High quality Proximity-Coupled Al/Au Bilayer Kinetic Inductance Detectors

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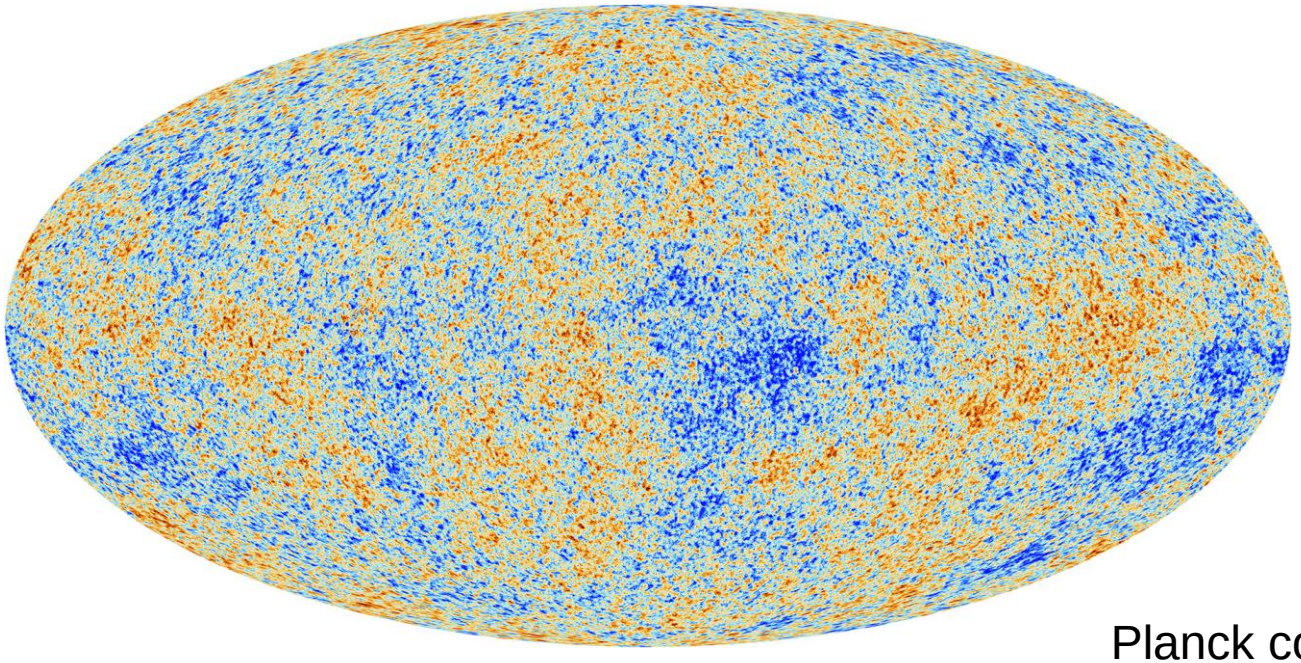
Motivation

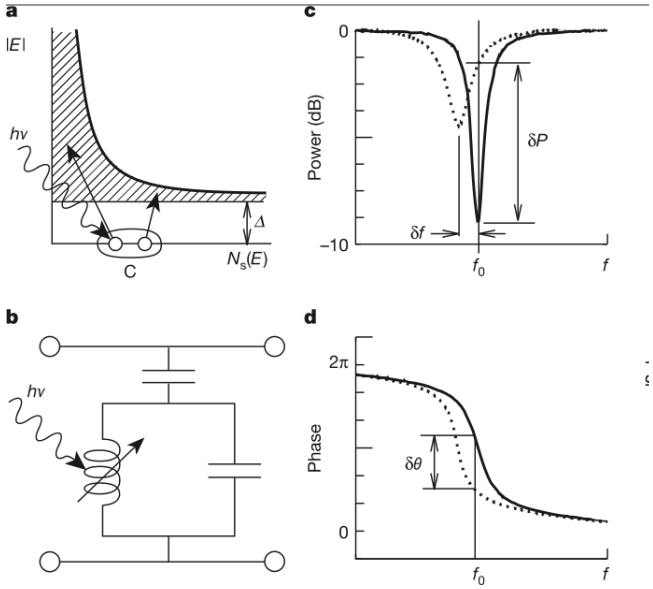
CMB detection below 90GHz



Planck collaboration

- B-mode detection: Separate foreground emissions

Kinetic inductance detectors



Mazin, Ph.D Thesis, Caltech 2005

- Photon noise limited
- Naturally frequency multiplexed
- Easy fabrication
- Very wideband
- With energy resolution

Detectable signal: $h\nu > 2\Delta(\mathrm{T})$

Energy gap: $\Delta(0) \approx 1.76 k_B T_c$

Common Material in KIDs

	Al	TiN	PtSi	Nb
T_c(K)	1.2	0.6~4.6	0.9	9.2
f_{min}(GHz)	~90	~45	~67	~700
$L_k(pH/\square)$	1.08 @20nm	7~24 @60nm	10.5 @60nm	0.2 @100nm
Lifetime (μs)	~200	~200	~15	~0.01
Fabrication	Mature	Difficult	Expensive	Mature

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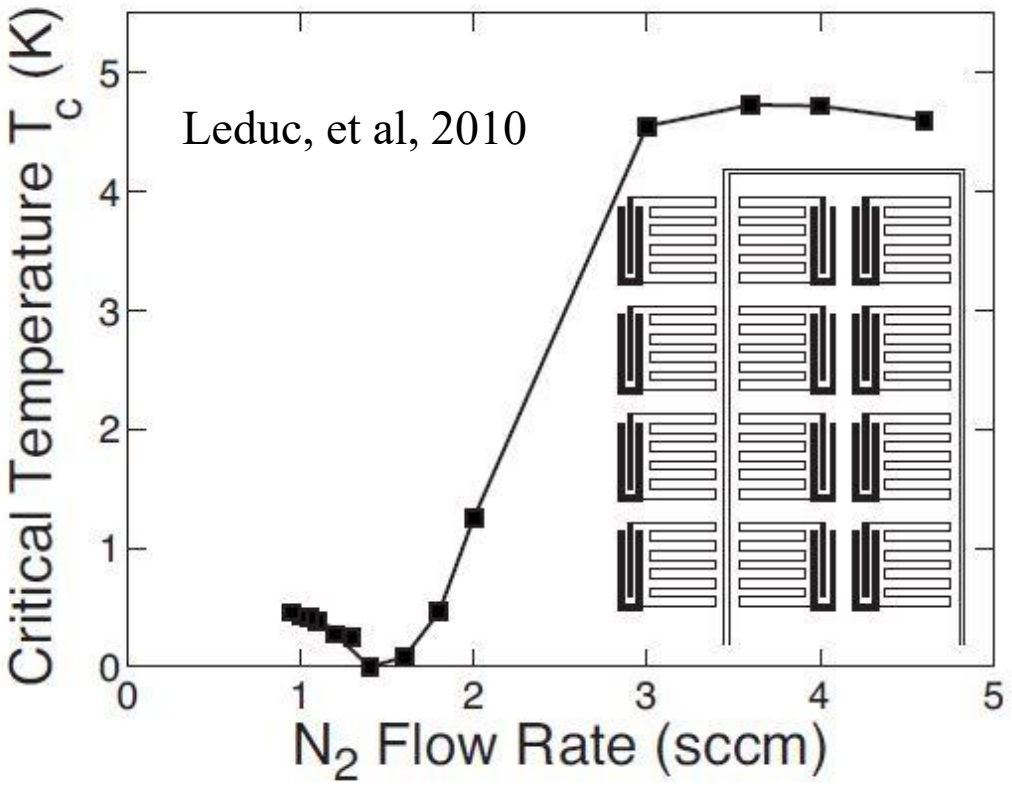
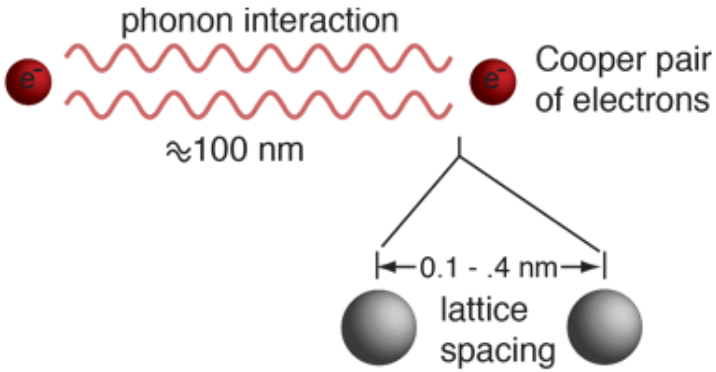


The proximity effect

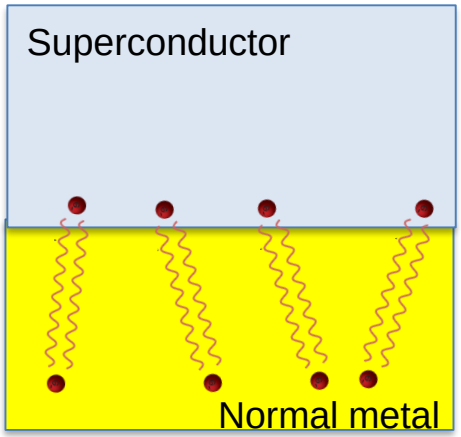
- Superconductivity



➢ Coherence length: $\xi \sim \mu m$

- Proximity Effect

  When a normal metal is placed close to a superconductor, the cooper pairs can ‘leak’ into the normal part, making the normal metal superconducting.



The Proximity Effect

- Advantage
  - Lower critical temperature
  - Higher kinetic inductance than Al or Nb
  - Tunable critical temperature
  - Much easier fabrication
- Disadvantage
  - Increasing loss

$$\frac{d\theta}{dN_{qp}} \propto \frac{1}{\sqrt{\Delta k_B T}(2\Delta + k_B T)} \frac{\alpha Q}{N_0 V}$$

Mazin, 2005

α : Fraction of kinetic inductance

Q : Quality factor

V : Volume of the resonator

The Proximity Effect KIDs

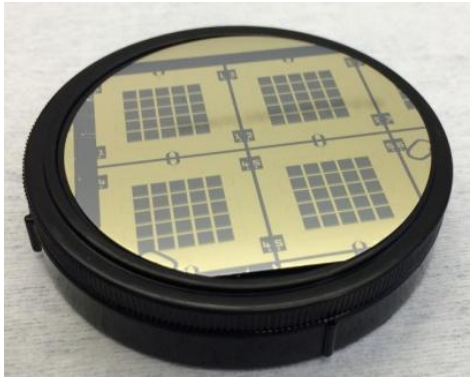
- Combinations been investigated

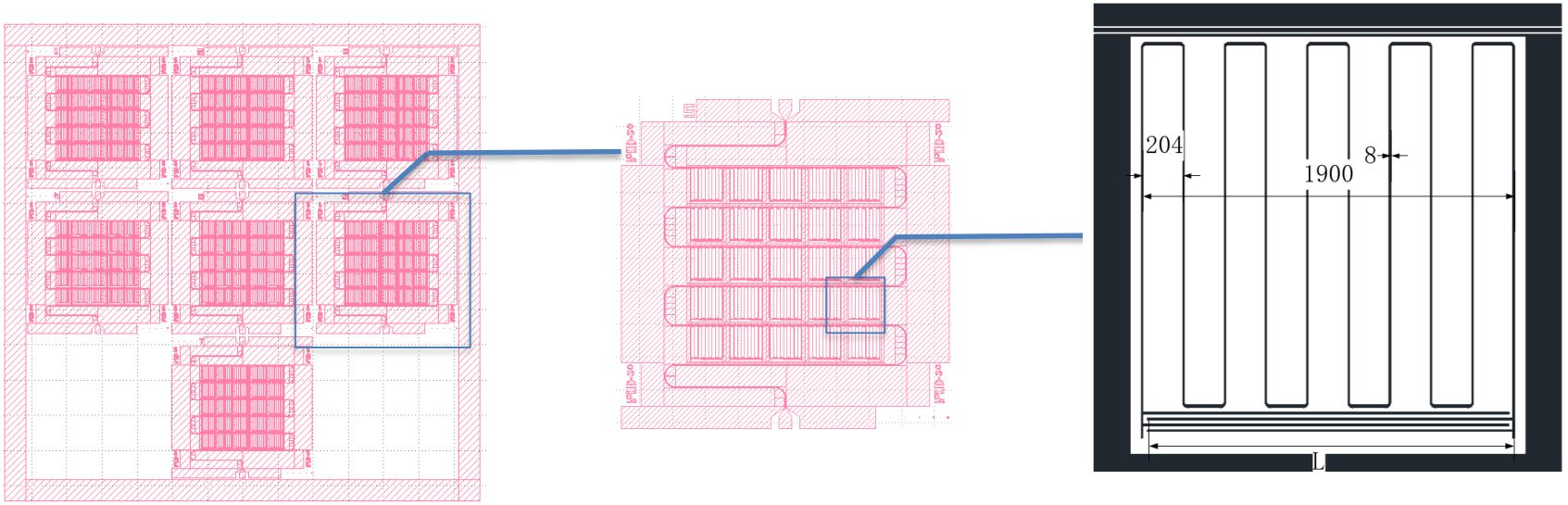
Combinations	Thickness (nm)	T_c (K)
TiN/Ti/TiN	4/10/4	~1.3
Al/Ti/Al	14/33/30	~0.8
Al/Ti	10/25	~0.9
NbTiN/Au	300/10	13.6
Nb/Cu	8/22	1.65

Barends, Daalman et al. 2009
Vissers, Gao et al. 2013
Catalano, Goupy et al. 2015
Dominjon, Sekine et al. 2016
Cardani, Casali et al. 2018

KIDs Design

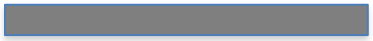
- Based on NIKA KIDs
- Three different samples
  - # 10nm Au 30 nm Al
  - # 10nm Au 30 nm Nb
  - # 30 nm Al





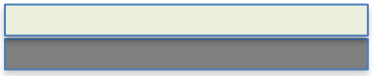
Fabrication Procedure

1



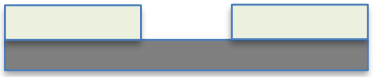
Surface cleaning

2



HMDS+photoresistor

3



AZ726 MIF

4

Gold evaporation

5

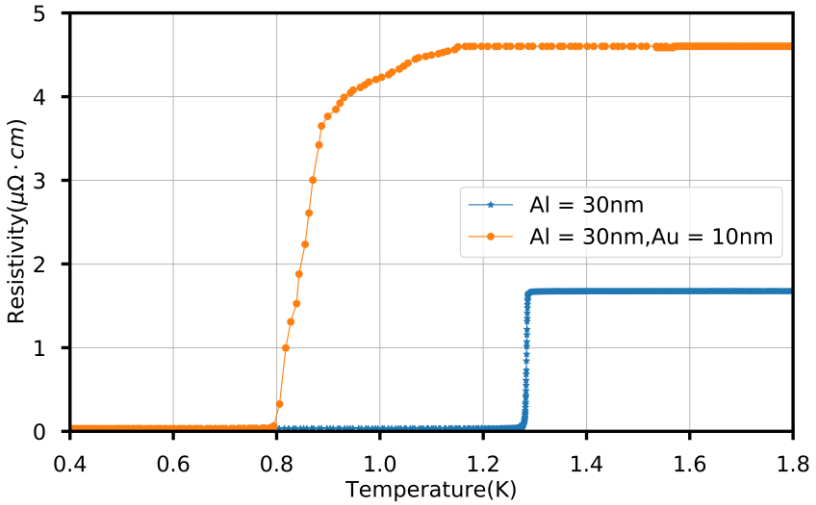
Al sputtering

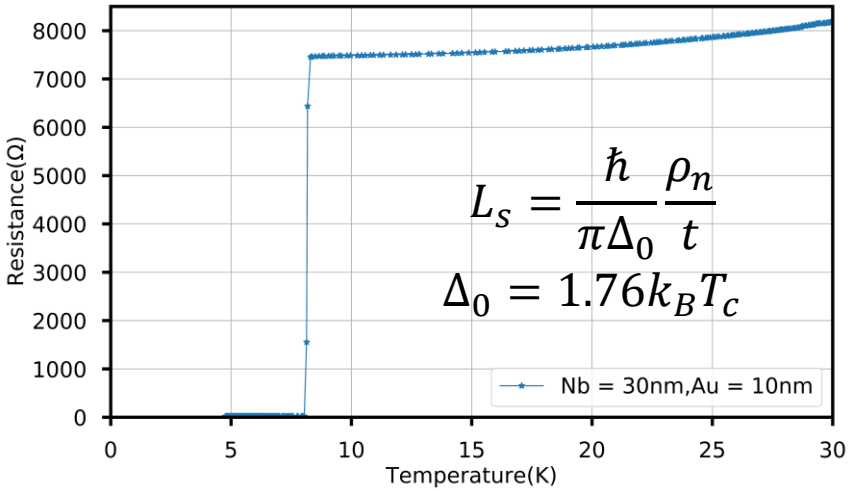
6

Liftoff

Critical temperature

4 wires measurement in 300mK cryostat.

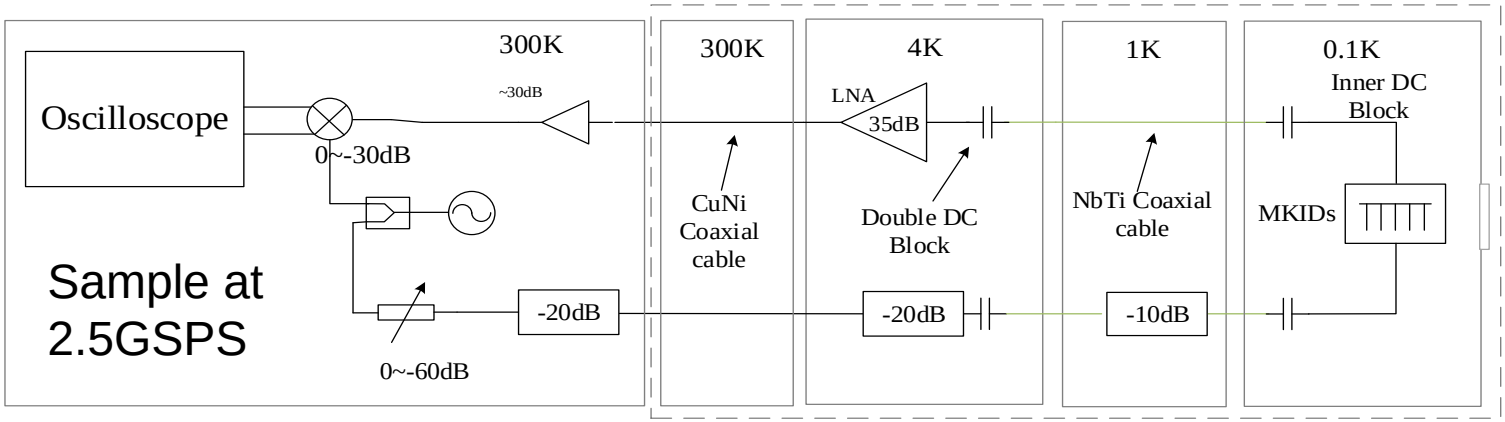


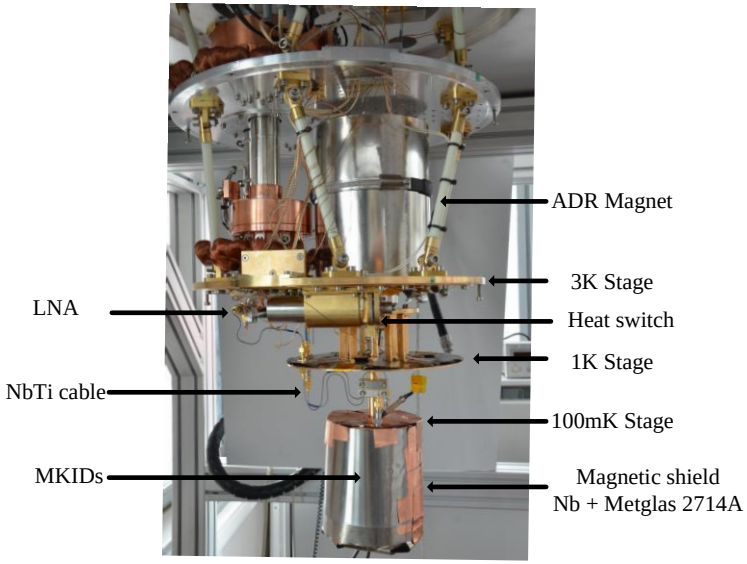


- The aluminum starts to become superconducting around 1.2K
- The transition of Al/Au is not sharp as that of Nb/Au

Parameters	Nb/Au	Al/Au	Al
Tc(K)	8.2	0.8	1.28
Resistivity ($\mu\Omega \cdot cm$)	5.17	4.6	1.7
L_s(pH/□)	0.218	1.9	0.6

KIDs Readout system

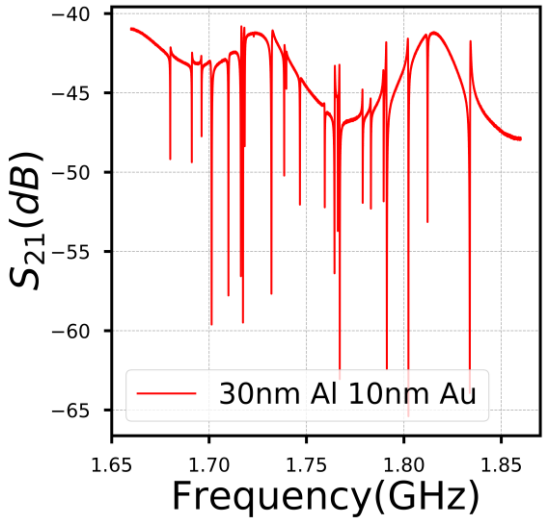




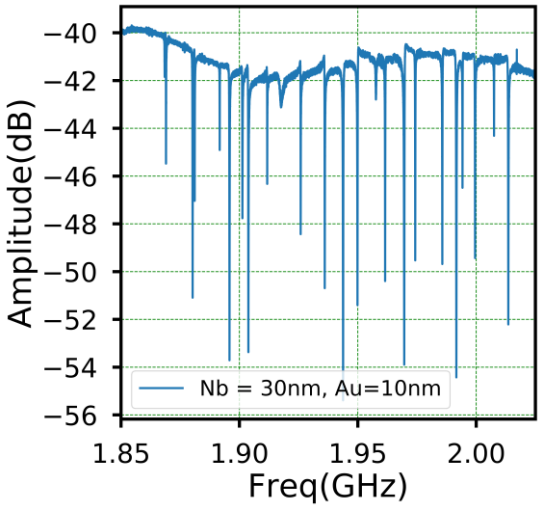
- Pulse-tube based ADR
- Readout by an oscilloscope or VNA
- Magnetic shielding around sample
- Holding time at 100mK: around 4h

Measured Transmission

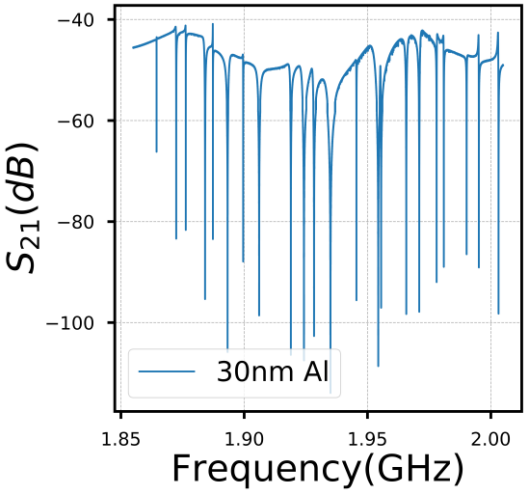
Al/Au



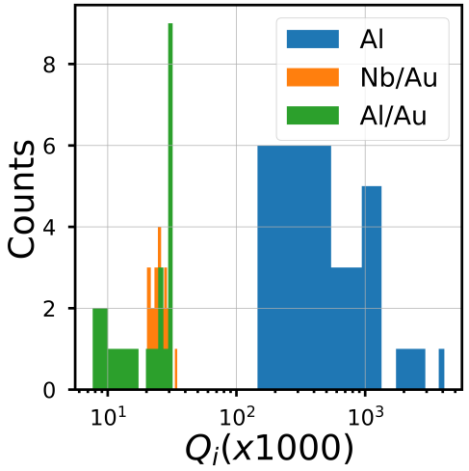
Nb/Au



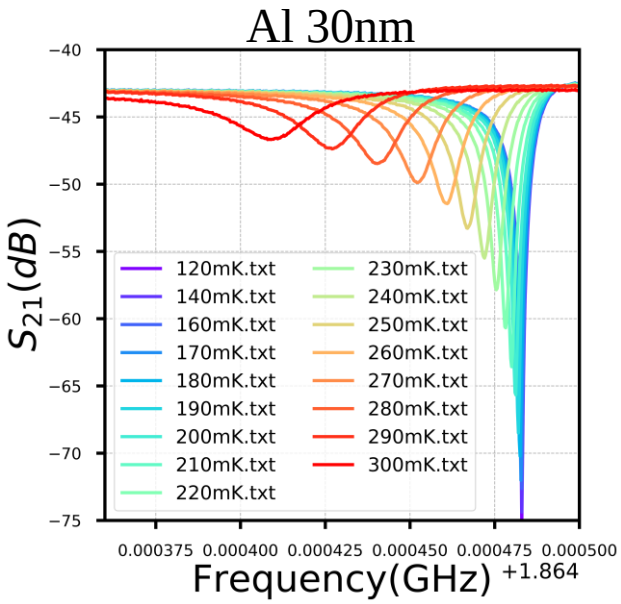
Al

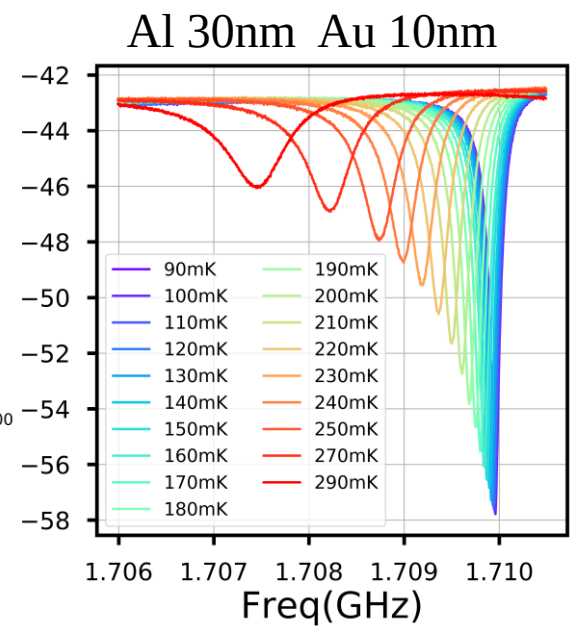


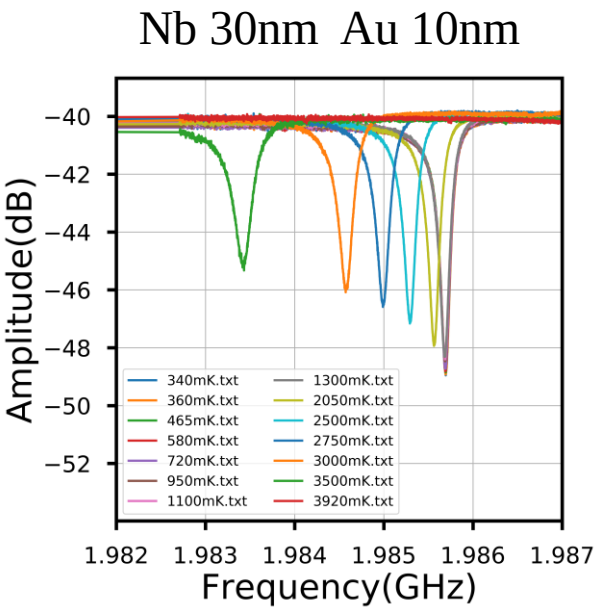
- Au/Al Qi~27000
- Au/Al show higher kinetic inductance proportion



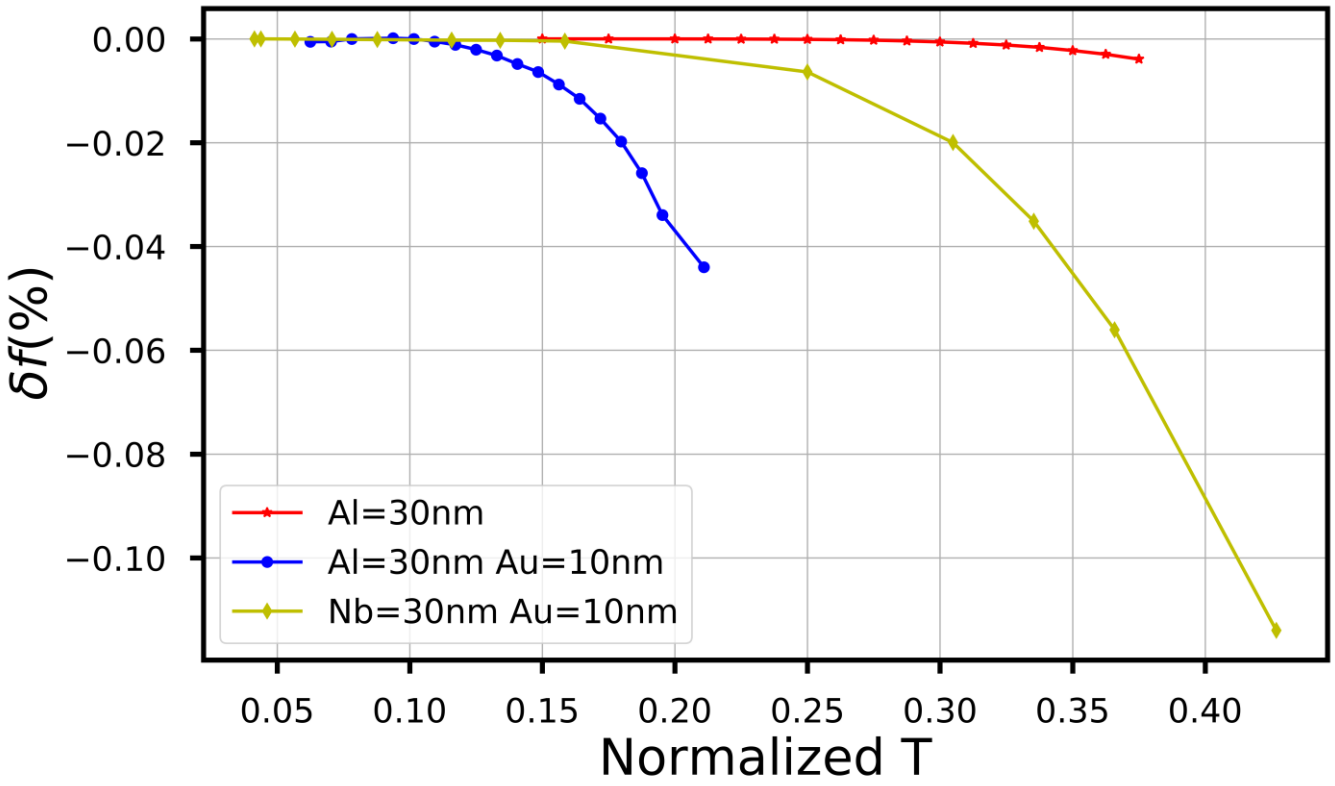
Temperature dependence



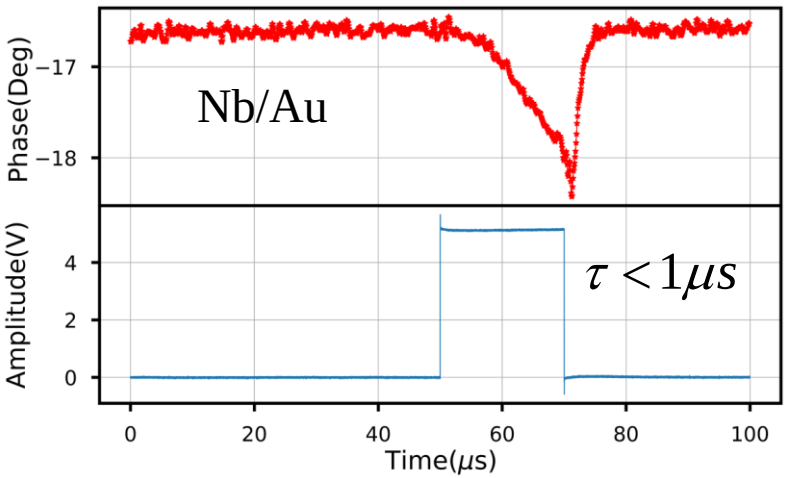


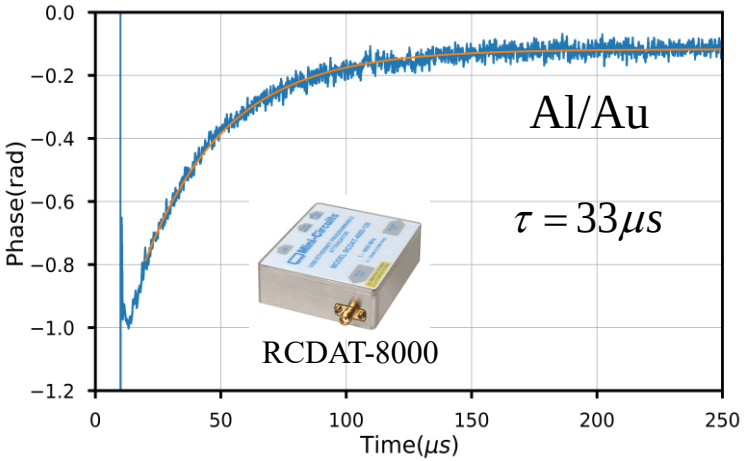


Temperature dependence



Quasi-particle Lifetime

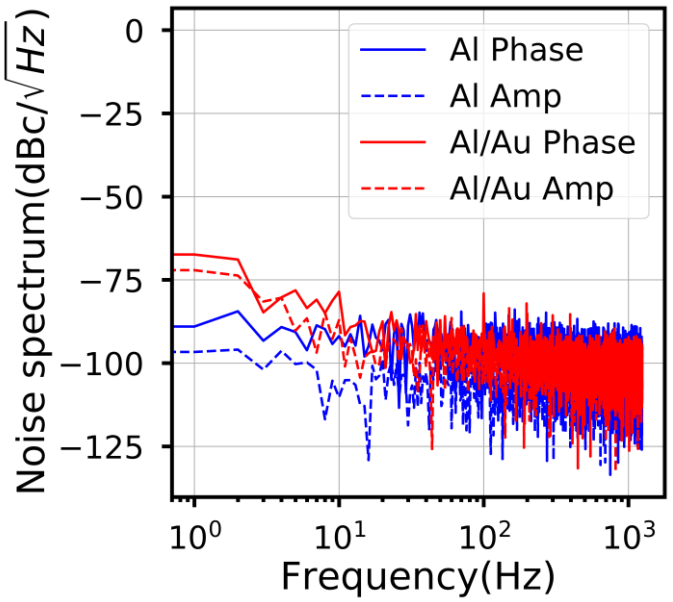


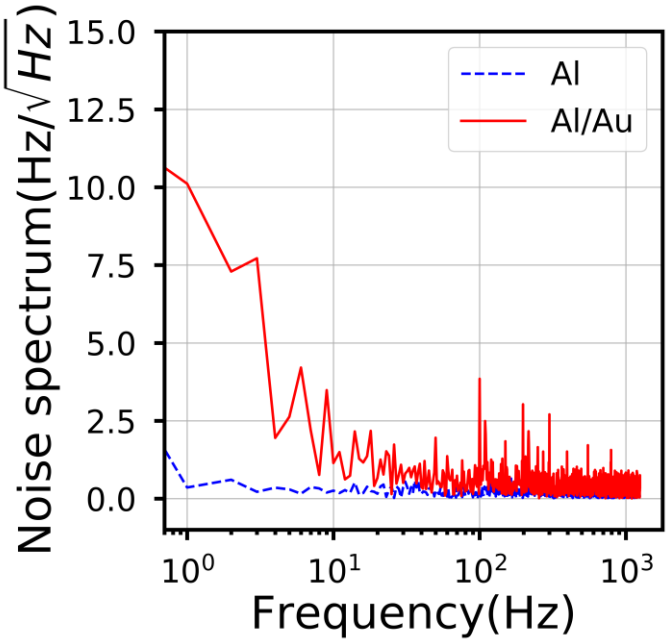


- The lifetime of Nb/Au is measured by LED illumination
- The lifetime of Al/Au is measured by changing readout power, which is controlled by readout power.

Kutsuma, Hattori et al. 2019

Noise spectrum

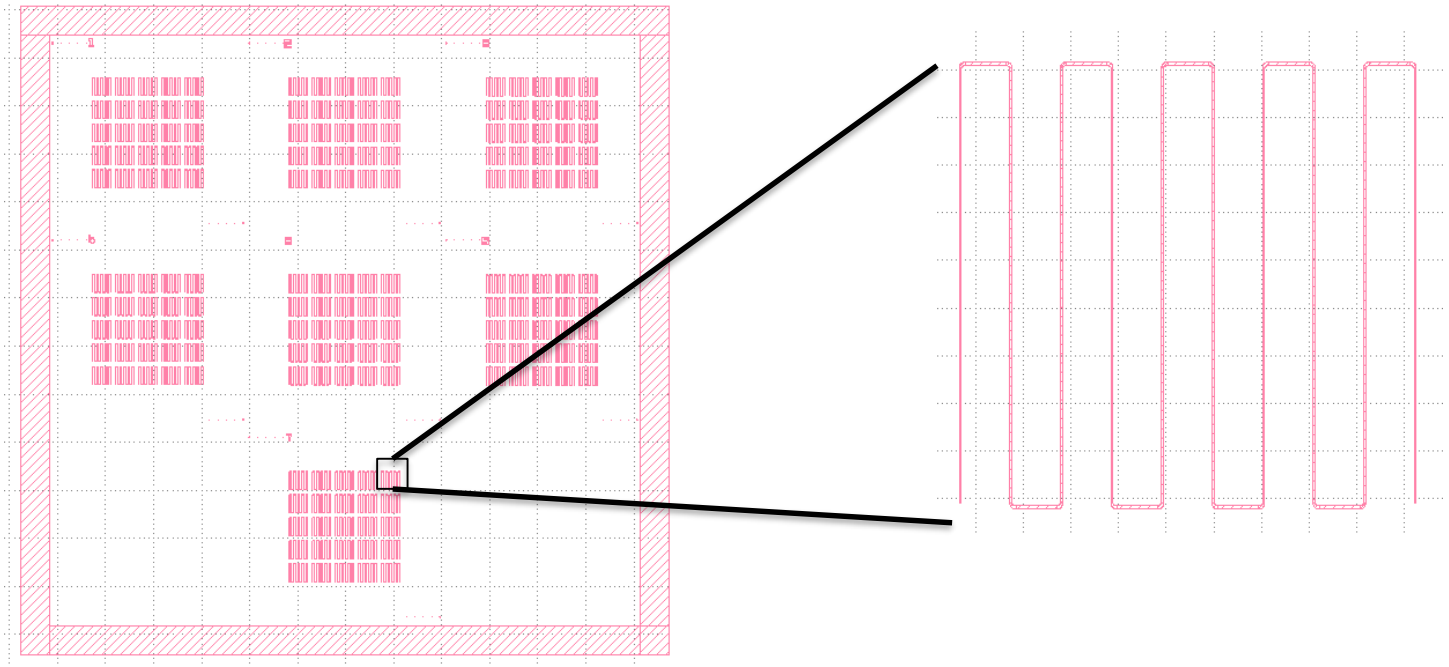




- The extra noise may originate from the interface between the Al and Au

Further development

- Measuring the aging effect of the Al/Au KIDs
- Optical response measurement for Al/Au KIDs
- Optimize the thickness of the layers
- Deposit the gold only in the inductor part
- Design resonances at lower frequency



Conclusion

- First successful high-quality Al/Au KIDs development and compared with Al and Nb/Au KIDs.
- The kinetic inductance of Al/Au (30nm/10nm) film is measured. The transition to superconducting is relatively wide.
- The lifetime of the Al/Au (30nm/10nm) KIDs is measured to be around 33um
- The measured noise spectrum of the Al/Au KIDs is about 20dB higher than Al KIDs, which may originate from the interface between the Al and Au interface.

Thank You