The properties of MKID made of crystal Al films and amorphous Al films

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T. Nitta (Univ. of Tsukuba)

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Outline

- Sub-millimeter camera developments at NAOJ
  - -lens, double slot antenna
- Motivation
- Epitaxial Al films using by MBE
- Results

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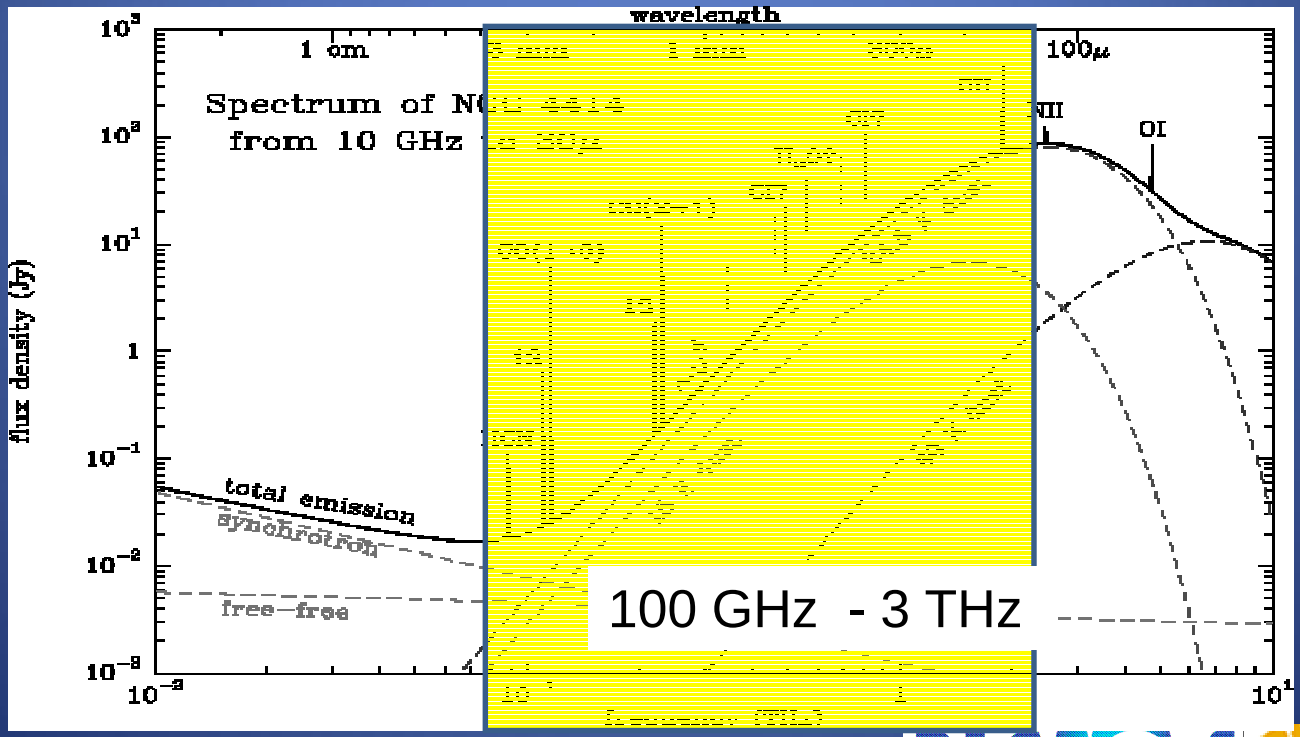
Long-term Goal

- Pixel : 10000 (2015)
- Frequency 100 GHz (3mm) – 3 THz (100 um)
- *NEP* ~ 10^{-19} W/Hz$^{1/2}$
- Dynamic Range > 10^5
- Simple, compact and low cost instrument as well as high performance



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Millimeter Camera Development at NAOJ ATC

Collaborator

- Satellite for B-Mode Polarization of CMB, LiteBIRD

KEK, RIKEN, Okayama Univ.

- mm-wave Telescope in Antarctica

Univ. of Tsukuba

Short-time Schedule

year	pixel	MKID + optics	Other task
2010	120	9 pixel	multiplex readout
2011	400	102 pixel	10^{-17} (W/Hz$^{1/2}$)
2012	1000	1024 pixel	System

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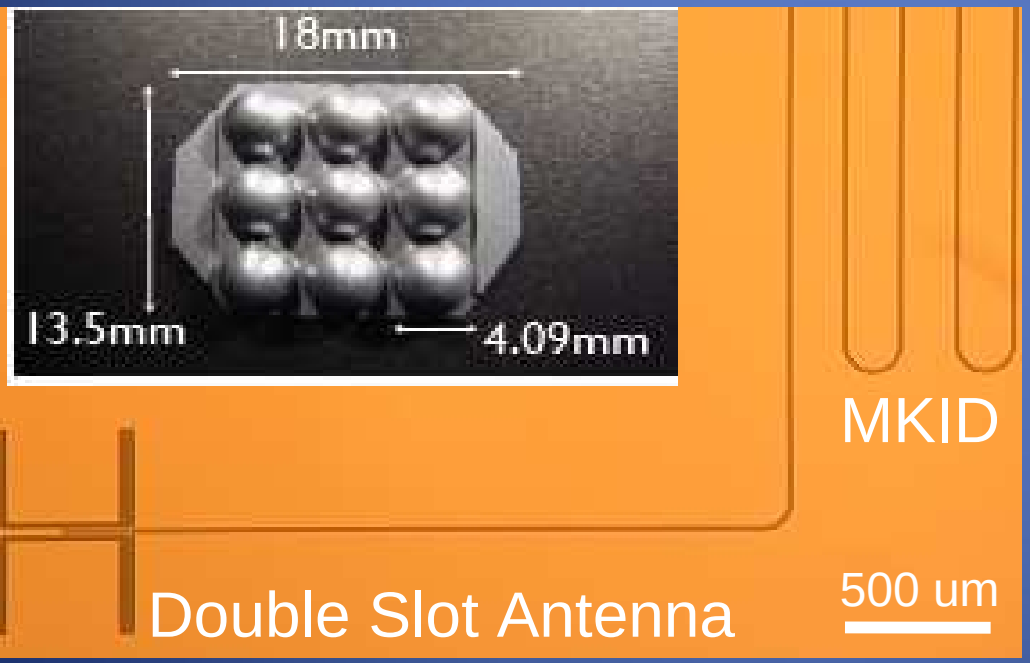
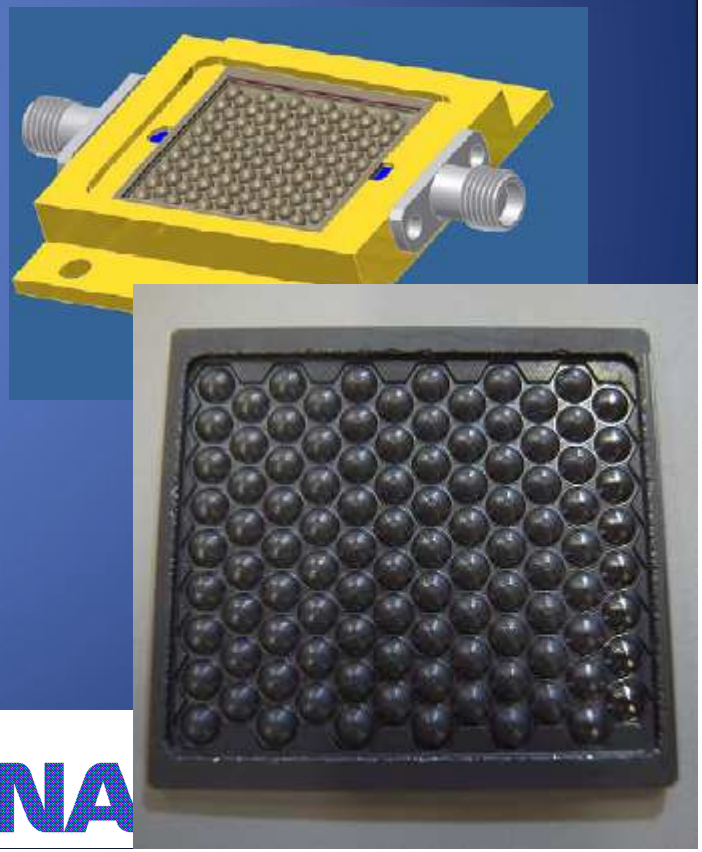
Overview of the camera design

- Microwave Kinetic Inductance Detector (Day, 2003)
- Lens coupled double slot antenna (Fillipovic, 1993)

102 pixel @ 440 GHz



9 pixel @ 220 GHz



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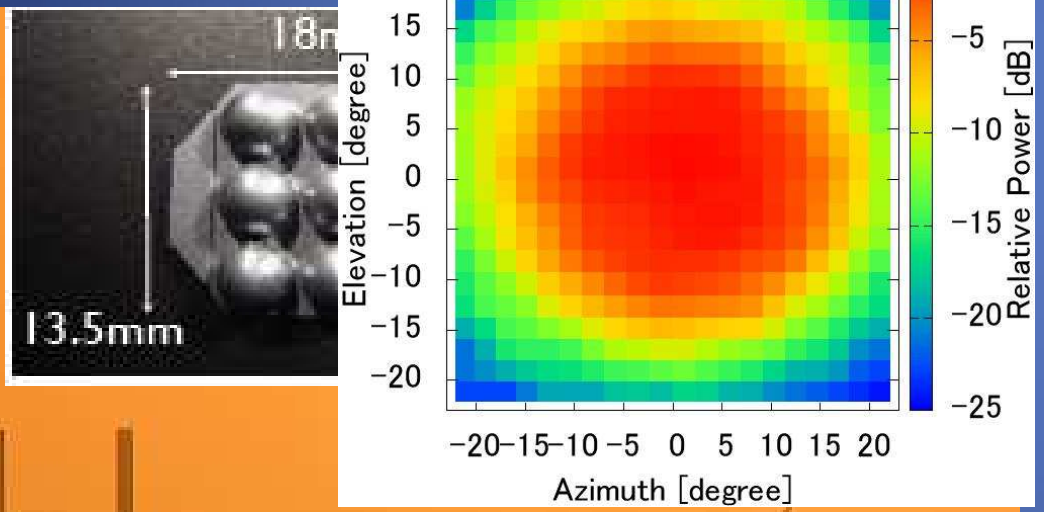
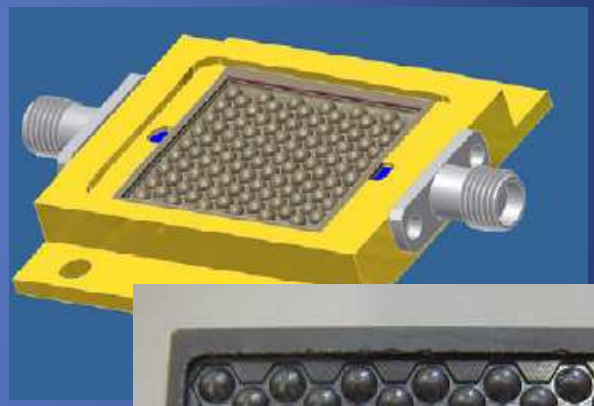




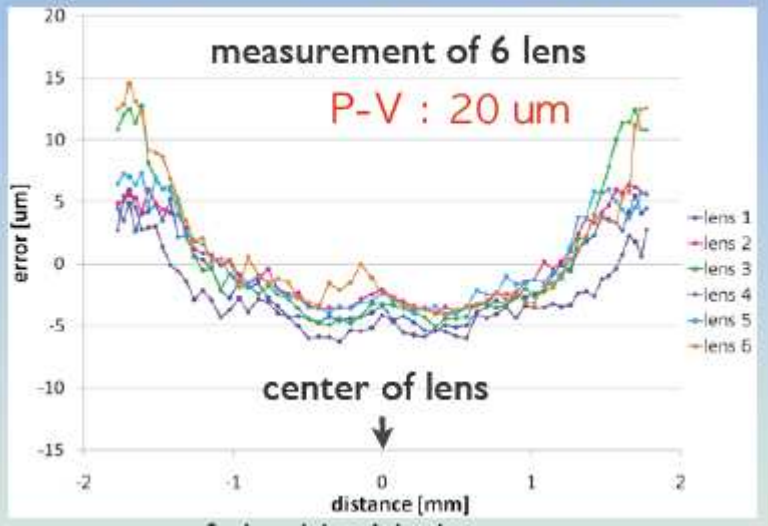
9 pixel @ 220 GHz

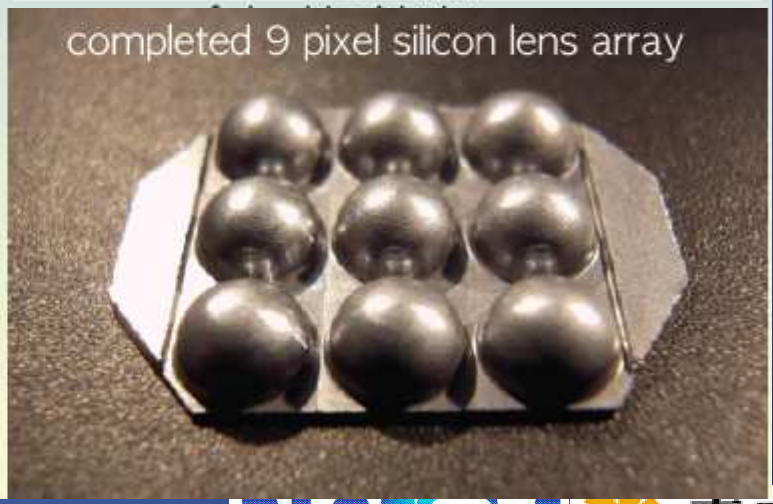
Fabrication of Lens Array

Machining by High-speed spindle

- Prototype Silicon Lens Array
  - 3×3 array
  - lens diameter : D=4.09 mm
    →3×1.36 mm (=220GHz)
  - Extension thickness : L=0.35 mm
    →good beam quality

- Error from the radius of lens (R=2.045mm)





Nitta

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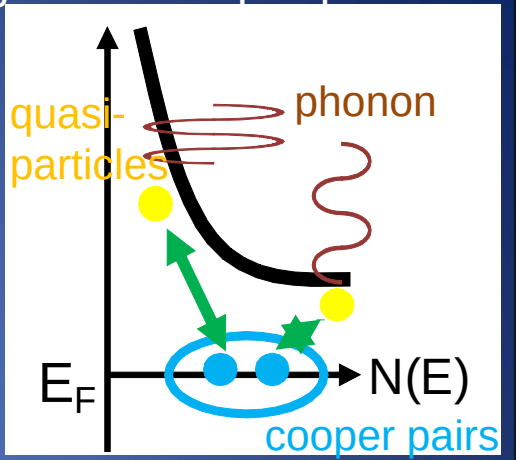
Origins of Noise

Generation-Recombination diagram of cooper pair

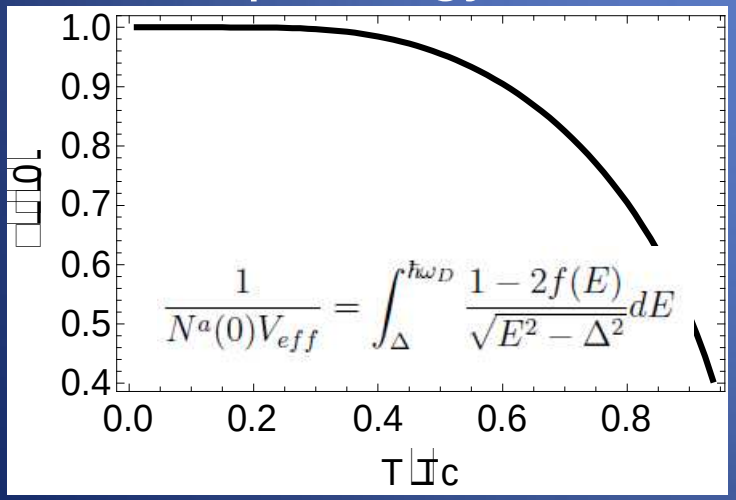


Generation-Recombination Noise (Barends, 2009)

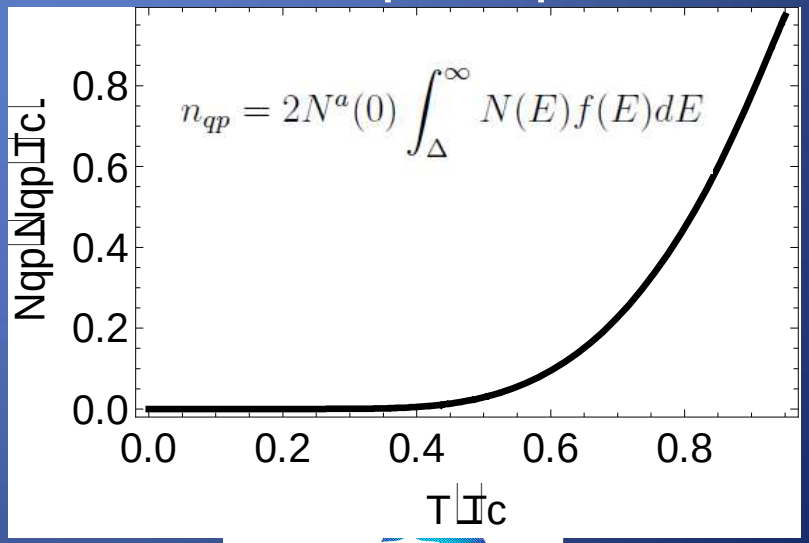
$$NEP \propto (N_{qp}/\tau_{GR})^{1/2}$$

N_{qp} ↘ → low temperature (< Tc/10)

Gap energy vs T



Number of quasi-particle vs T



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Improvement of Sensitivity

Generation-Recombination Noise (Barends, 2009)

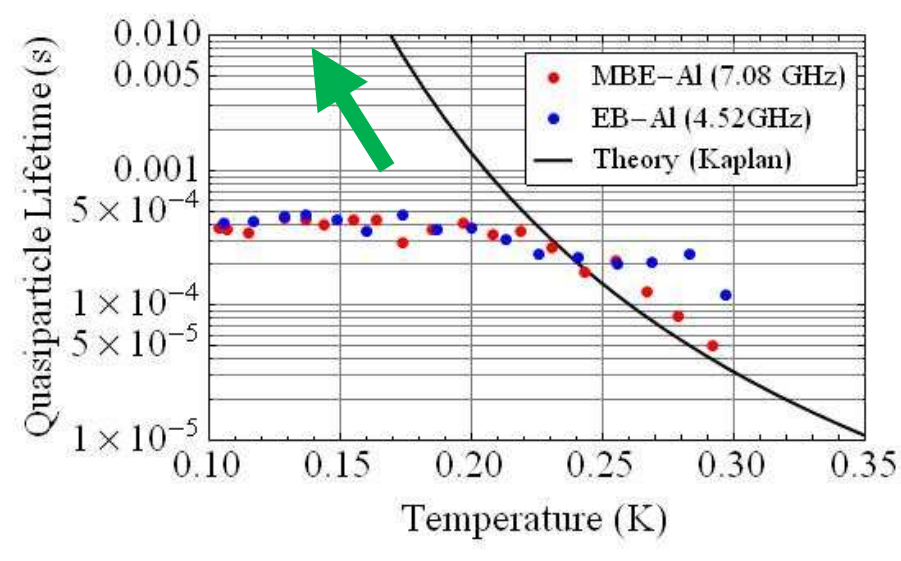
$$NEP \propto N_{qp}/\tau_{GR}$$

N_{qp} ↘ → low temperature ($< Tc/10$)

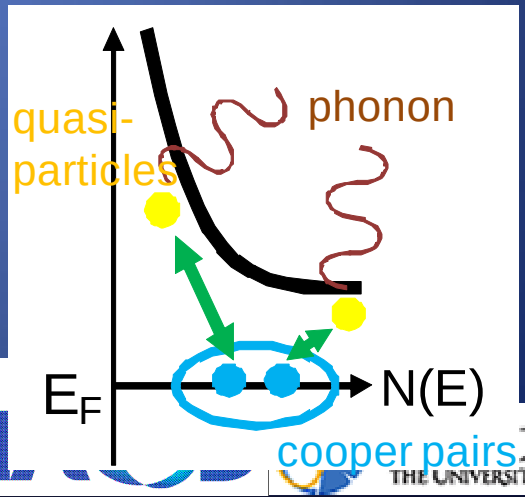
τ_{GR} ↗ → weak electron-phonon coupling (Al, Ta, TiN)

→ high-quality superconducting films

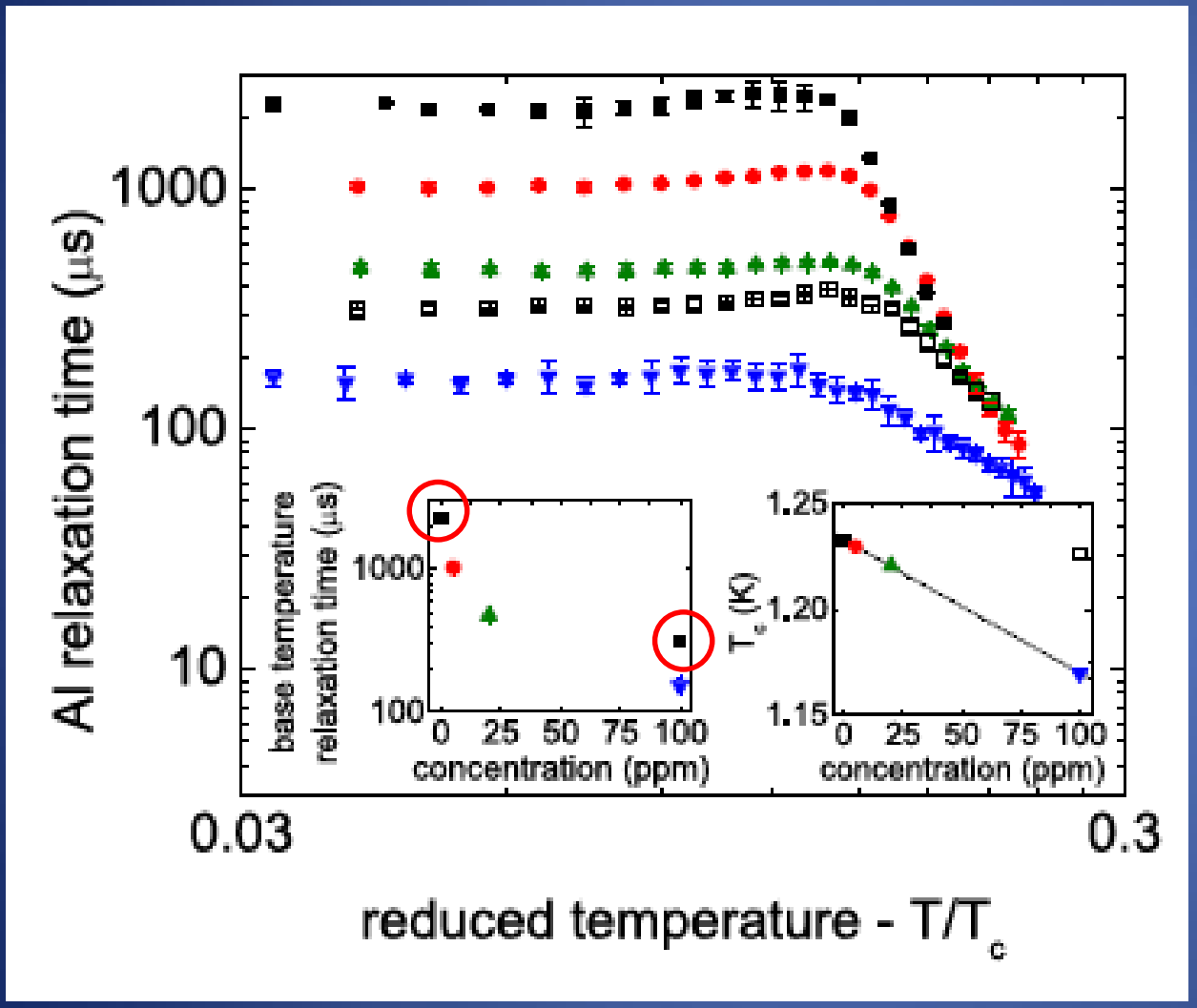
T dependence of Quasiparticle lifetime



Generation-Recombination diagram of cooper pair



Is Film Quality Important?



Barends, 2009

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Epitaxial Aluminum films

Metal	Dielectric	W (μm)	$\tan\delta_{\mathrm{eff}}$
Nb (poly)	"wet" SiO_2/Si	10	2.4e-5
Nb (poly)	Si	10	1.5e-5
Nb (poly)	Sapphire	10	1.8e-5
Al (poly)	"dry" SiO_2/Si	10	2.0e-5
Al (poly)	Si	10	1.5e-6
Al (poly)	Sapphire	10	1.6e-6
Al (epi)	Sapphire	10	1.8e-6
Re (epi)	Sapphire	10	1.8e-6
TiN (poly)	Si	10	9.6e-7

(Sage, 2011)

Only Q measurements!

poor

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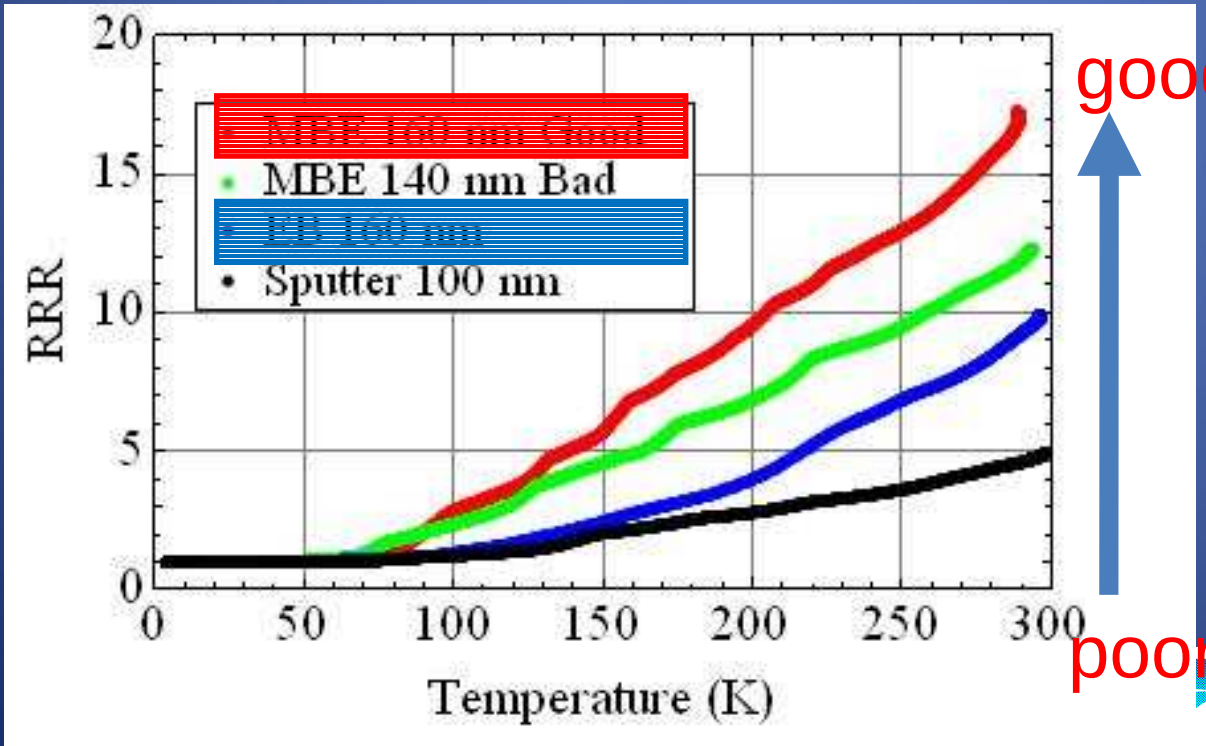
What is a good quality film?

Deceasing defects and impurities, smooth surface

Reduce the probabilities of scattering and resistivity



good

poor

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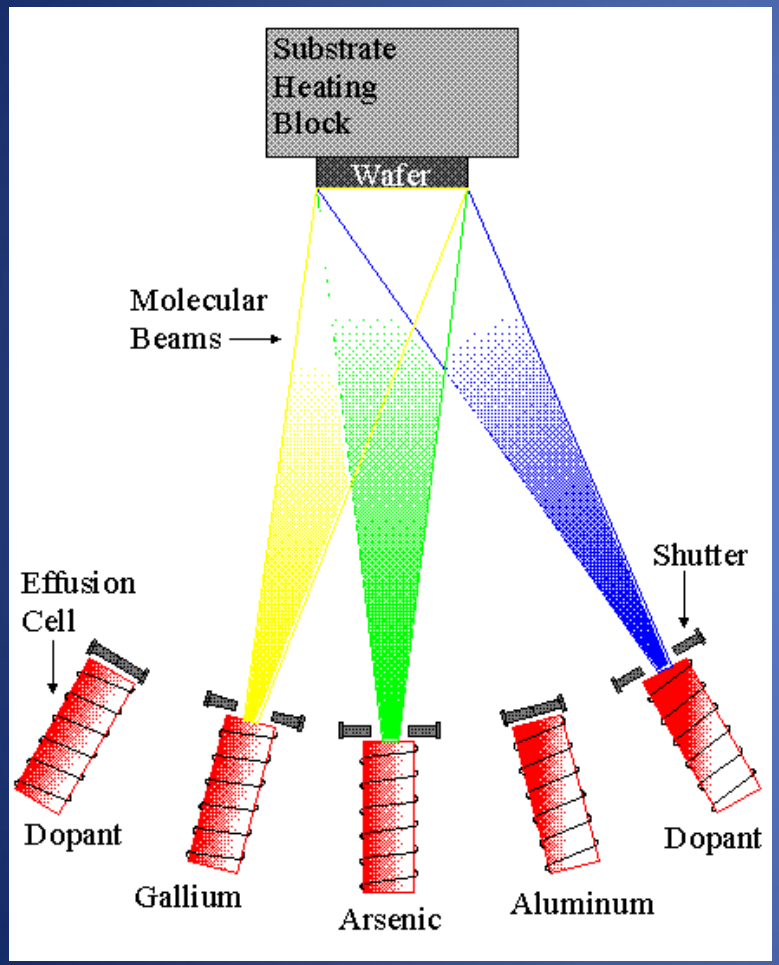
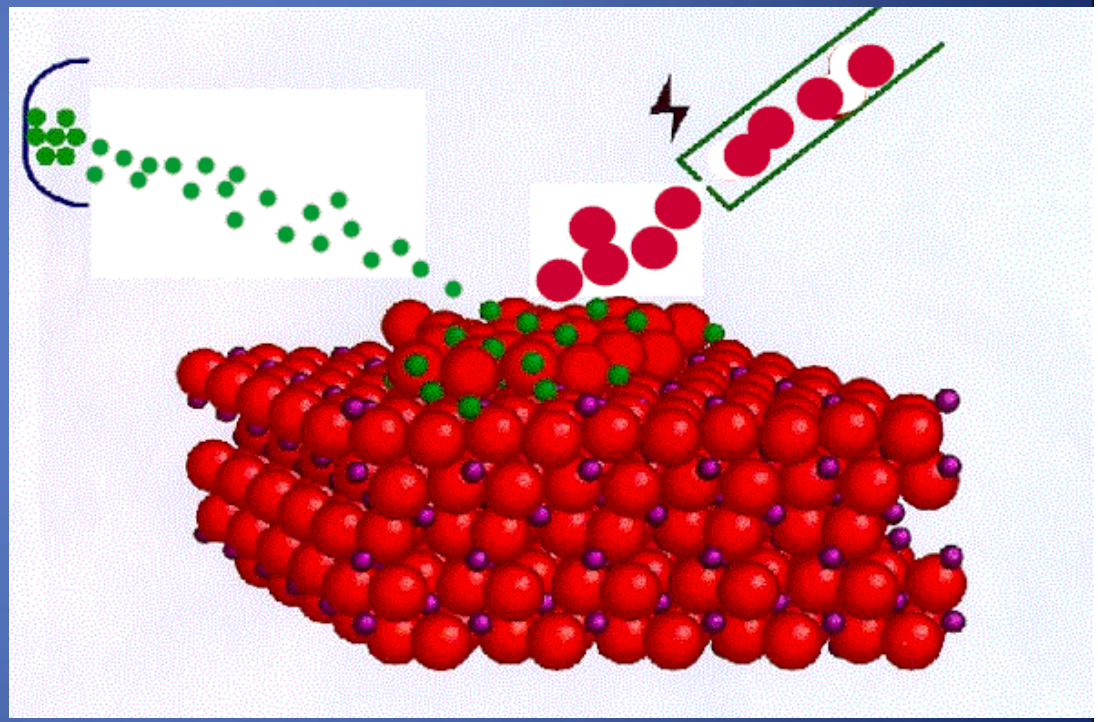
Molecular Beam Epitaxy

Cartoon of MBE chamber



nber.org

Cartoon of crystal growth



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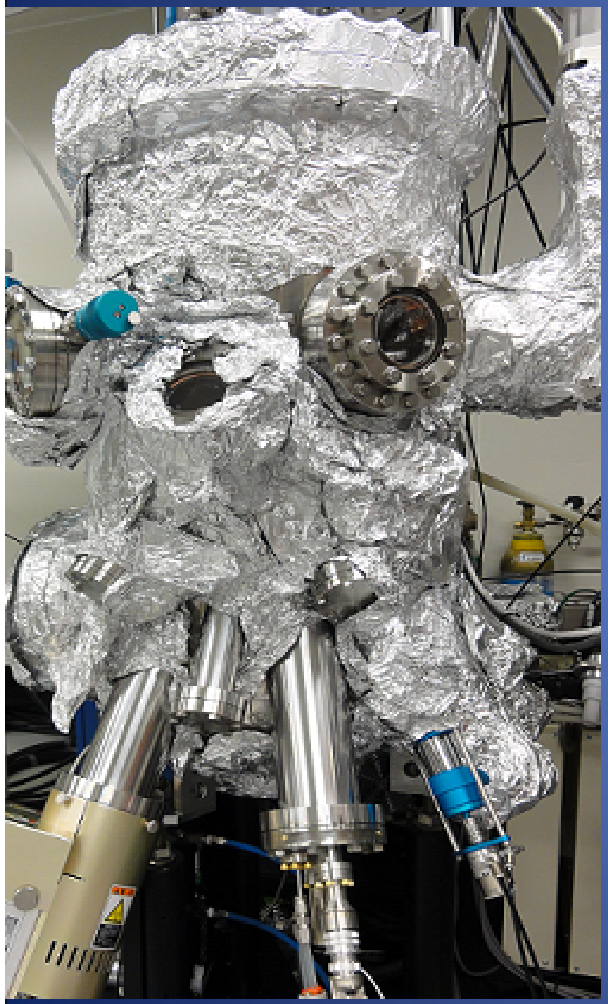
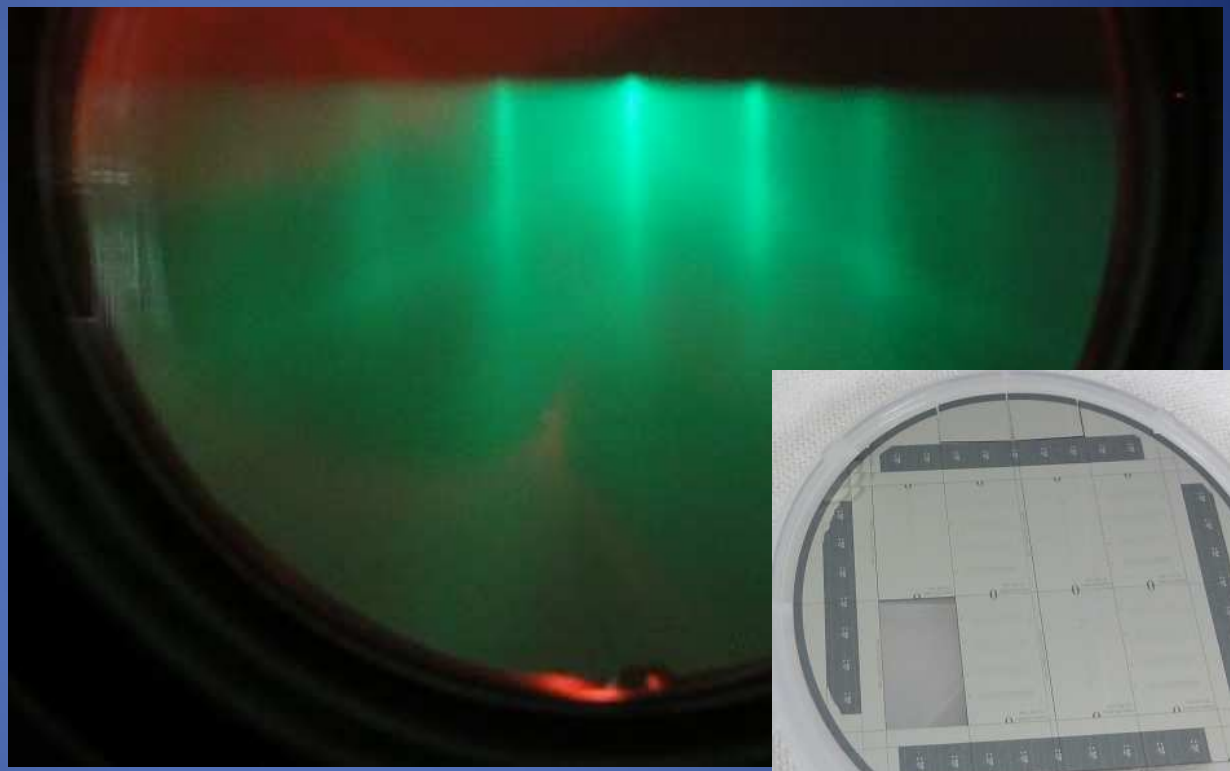
Crystal Aluminum on Si wafers

Molecular Beam Epitaxy



Picture of RHEED



Al on Si (111) wafer
Thickness 160nm
Cleaning: BHF + 650 deg. (20 min)
Back ground: 2×10^-8 Pa
Wafer: 75 deg.

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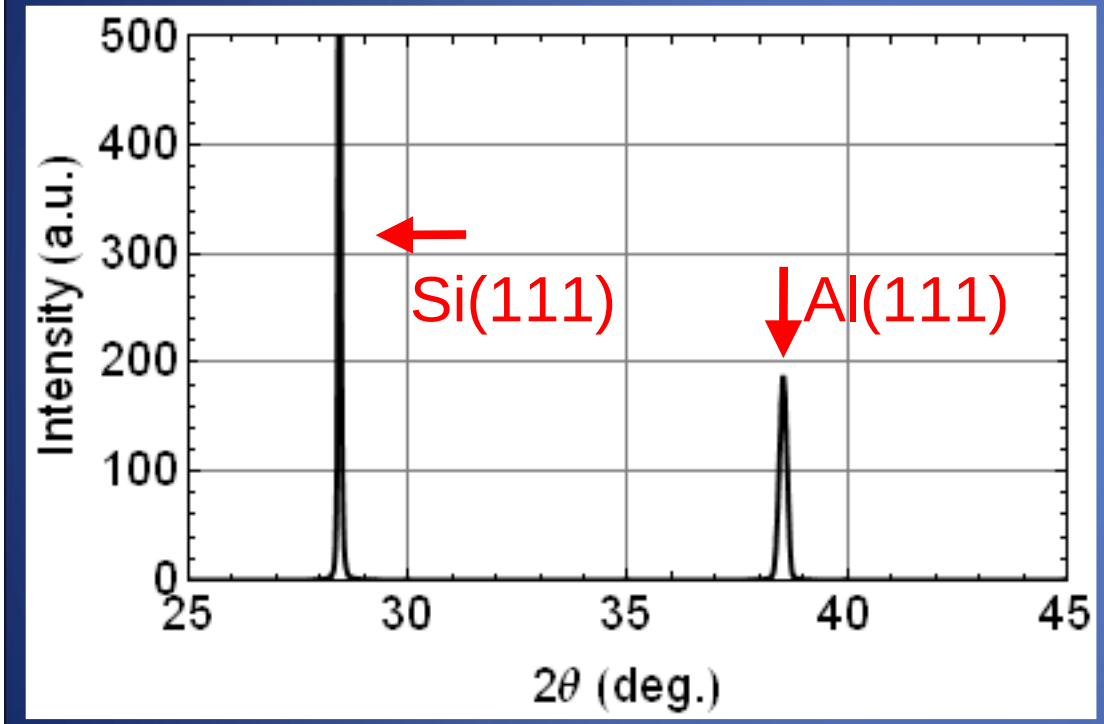
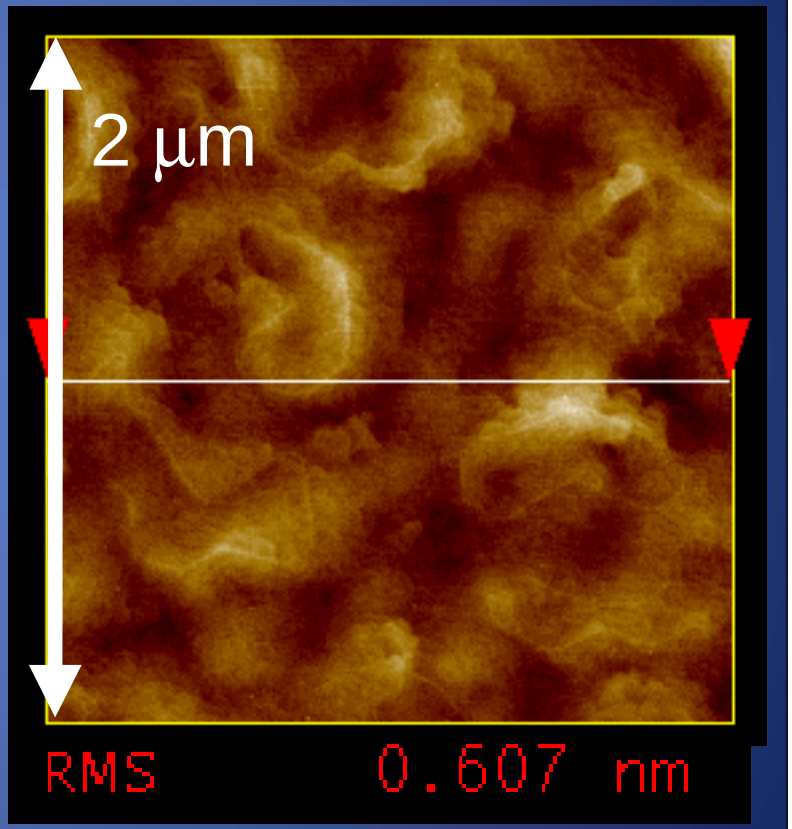
XRD and AFM measurements

X-ray diffraction pattern



Picture of Al surface with AFM



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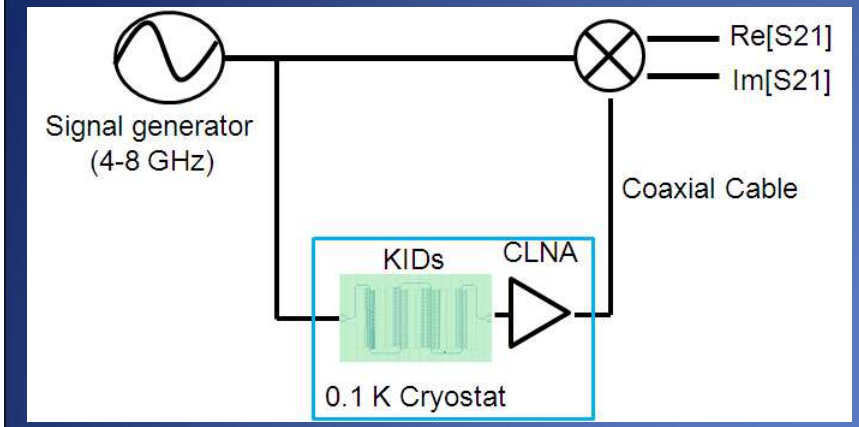
Measurement Set-up

Block diagram



lab

0.1 K dilution refrigerator

0.1 K Stage

NEP Calculations (Baselmans, 2008)

Eq. (1) $$\mathrm{NEP}^2 = S_x \left(\frac{\pi\,\tau}{\Delta} \frac{\partial x}{\partial N_{qp}} \right)^{-2} (1+\omega^2\tau^2)(1+\omega^2\tau_{res}^2)$$

Eq. (2) $$\frac{\partial\theta}{\partial N_{qp}} = \frac{\partial F}{\partial N_{qp}} \cdot \frac{\text{responsibility}}{F_0} \cdot \frac{4\,\text{lifetime}}{F_0}$$

Eq. (3) $$\frac{\partial R}{\partial N_{qp}} = \frac{\partial R}{\partial \theta}\frac{\partial \theta}{\partial N_{qp}} = 0.26\,\frac{\partial \theta}{\partial N_{qp}}$$

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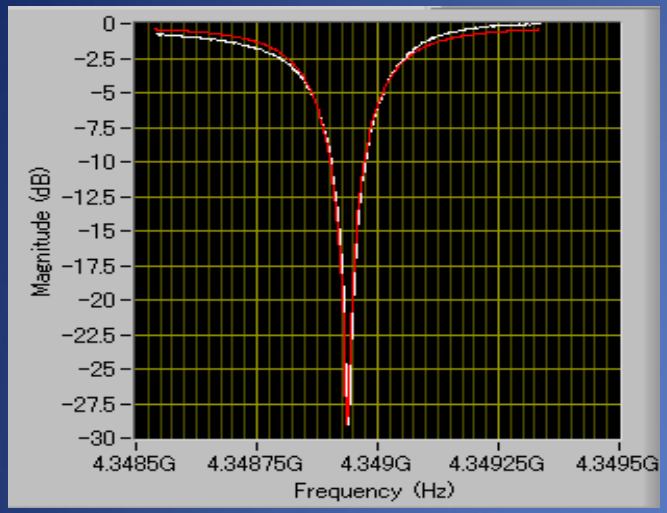
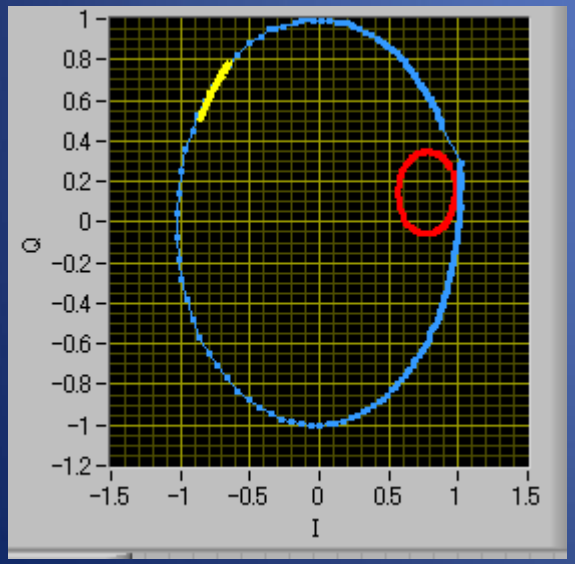
Noise Measurements

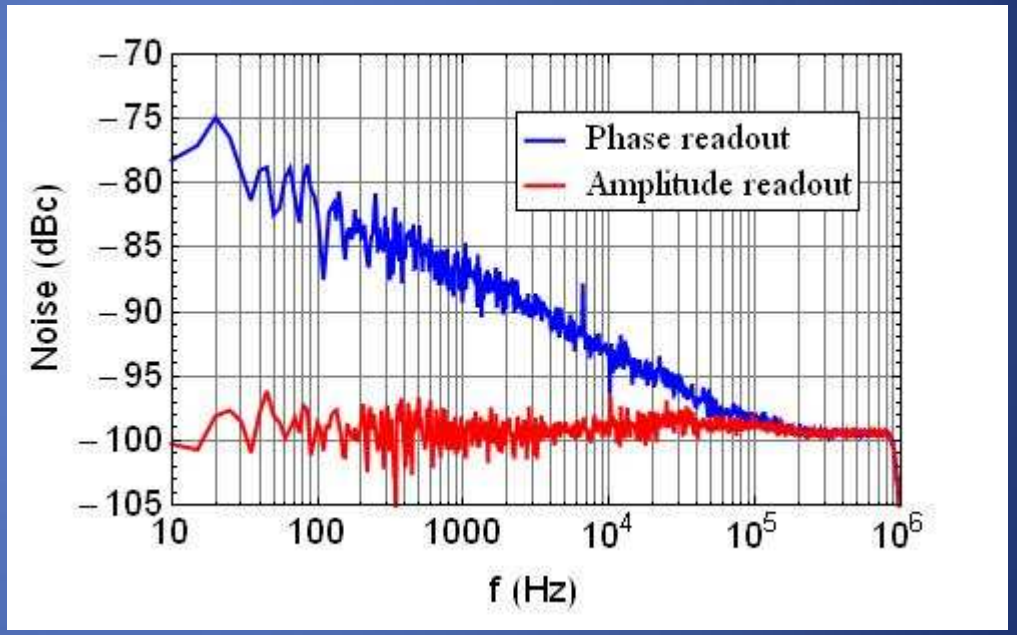
S21 spectrum @140 mK



IQ spectrum and fluctuation



Noise Spectrum



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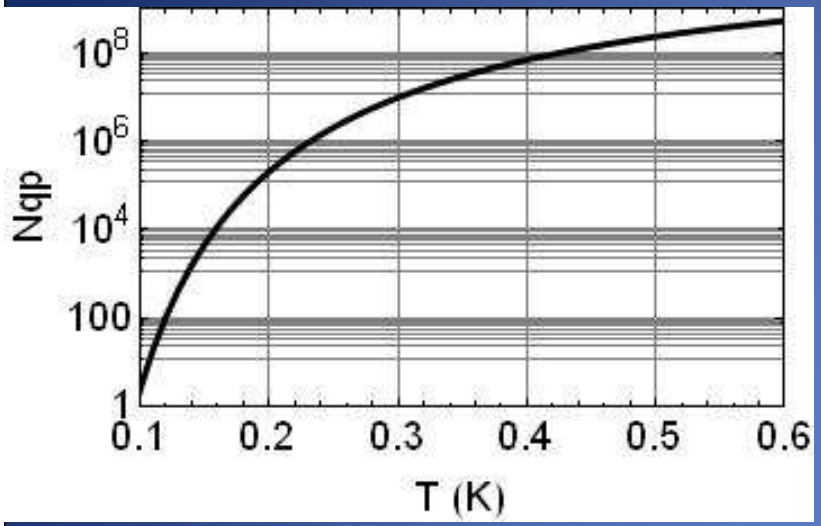
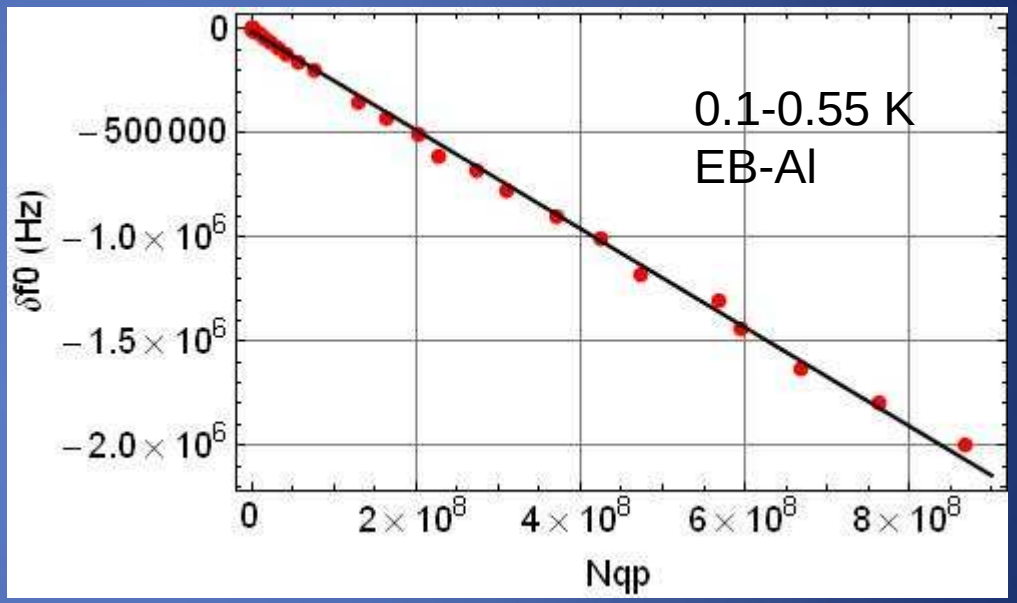
F_0 vs Nqp

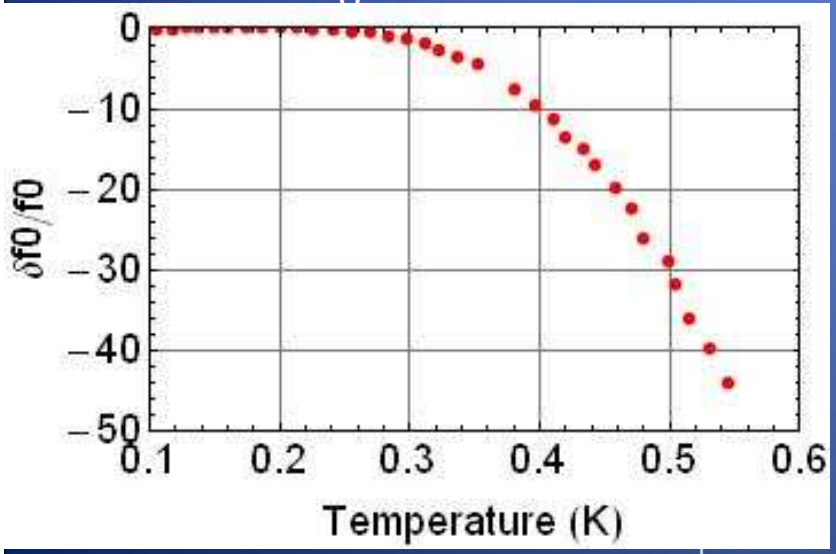
N_{qp}/volume (um^3) v s T



f_0 vs .N_{qp}



f_0 vs T



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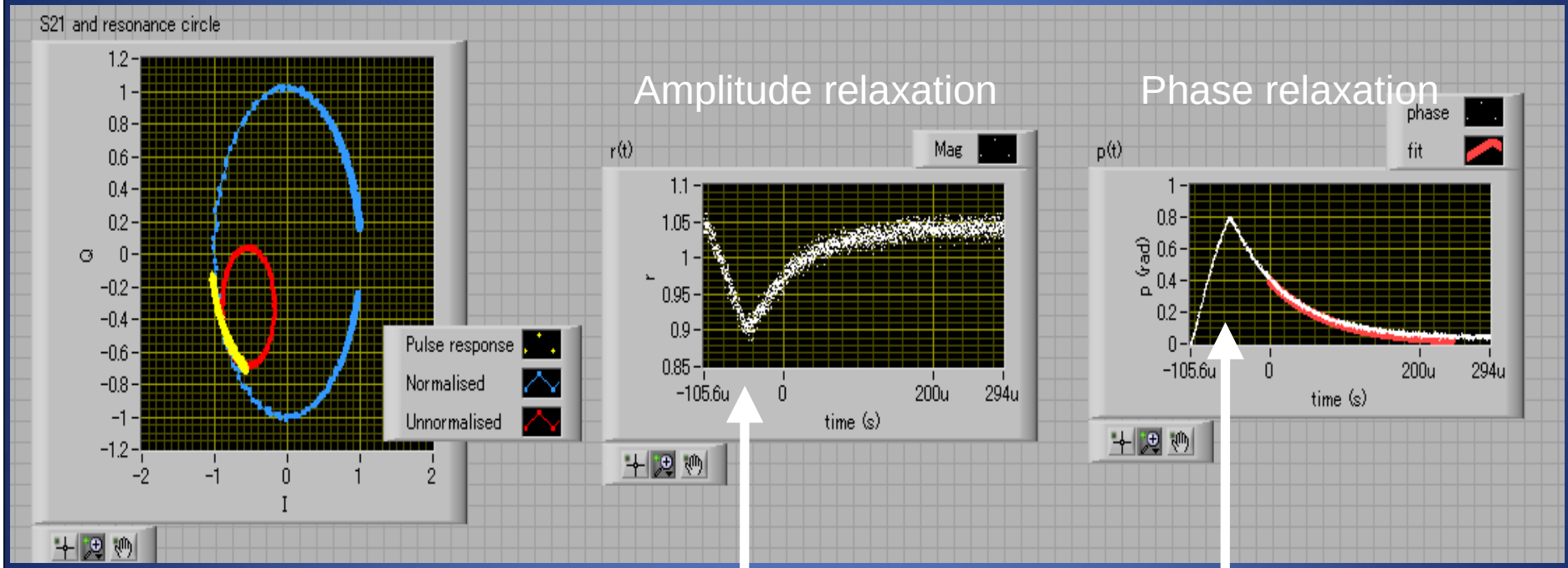
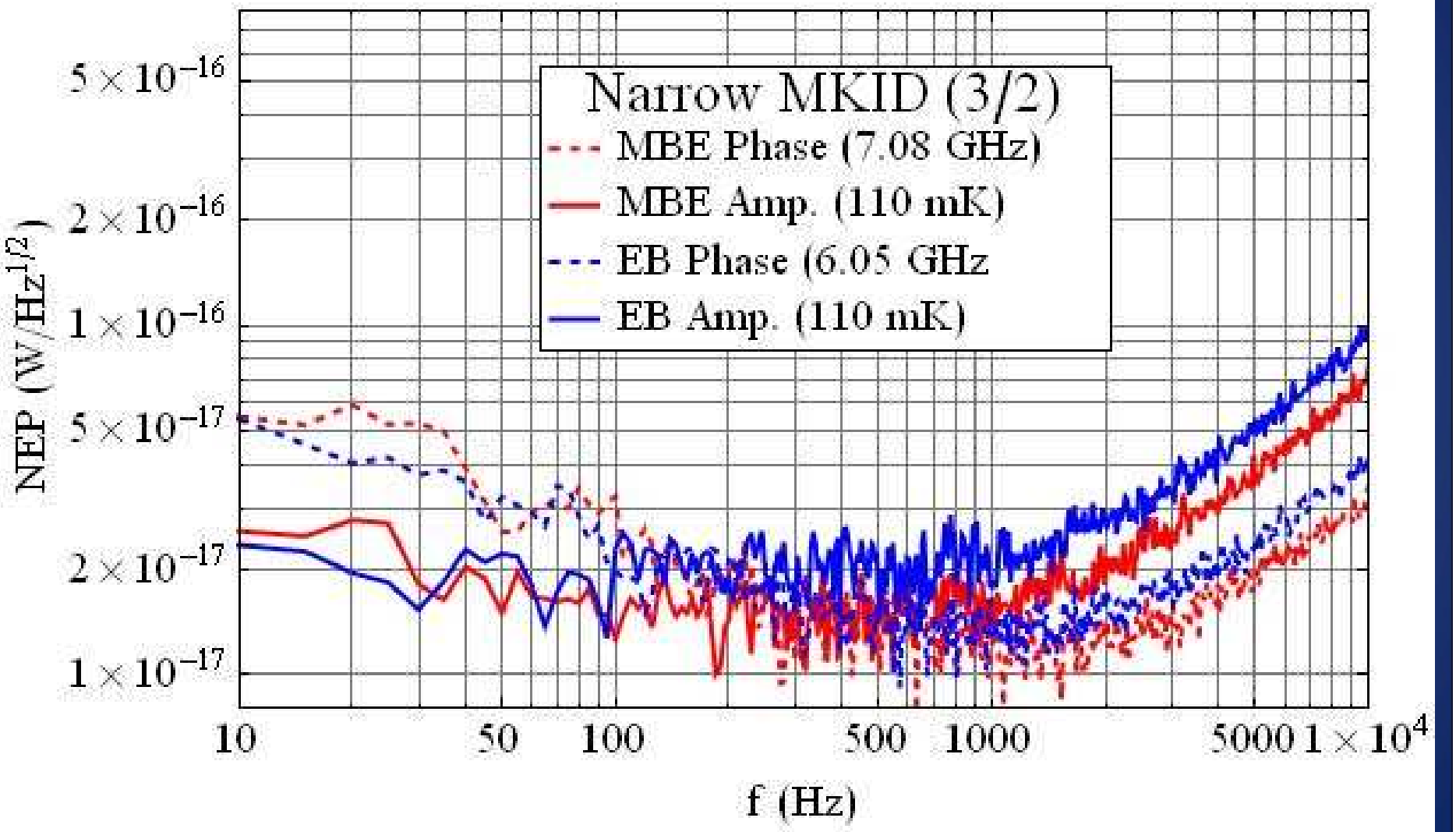
Relaxation Measurements

MBE-Al on Si(100) @230mK
LED pulse duration 50 us



Electrical NEP of MKID



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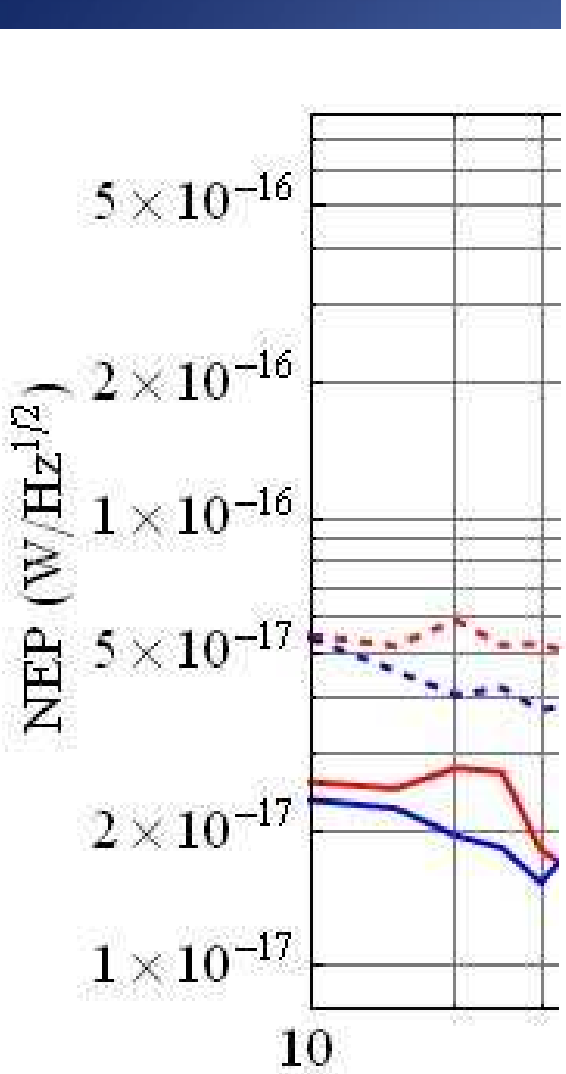
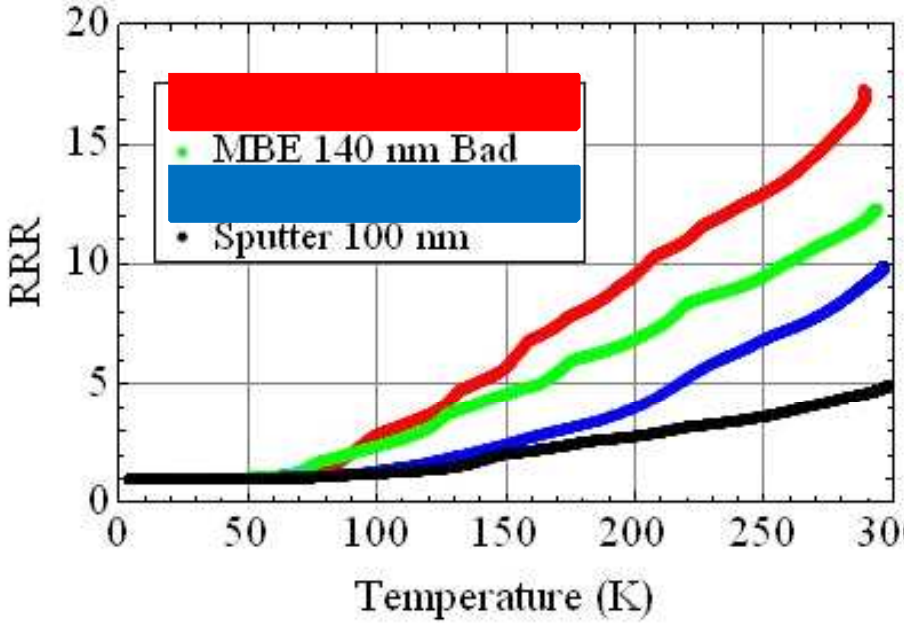
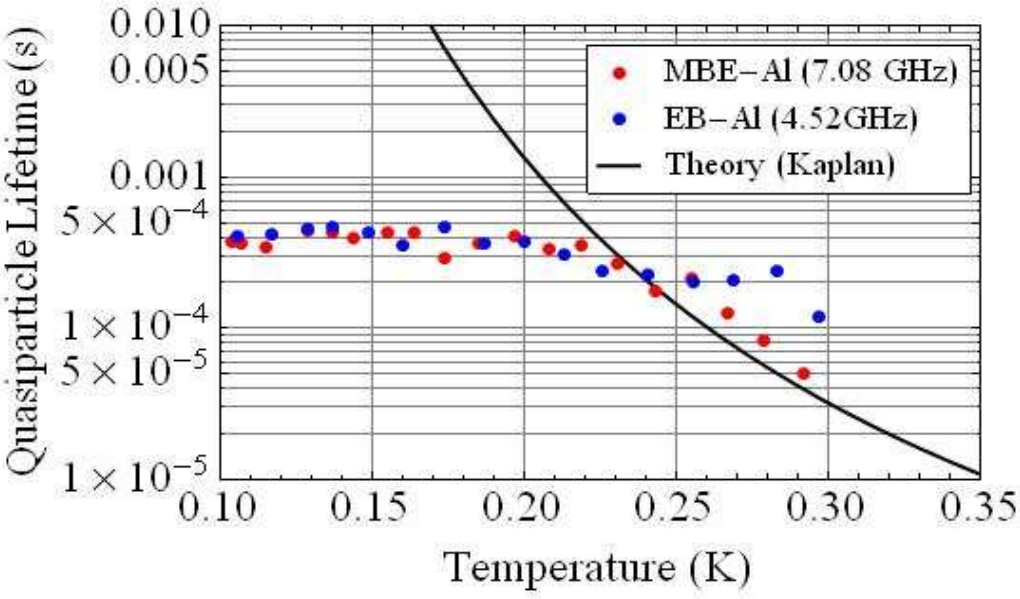
Why NEP is Equivalent ?

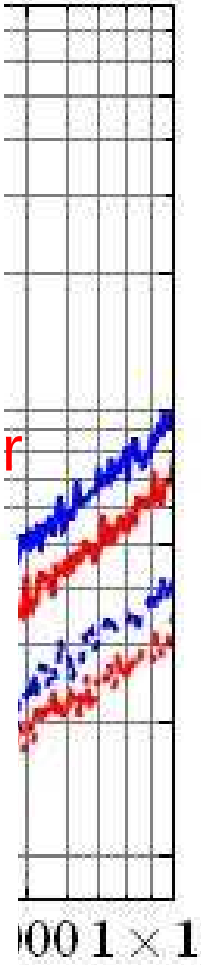




good

poor





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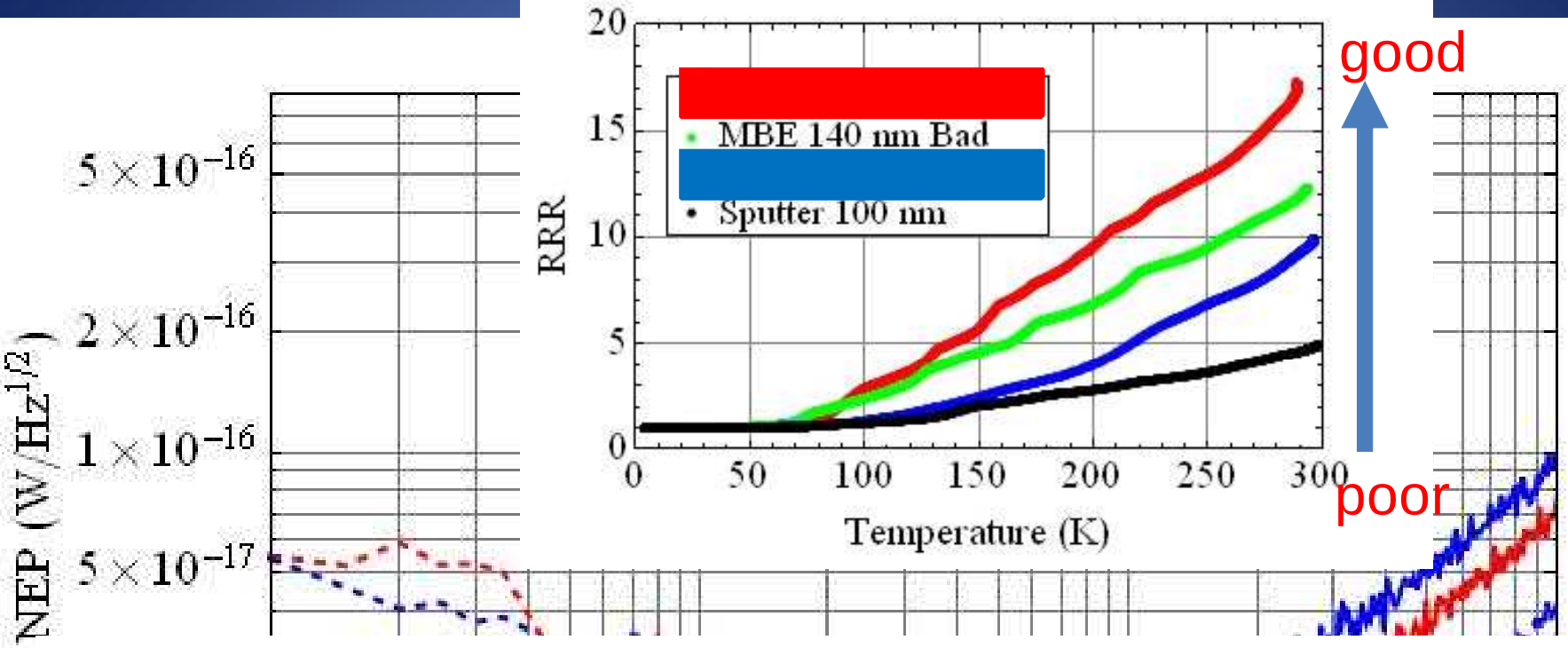
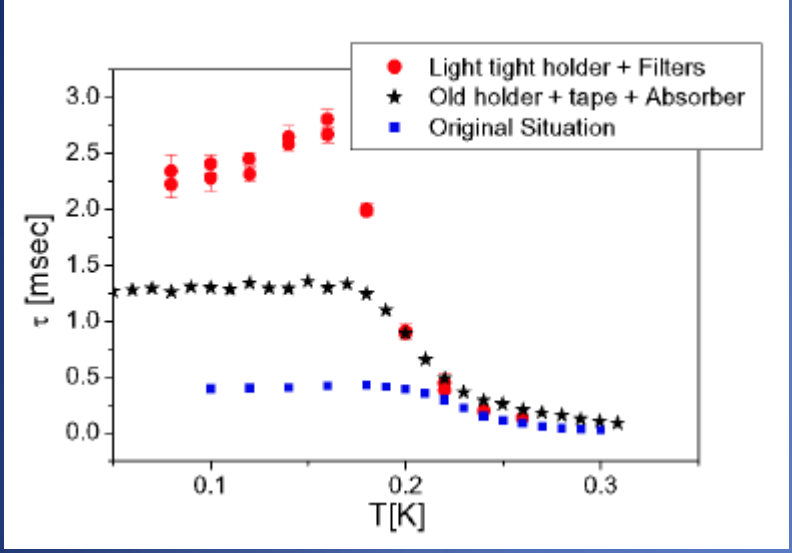


- Limited by the measurement system?
- The film quality is not enough?

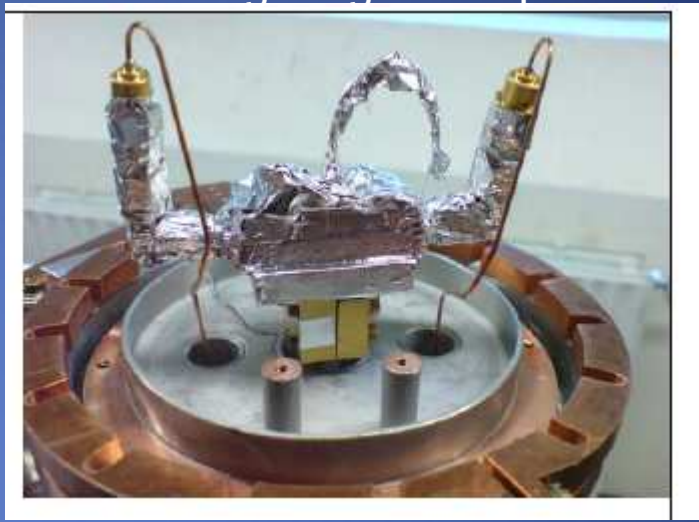
Light-tight Set-up

Baselmans, 2008

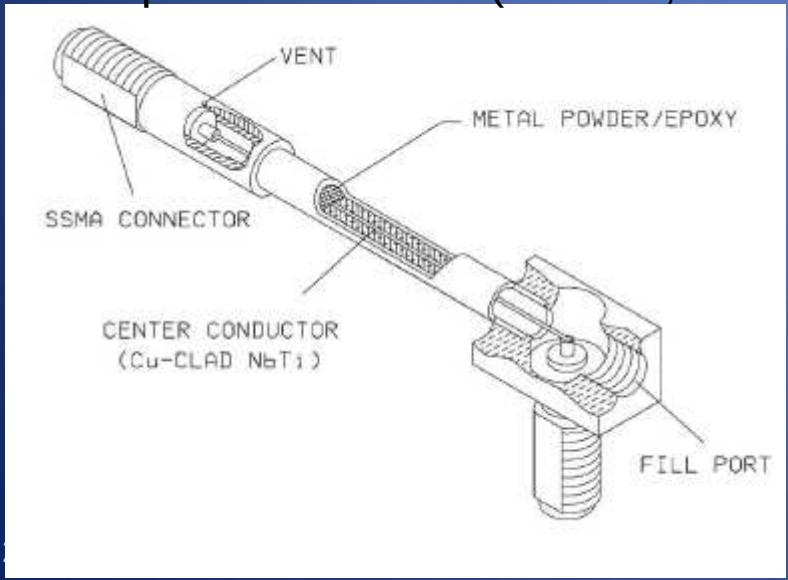
Life time vs T

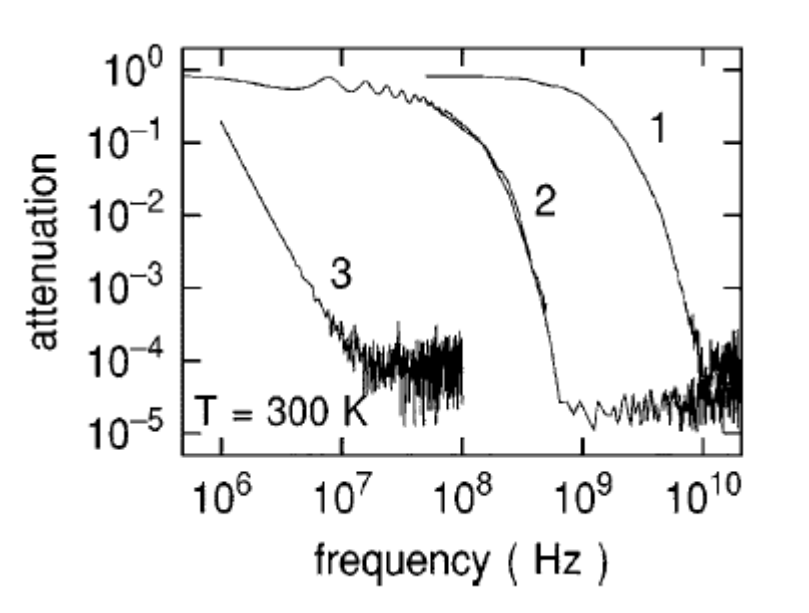


Light tight setup

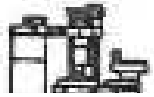


Low pass coax filter (Milliken, 2007)



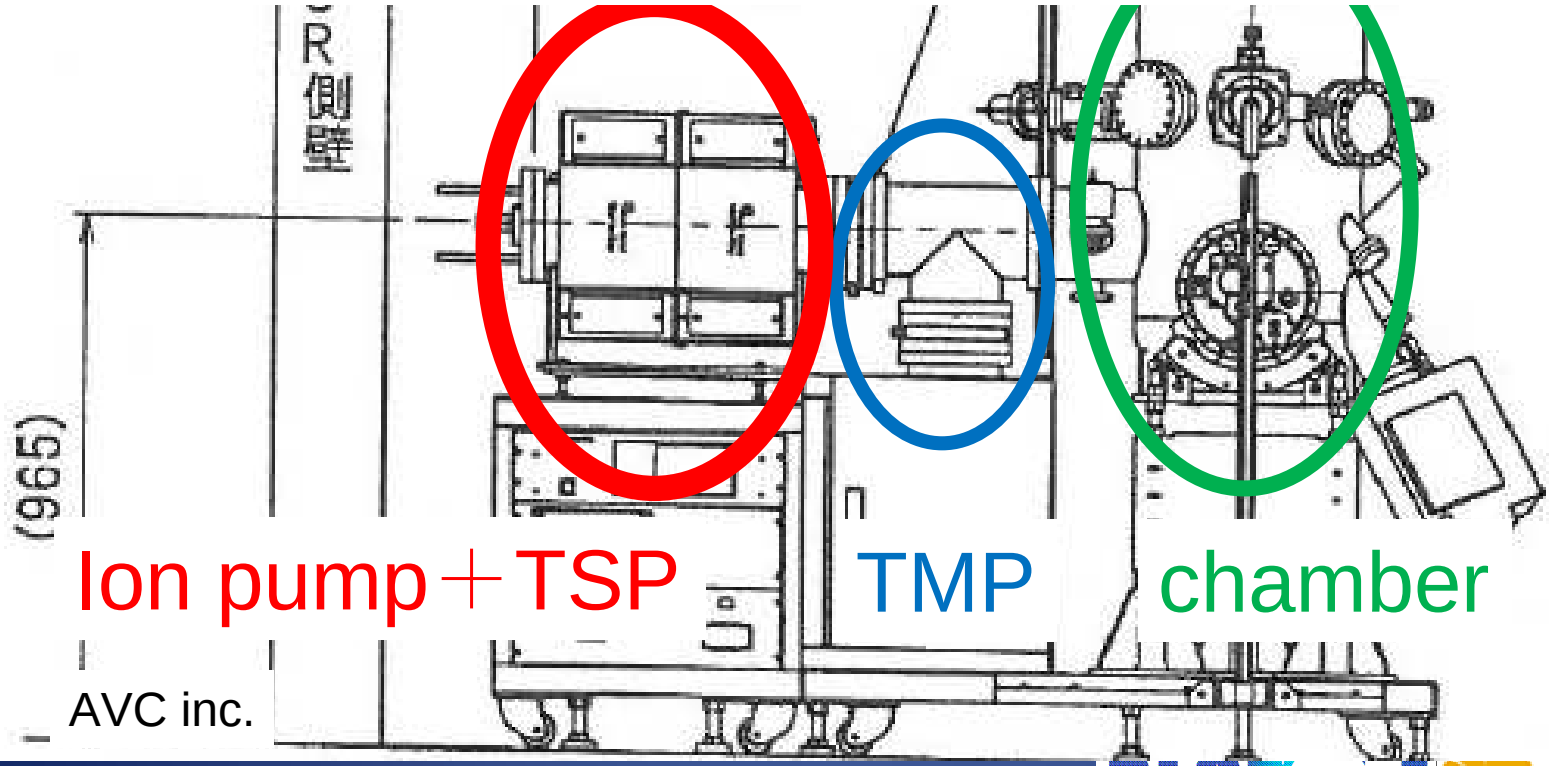


Additional Vacuum System



Background Pressure

$2*10^{-8}$ Pa → $<10^{-9}$ Pa



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Summary

- MKID camera @ NAOJ.
- The properties of the epitaxial Al film is so far equivalent to that of amorphous one.
- Improving the set-up and vacuum system.

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