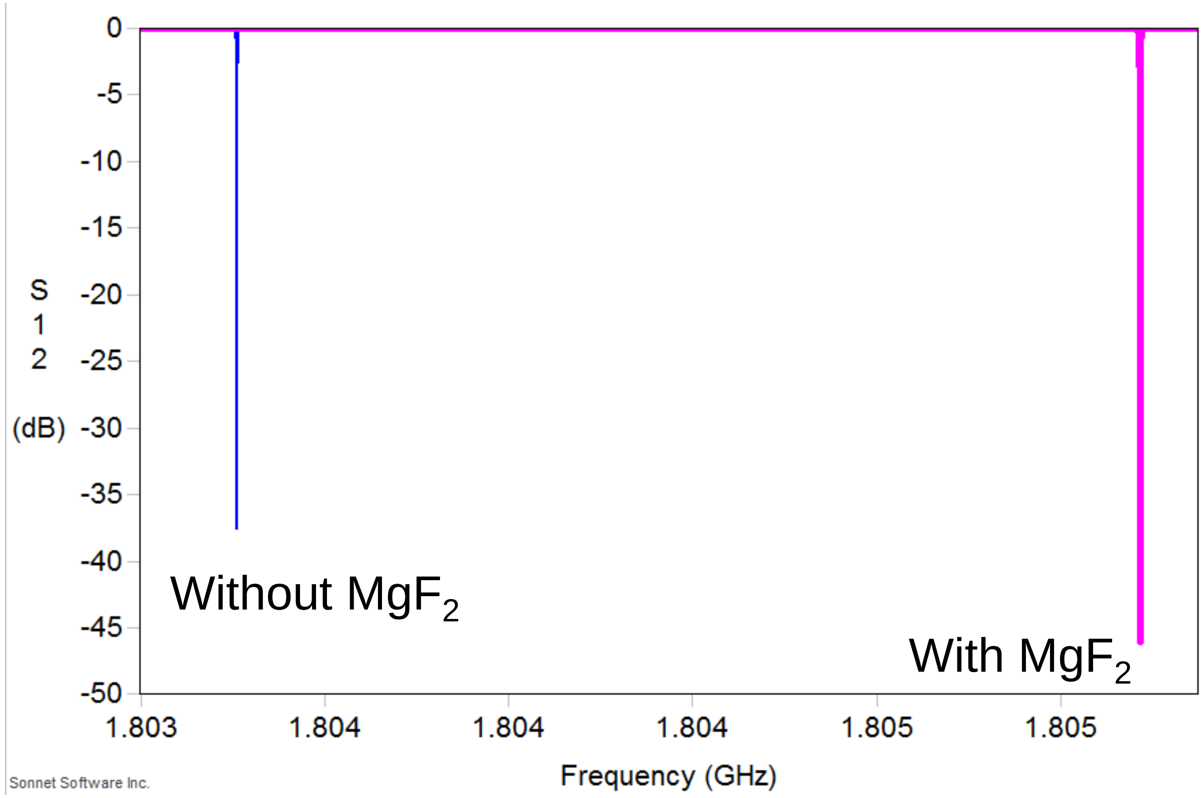
Near Infrared and visible MKIDs

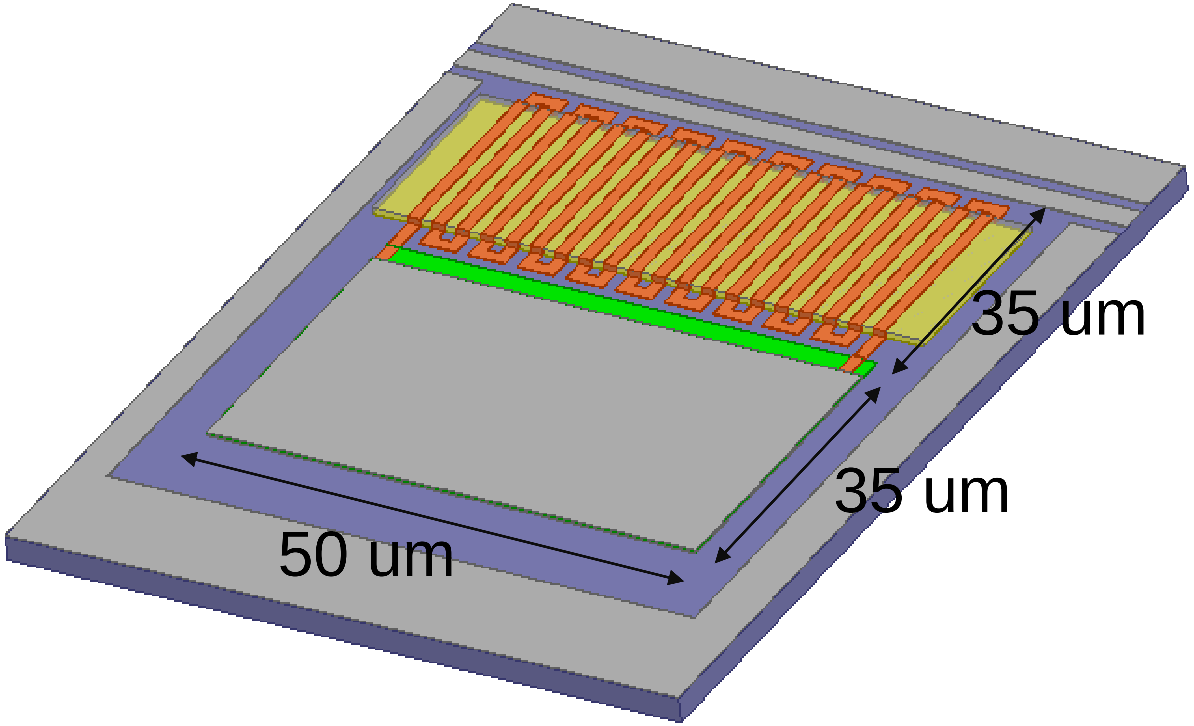
New concept to Increase the detection efficiency ?



Au Reflectance

Near Infrared and visible MKIDs

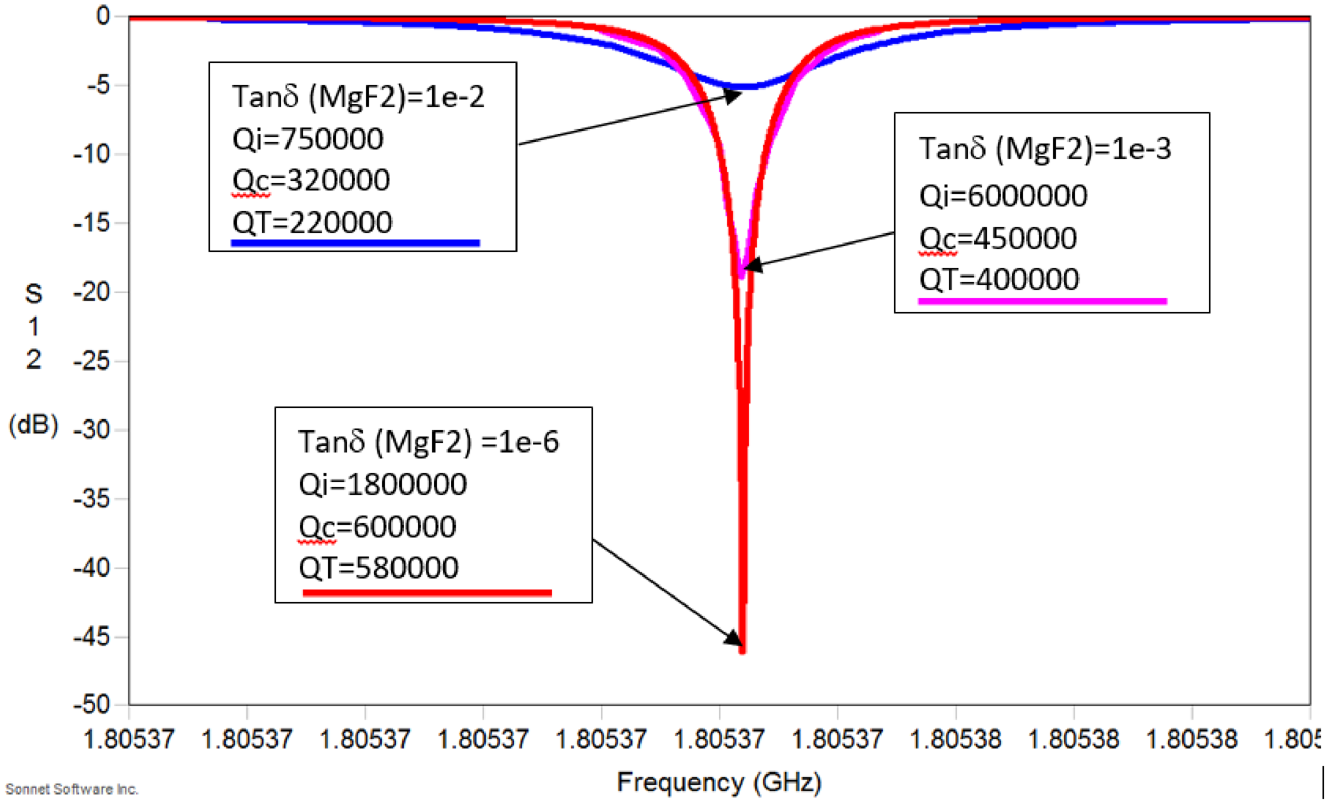


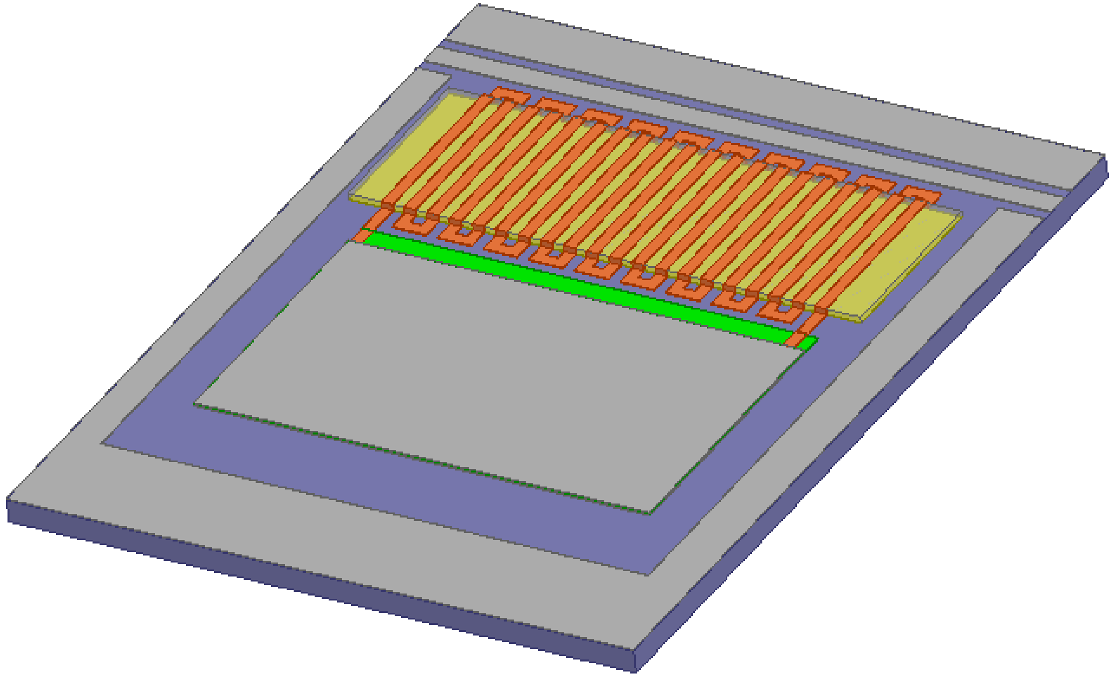


- Simulation of LEKID without and with a reflector and MgF2 layer.

Near Infrared and visible MKIDs

Effect of the MgF_2 dielectric loss factor tan(δ)

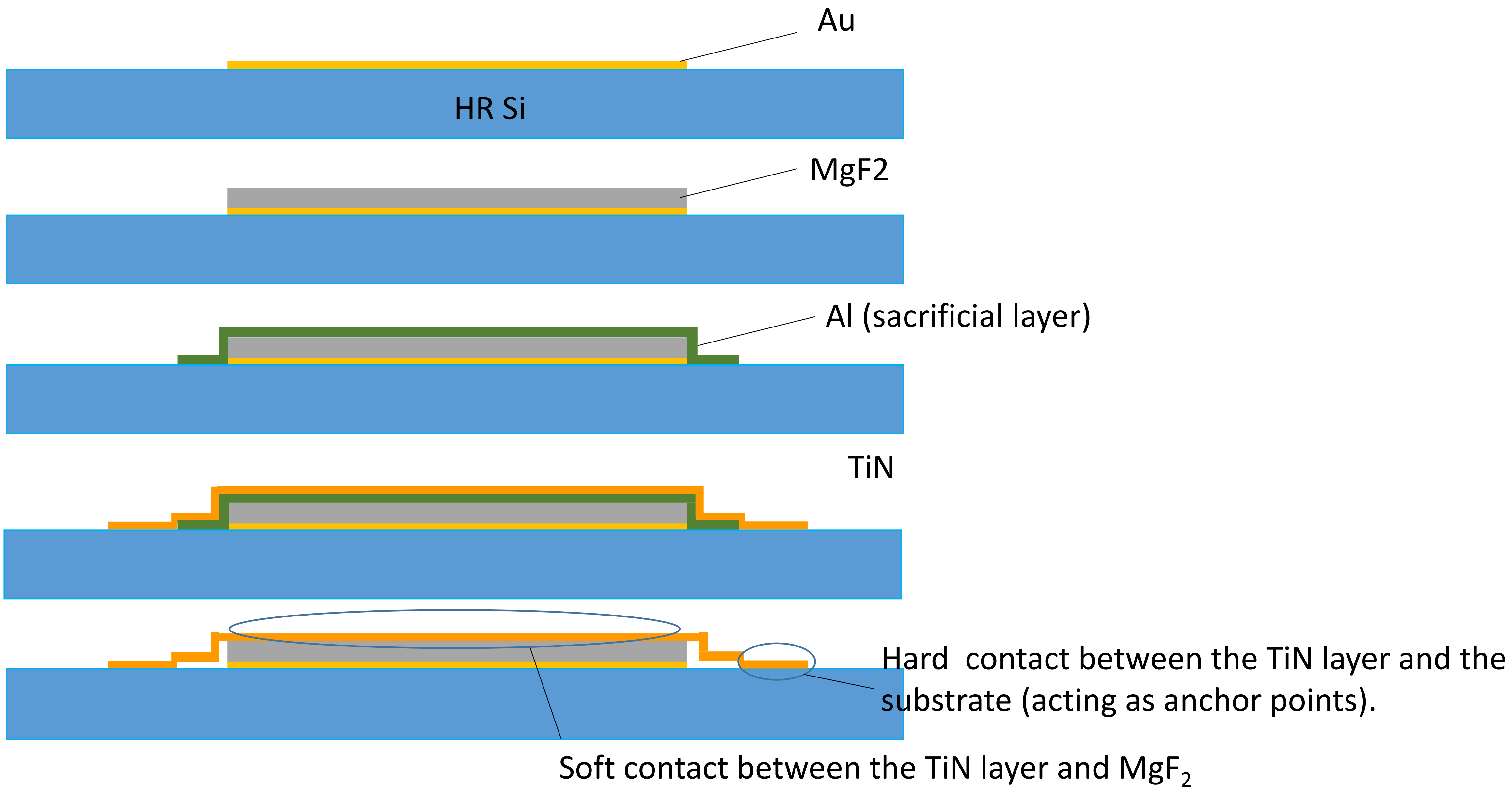




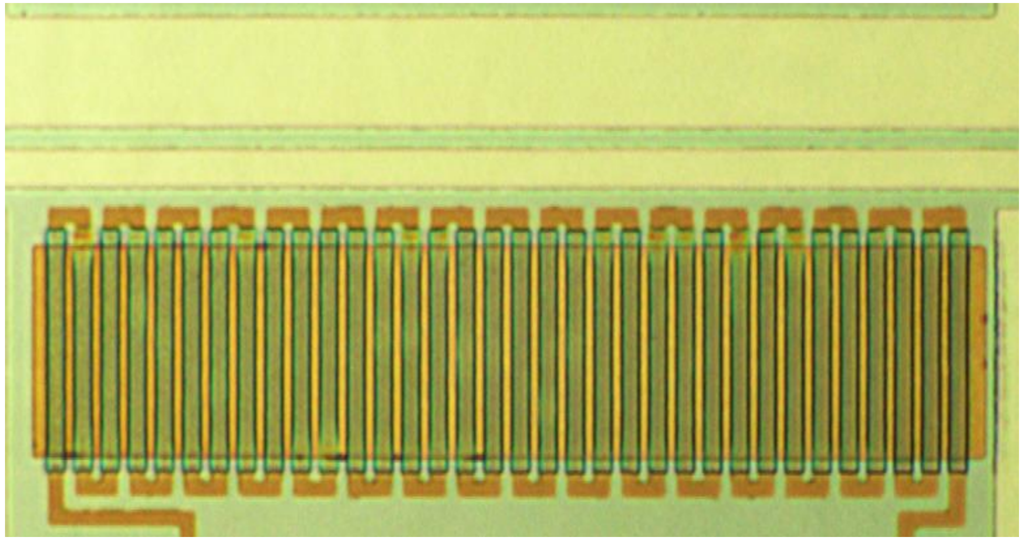
- MgF_2 is amorphous ⟶ probably a high TLS noise

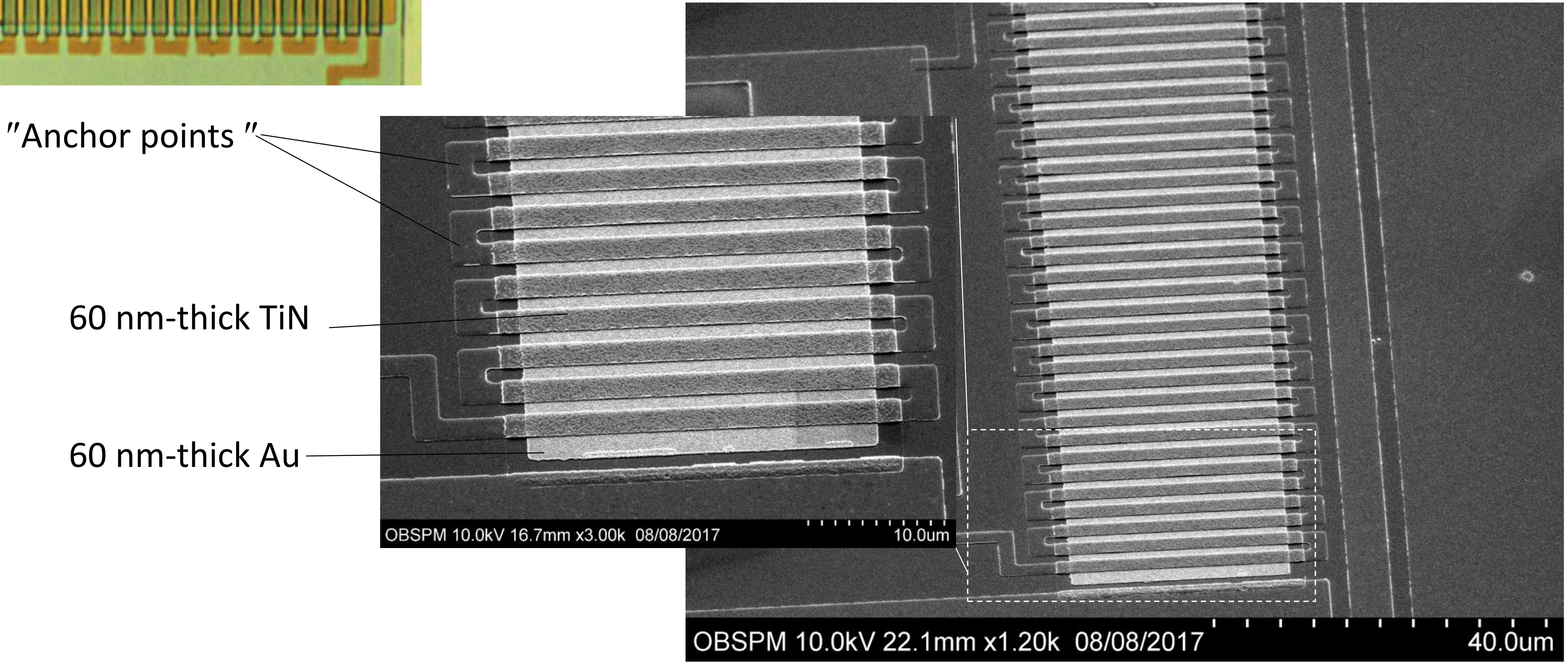
Can the softening of the chemical bonds between the superconducting layer and the substrate help to decrease the TLS noise?

Near Infrared and visible MKIDs

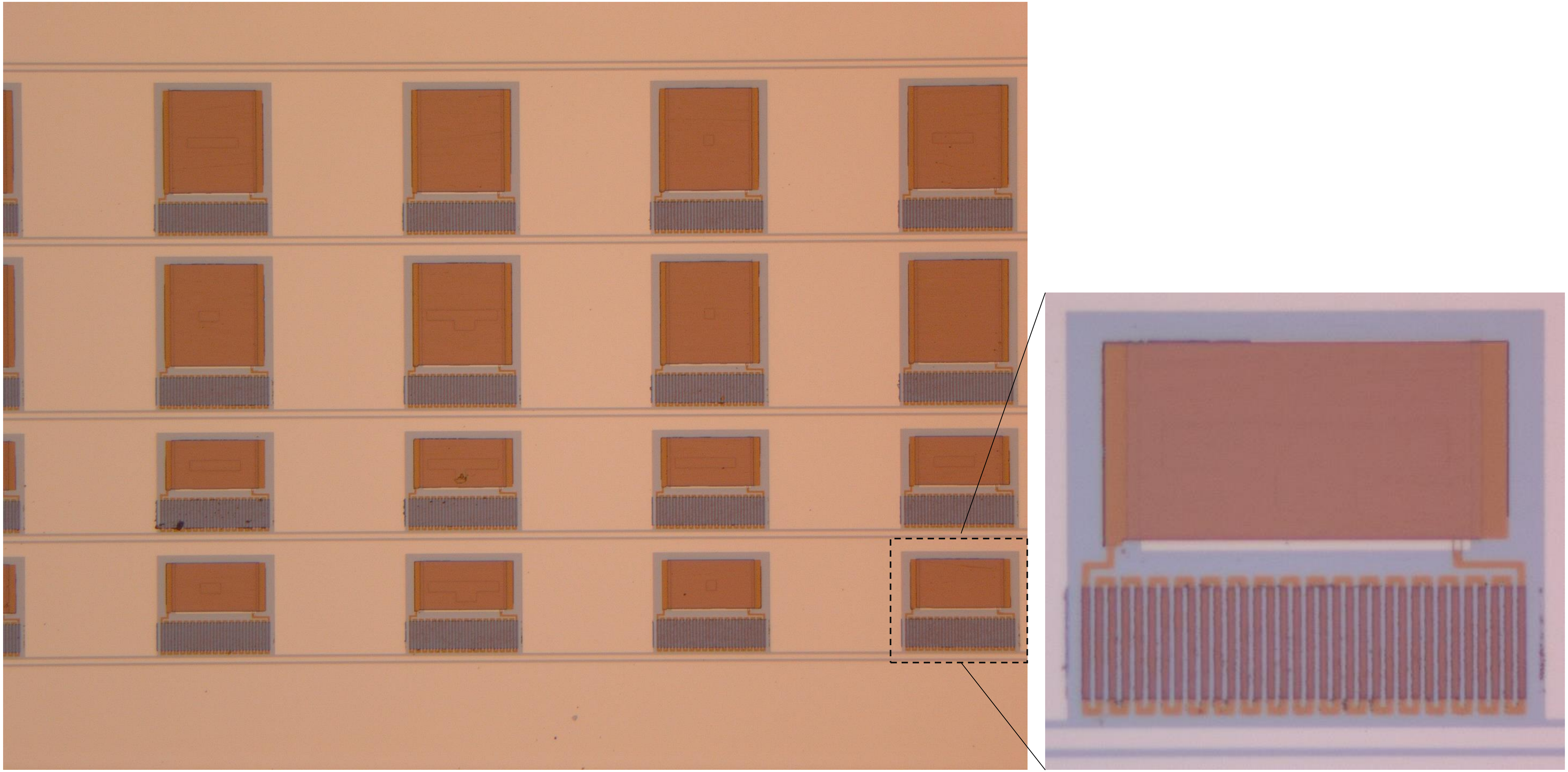


Near Infrared and visible MKIDs





Near Infrared and visible MKIDs

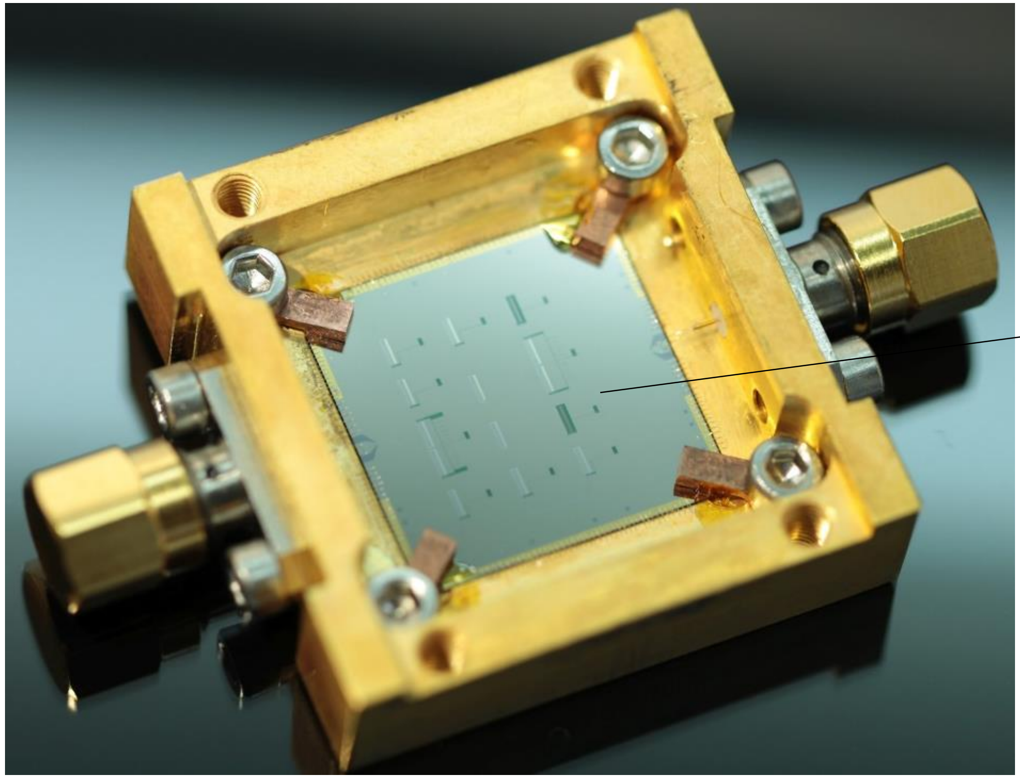


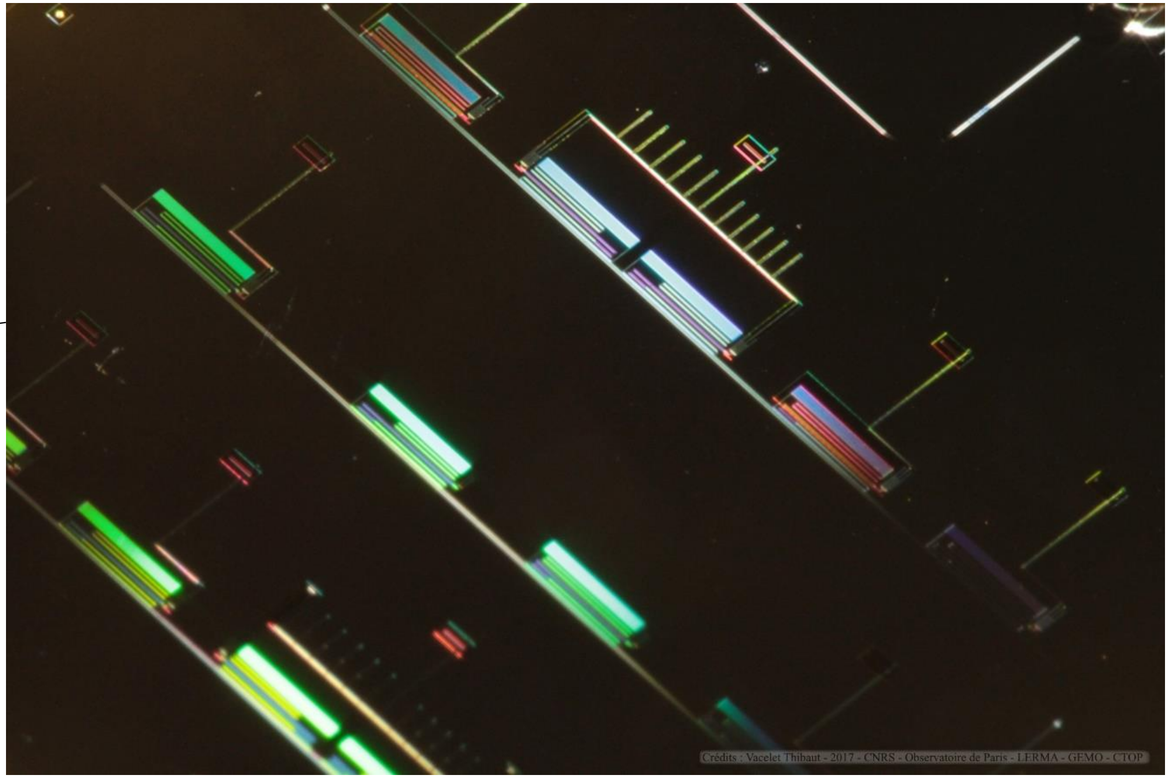
mm MKIDs

mm MKIDs (APC applications)

- Goal ⟶ Characterization of the polarization properties of cosmic microwave background CMB (B-Mode).

- Why MKIDs ? ⟶ high multiplexing capability (10^4 pixels)

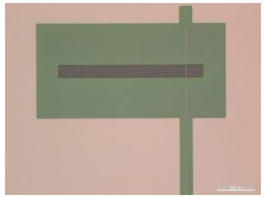




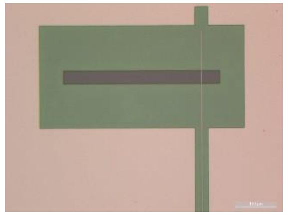
mm MKIDs (APC applications)

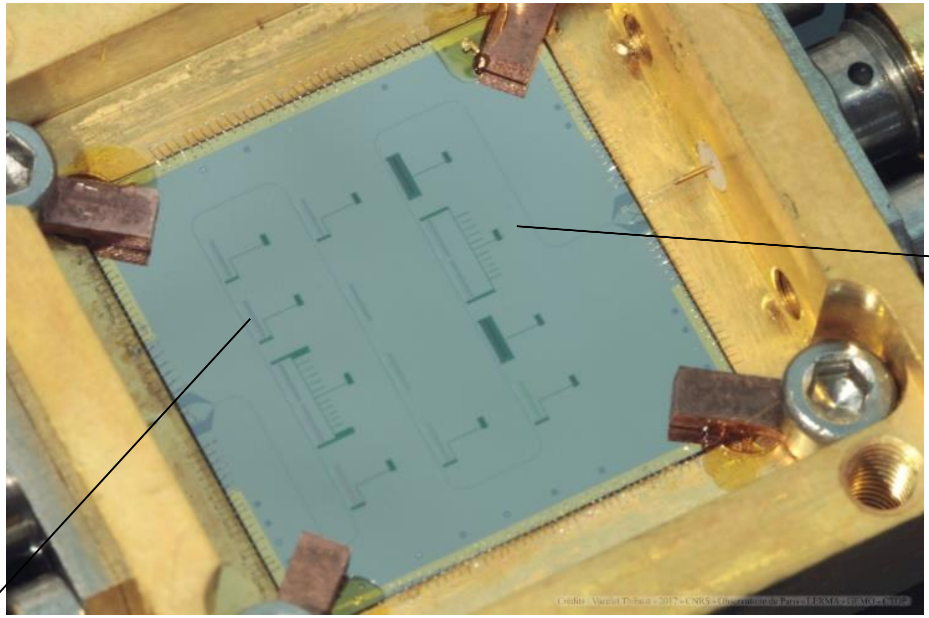
- **12 pixles, 3 designs**

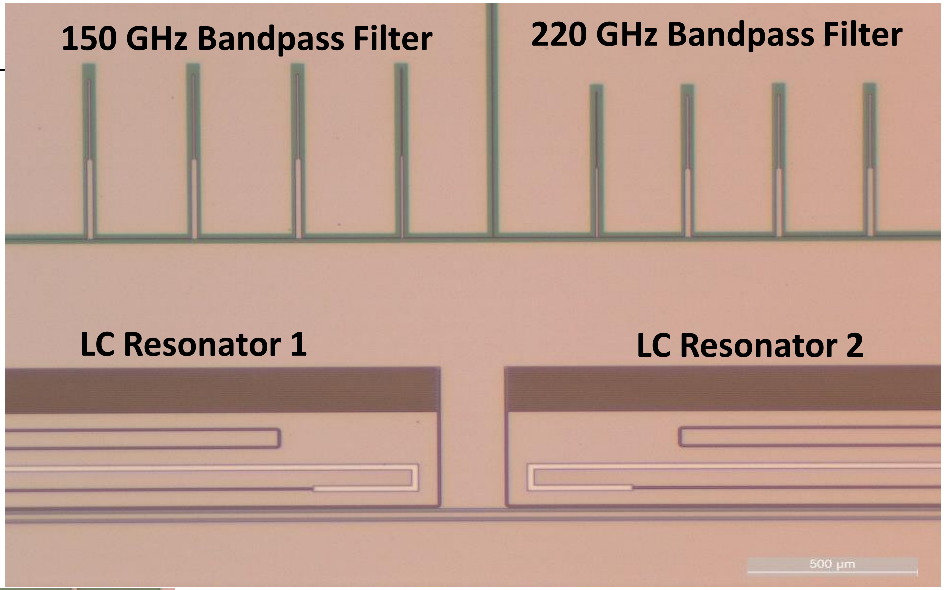
A. Traini et al., LTD 2017

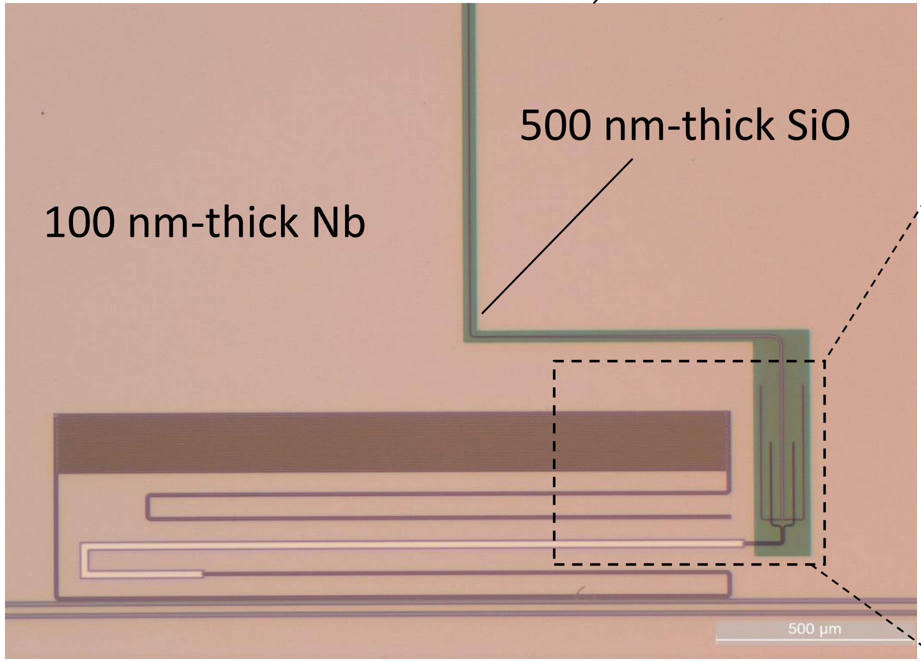


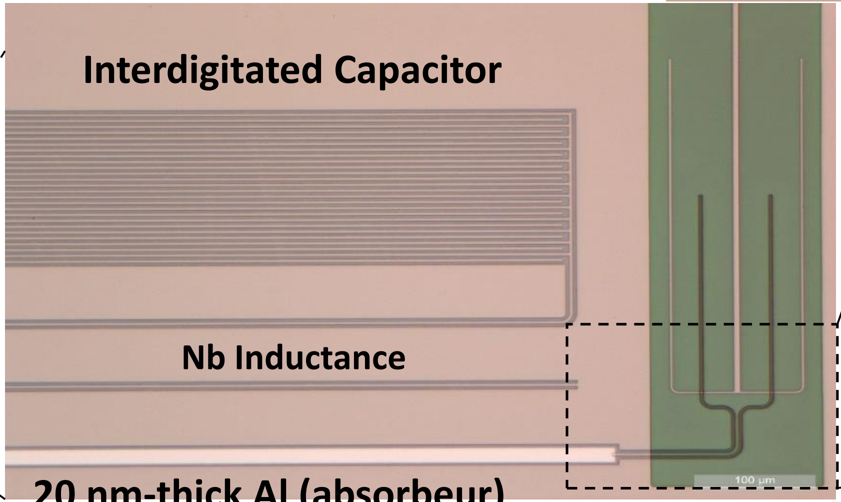
140-160 GHz Antenna slotline/2um-wide microstrip)

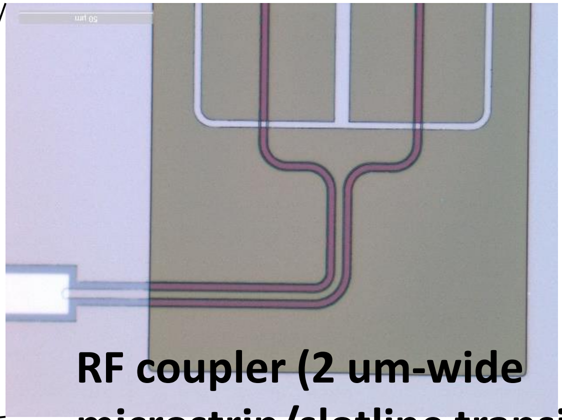






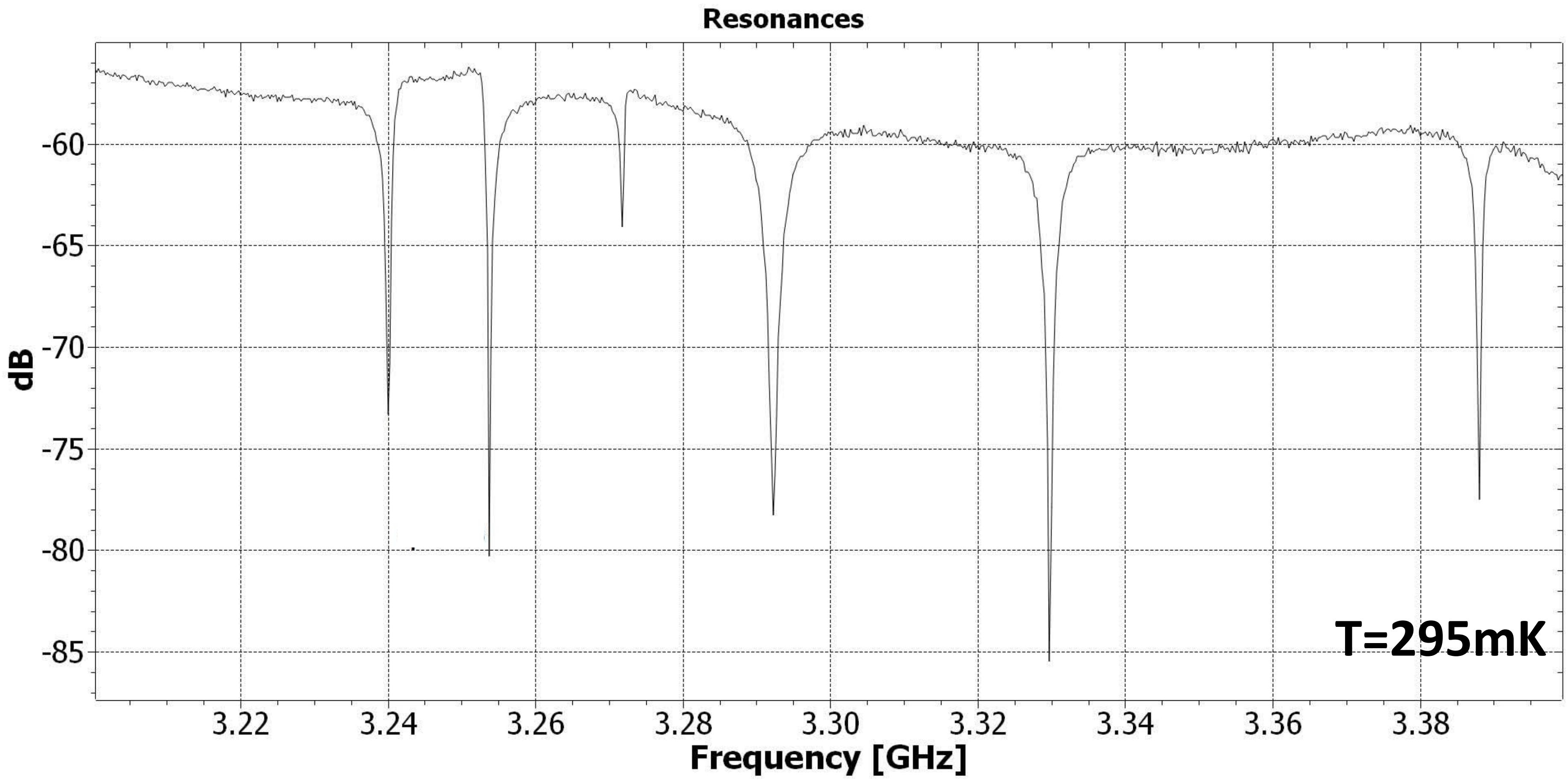






mm MKIDs (APC applications)

Preliminary experimental results



$Qi=10^3-10^4$

Conclusion

- We are developing Near Infrared and Visible MKIDs using parallel plate capacitors.

- A (new) concept to increase the detection efficiency, as well as to decrease the TLS noise ?