Development of Microwave Kinetic Inductance Detectors for phonon and photon detections

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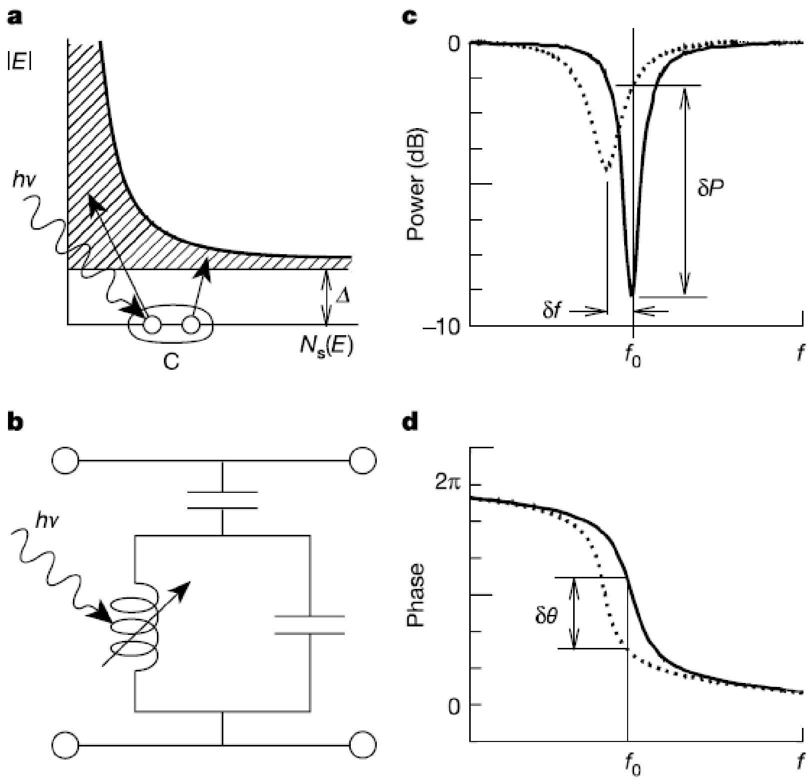
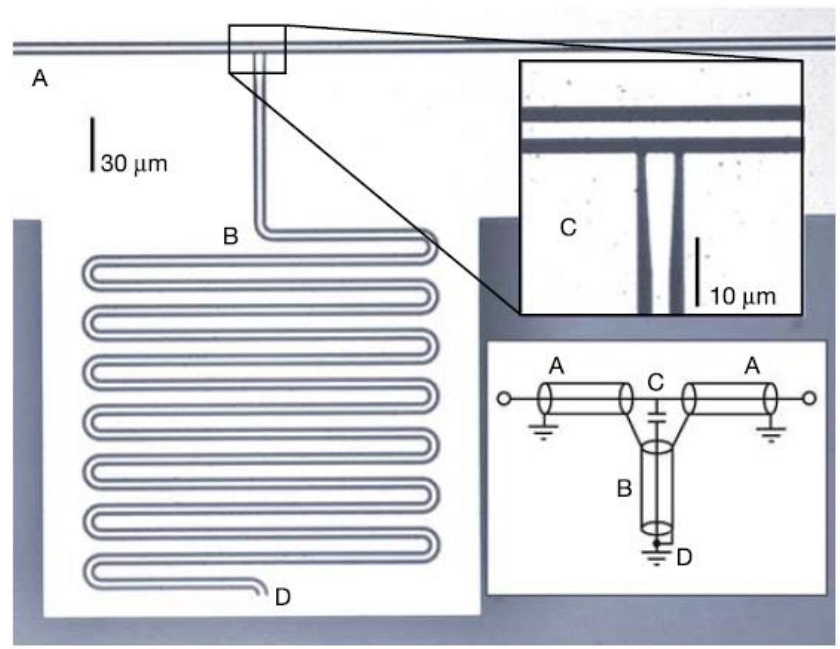
Introduction

- Superconducting Detector, MKID (Microwave Kinetic Inductance Detector)
  – Deposited energy breaks Cooper pairs and produces quasi-particles
  – By counting the number of quasi-particles, we can measure energy
  – Energy needed to break a Cooper pair ~meV
    - cf. ~3eV for the semiconductor detectors
  – A single technique enables us to measure wide wave length range
    - from millimeter waves to X, gamma rays, and alpha, beta rays

What is MKID?

first developed by P. K. Day *et al.*, Nature 425 (2003) 817-820

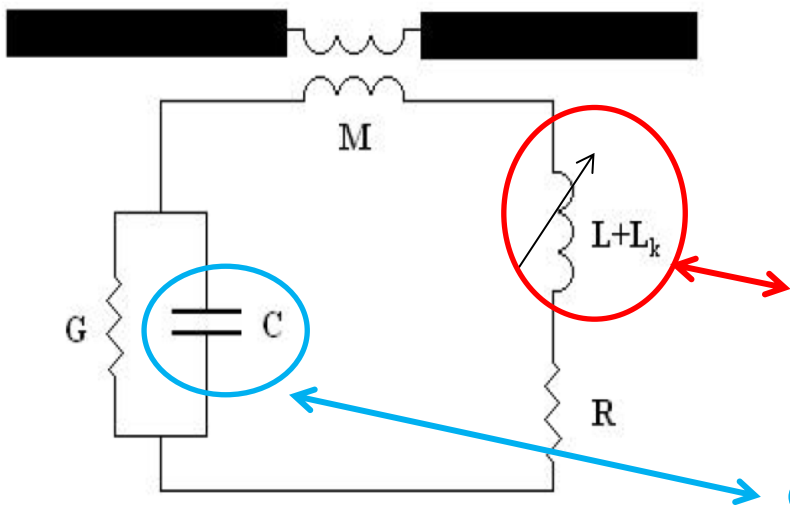


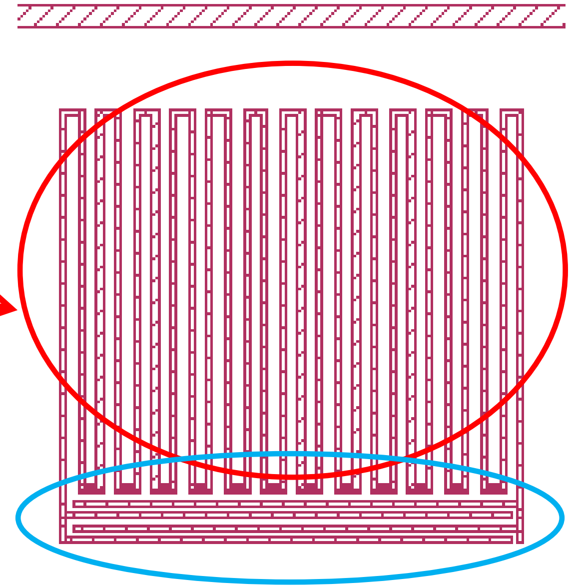


Advantages of MKID: -frequency domain multiplexing, multi channel readout with a single wire
- simple structure: formed with one or two layer(s)
- no need for bias

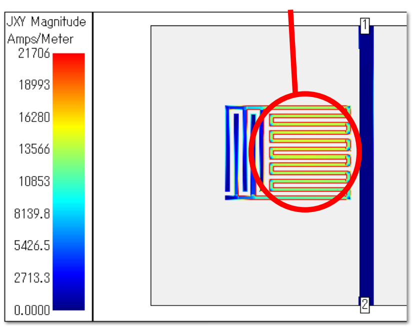
Lumped Element KID

S. Doyle et al., J. Low Temp. Phys. 151 (2008), 530-536.



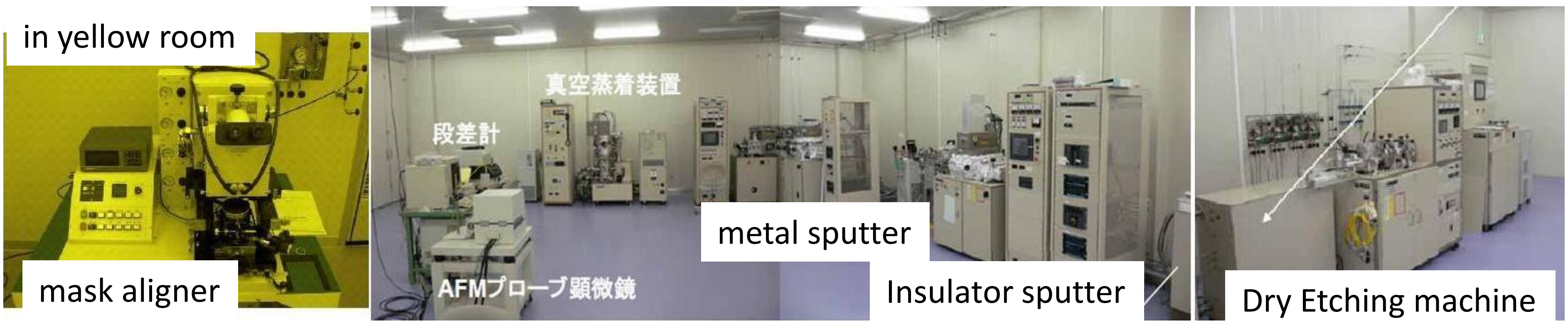


The electric current density at the inductance part is uniform, so this has uniform sensitivity to that area. LEKID can be used to detect phonons and photons.

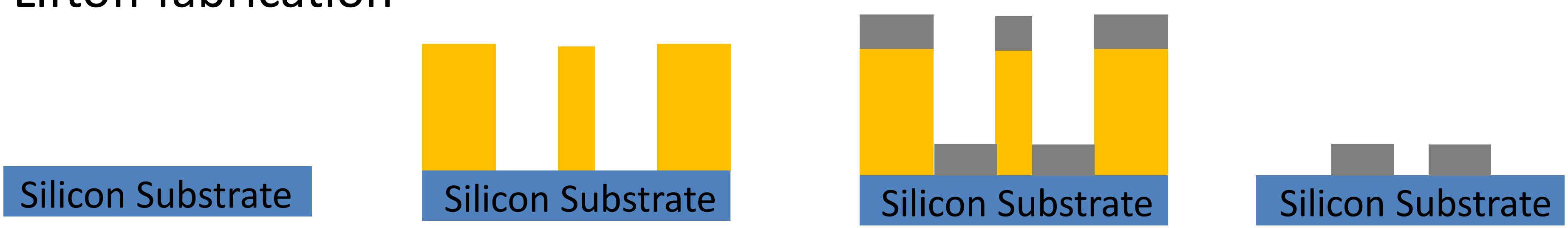


Fabrication facility

We fabricate the superconducting detectors in the clean room at KEK using the lithography technique.



Liftoff fabrication

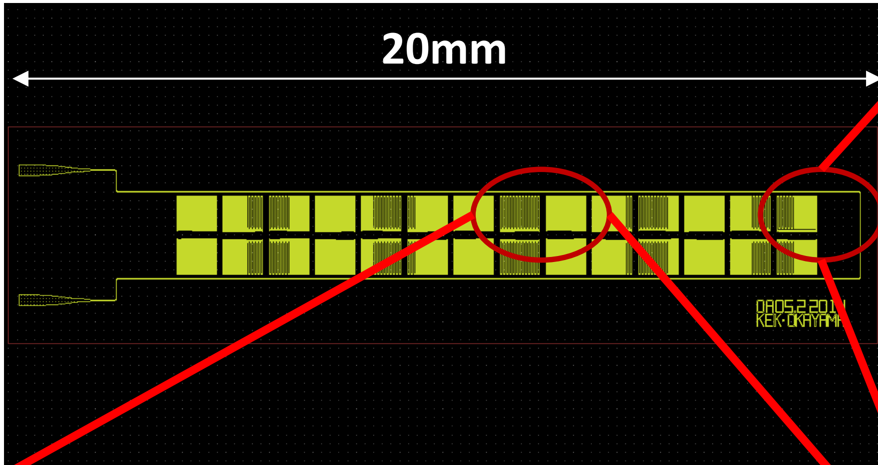


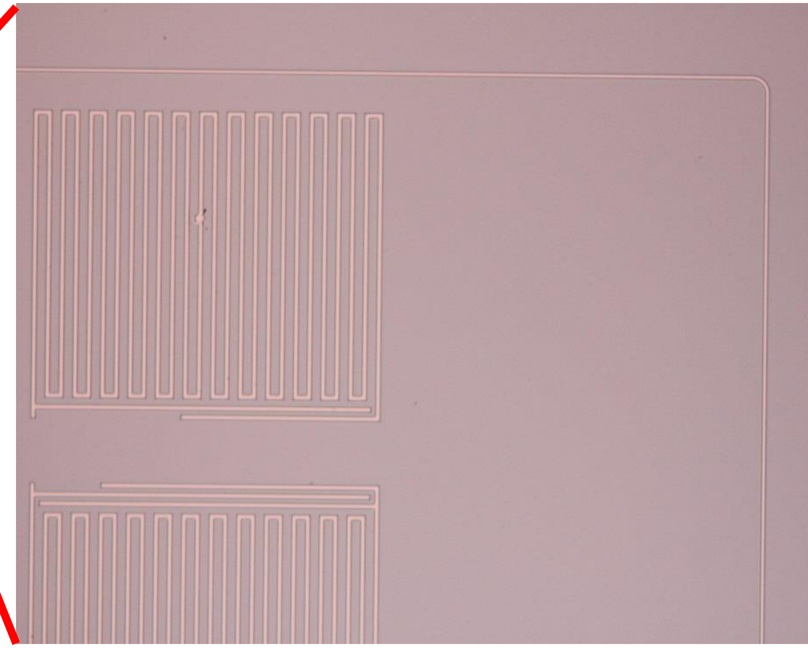
Put photo-resist, exposure (UV) and development

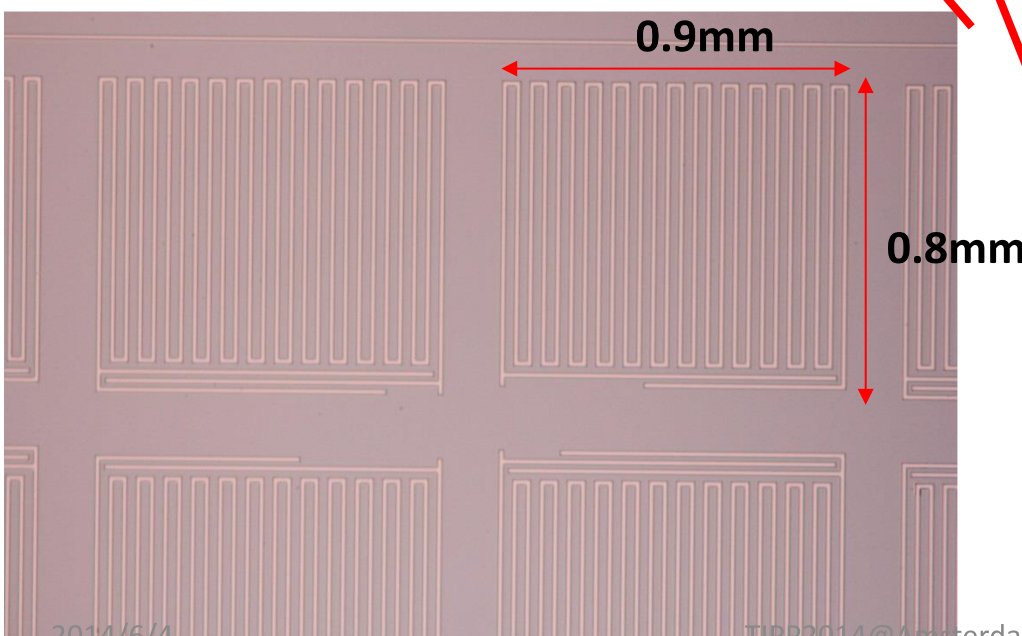
Sputter metal layer

Remove photo-resist

Mask pattern and fabricated LEKID array



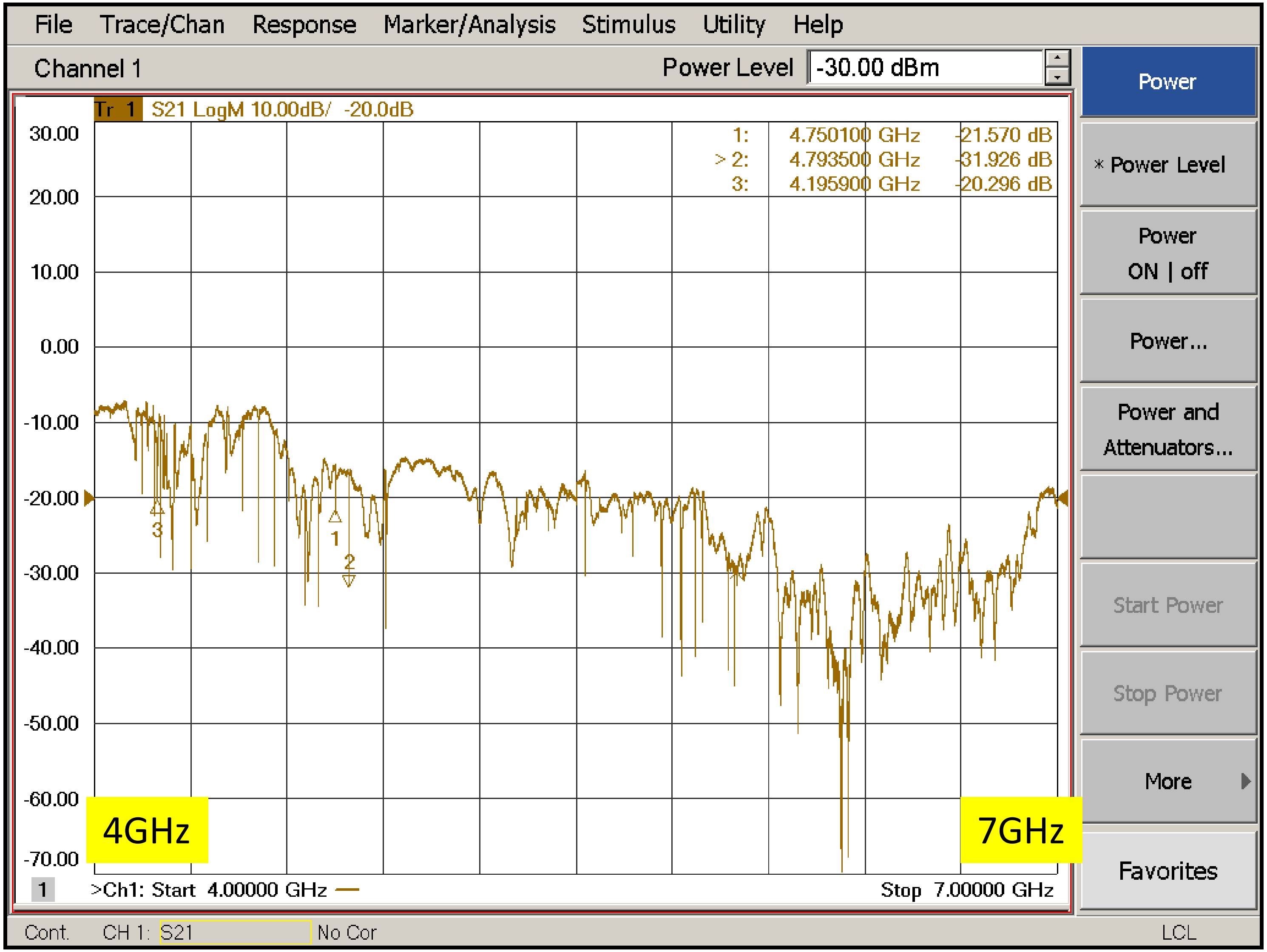




Made of 300nm Al layer.

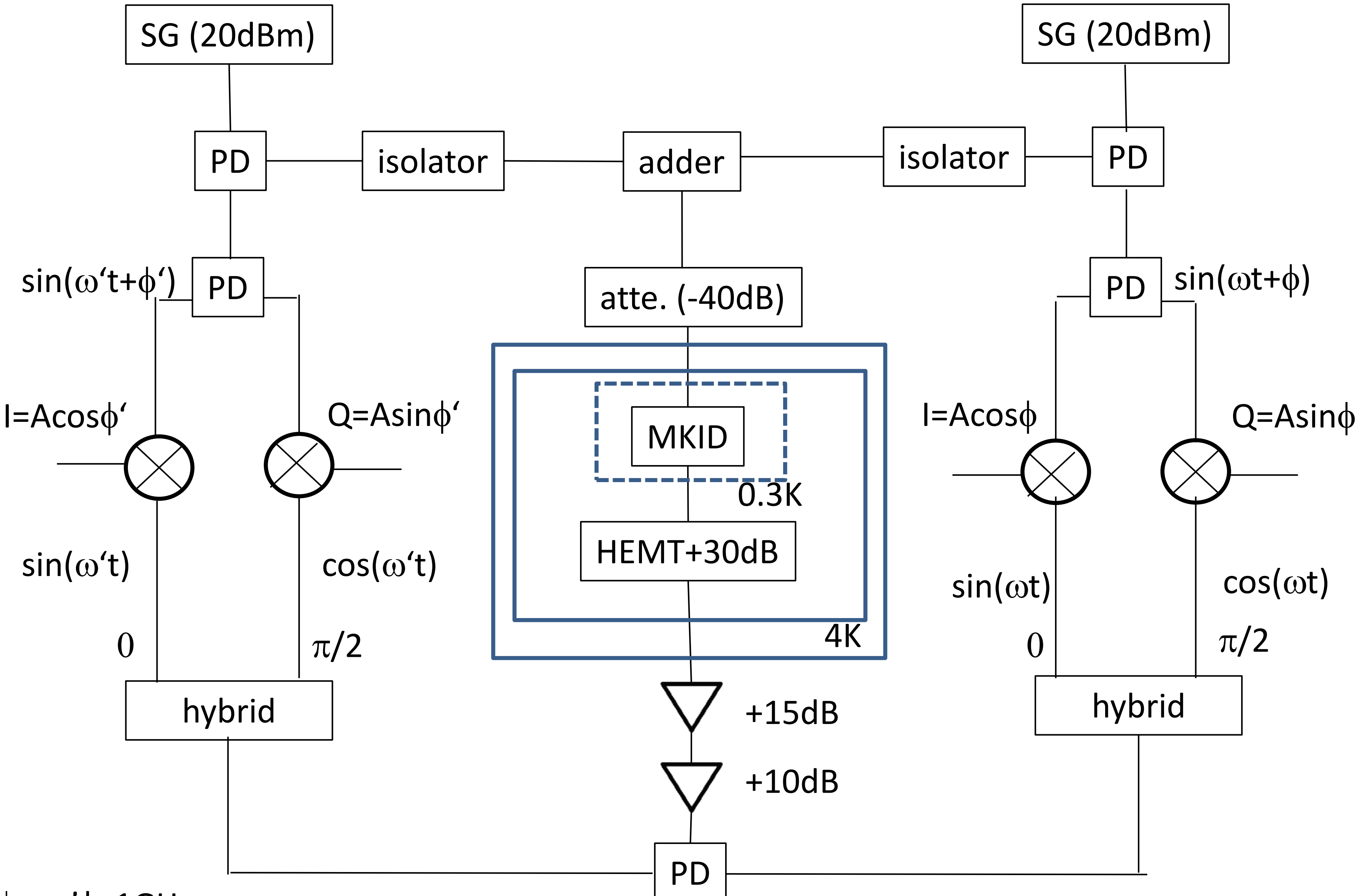
Tc of Al = 1.2K

Resonant peaks measured by a Network-Analyzer



Measured at 0.3K using He-3 sorption refrigerator.

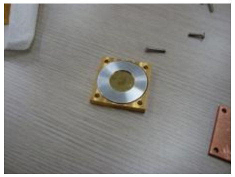
Two channel homodyne readout

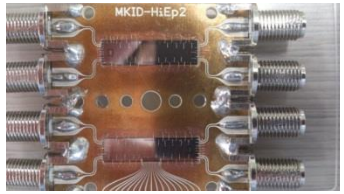


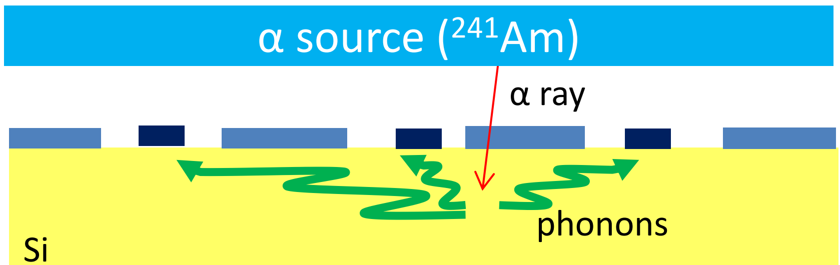
|ω-ω’|~1GHz

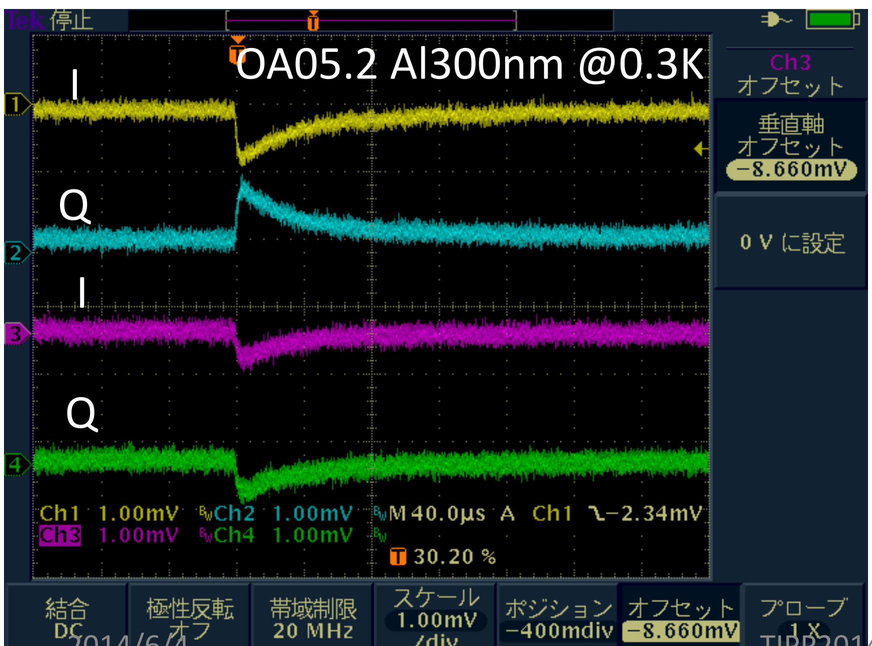
Detection of phonons from the Si substrate

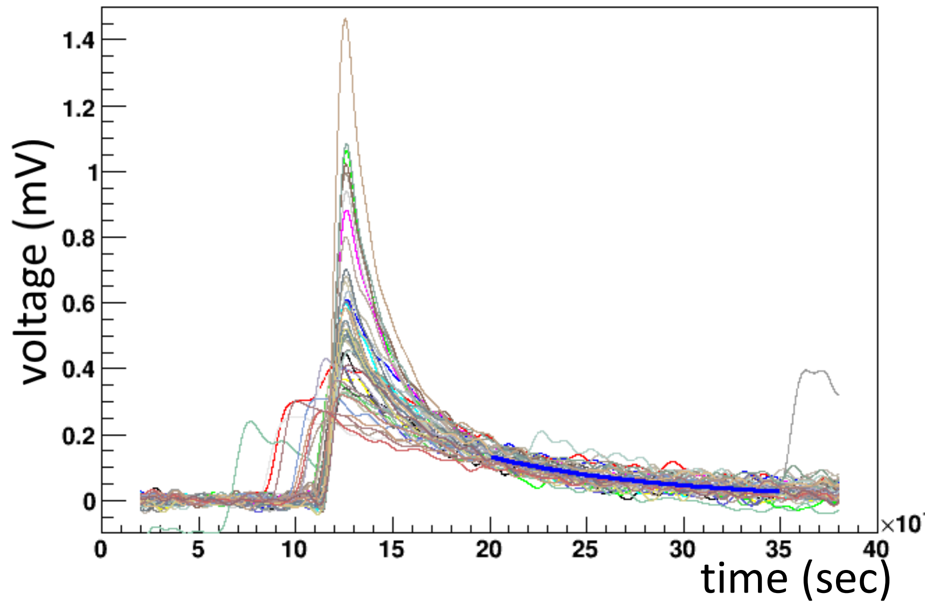
Shielded alpha source





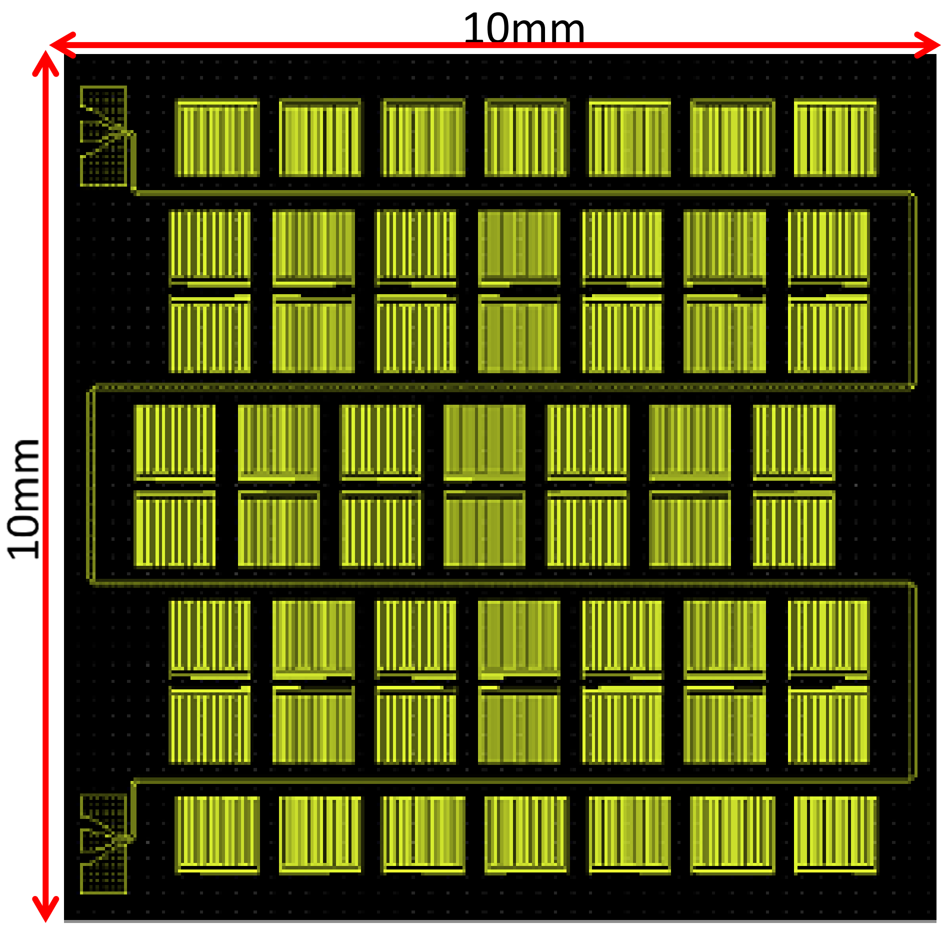


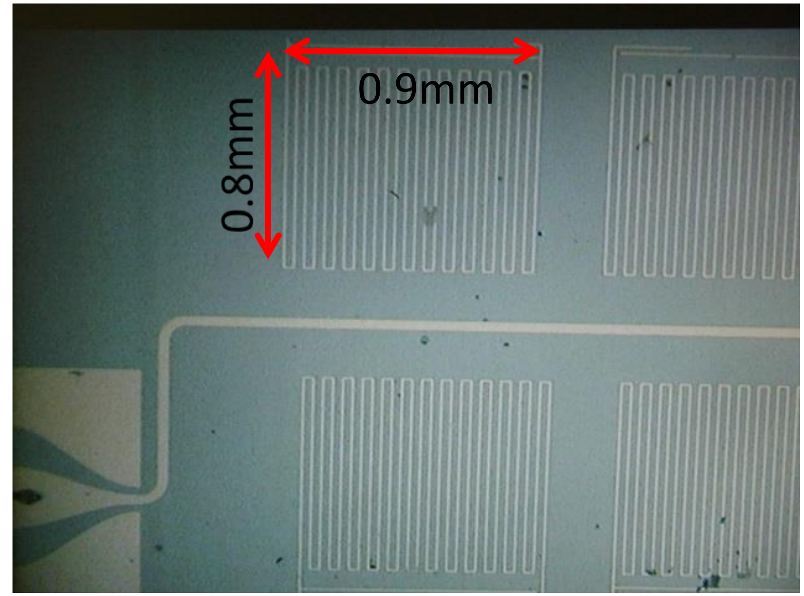




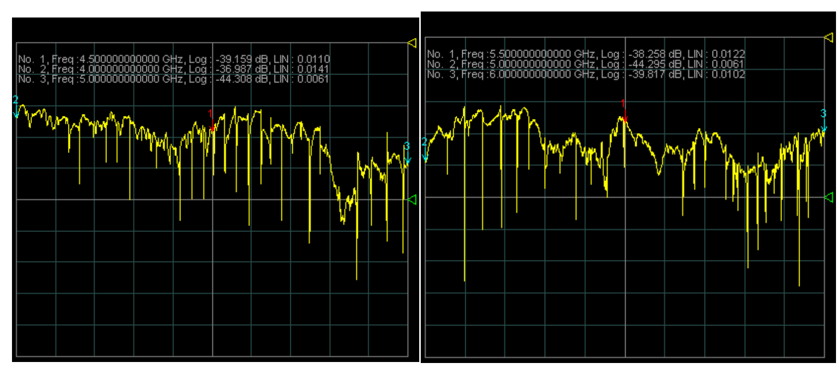
Superimposition of 50 signals of one channel. The pulse height indicates the location of alpha particle position.
The decay curve with t>20usec may indicate thermalisation of the substrate, $\tau = 9.3 \pm 0.4\ \mu$sec, comparable to a value calculated based on the thermal capacitance and conductance.

LEKID array





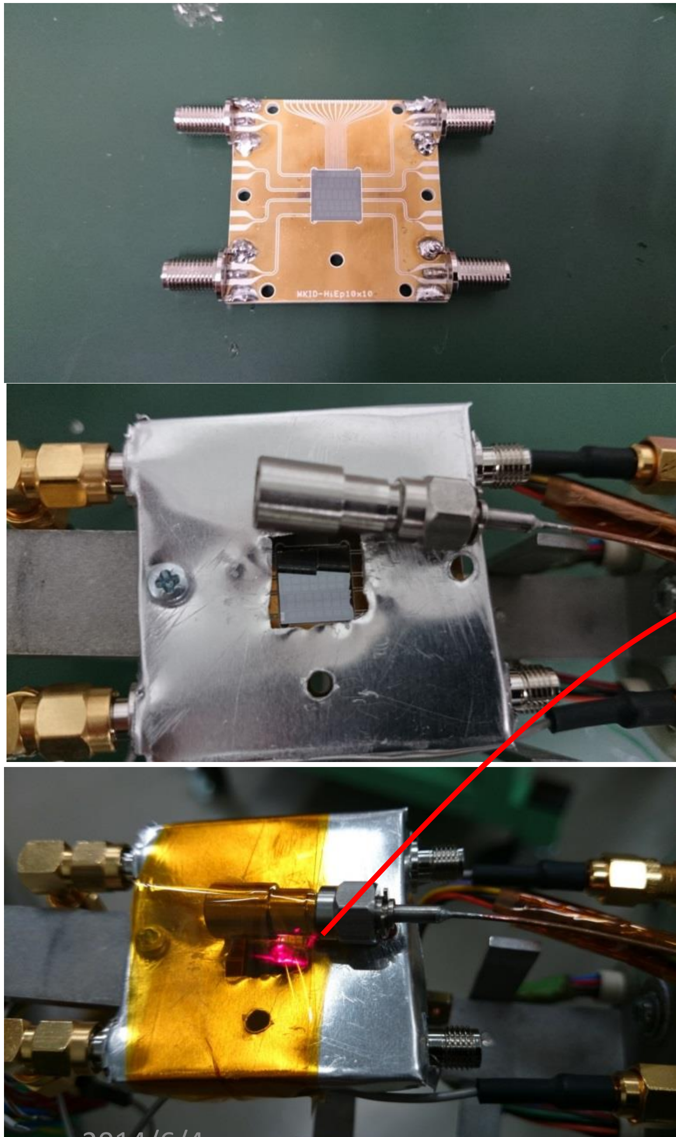
Measurements with Network Analyzer

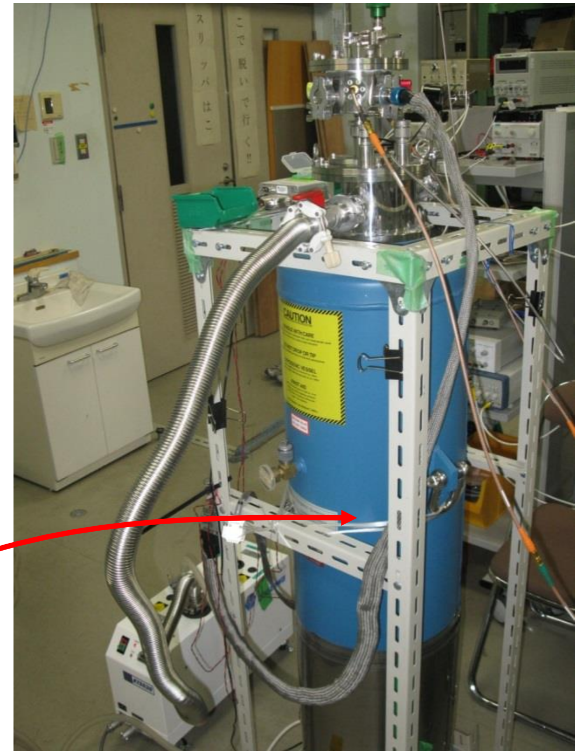


56 resonators
Nb 50nm thickness

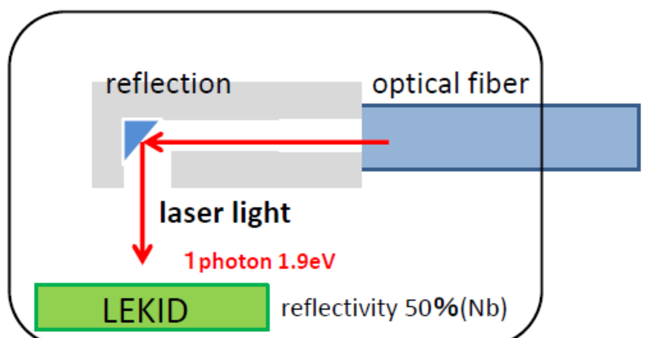
55 resonant peaks:
98% production yield

Visible light illumination test



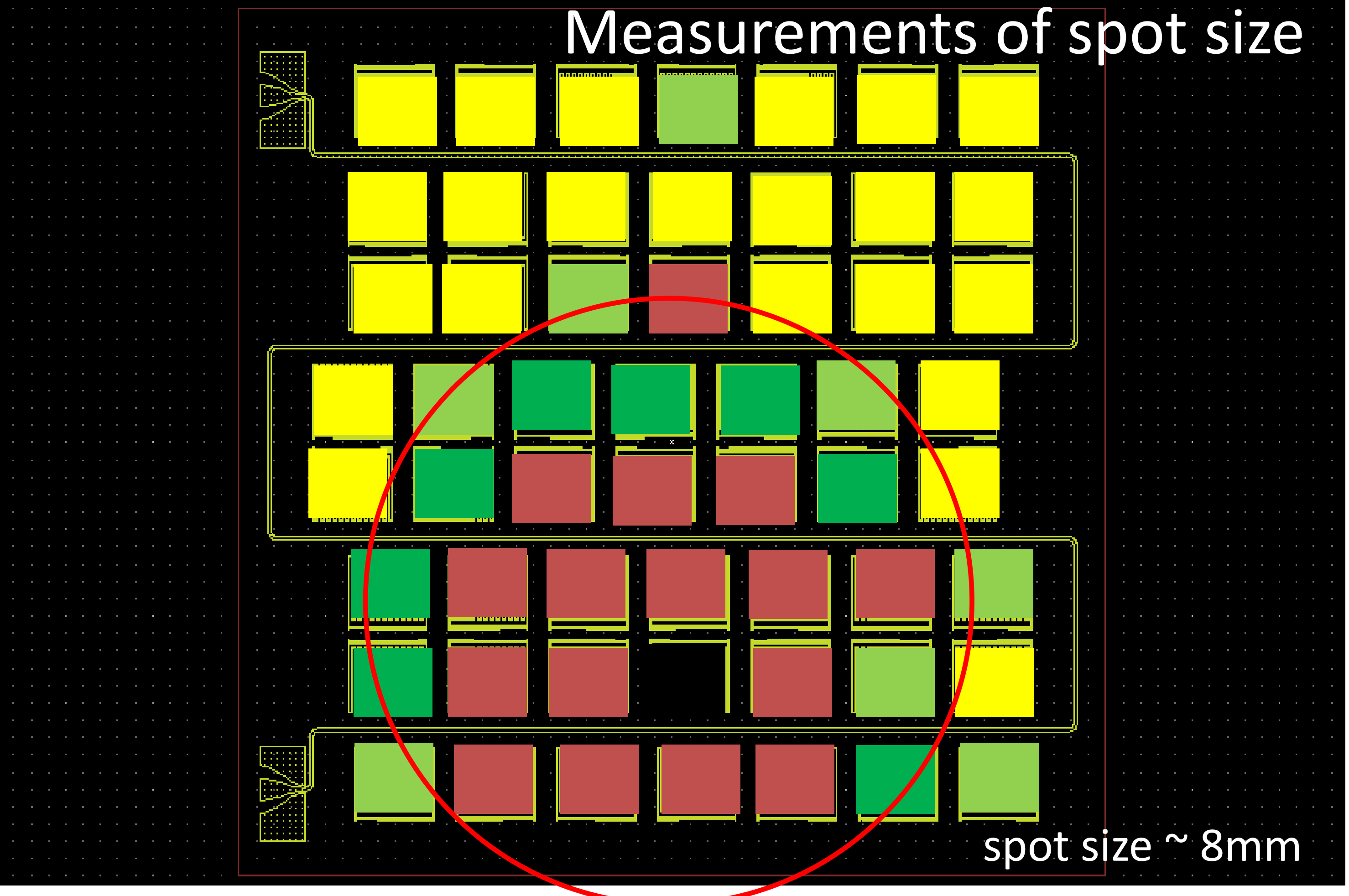


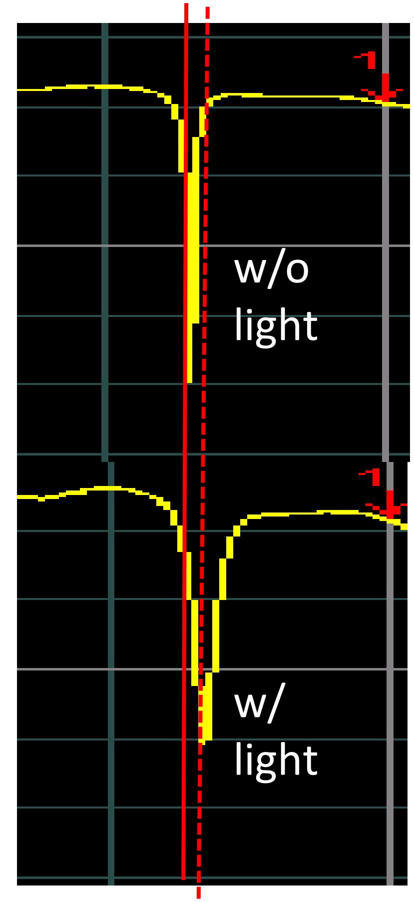
Cooling the detector to 1.6K by pumping liquid Helium



OBIS 660nm laser

Measurements of spot size



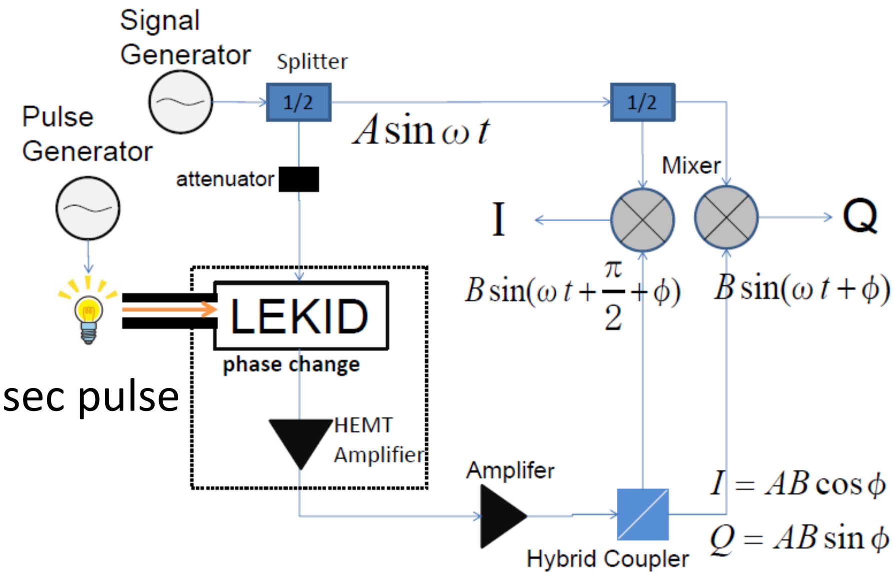


Δ f/f0	1	2	3	4	5	6	7
1	1.3E−05	0	2.46E−05	9.1E−05	1.45E−05	0	−2.8E−05
2	0	0	0	4.22E−05	3.37E−05	0	1.03E−05
3	−1.3E−05	4.32E−05	6.32E−05	−1	3E−05	1.14E−05	−0.00045
4	3.53E−05	8.74E−05	0.000196	0.000289	0.000353	0.000105	2.21E−05
5	1.5E−05	0.000183	−1	−1	−1	0.000319	−1.3E−05
6	0.000183	−1	−1	−1	−1	−1	0.000146
7	0.000187	−1	−1		−1	0.000105	1.56E−05
8	9.63E−05	−1	−1	−1	−1	0.000311	9.27E−05

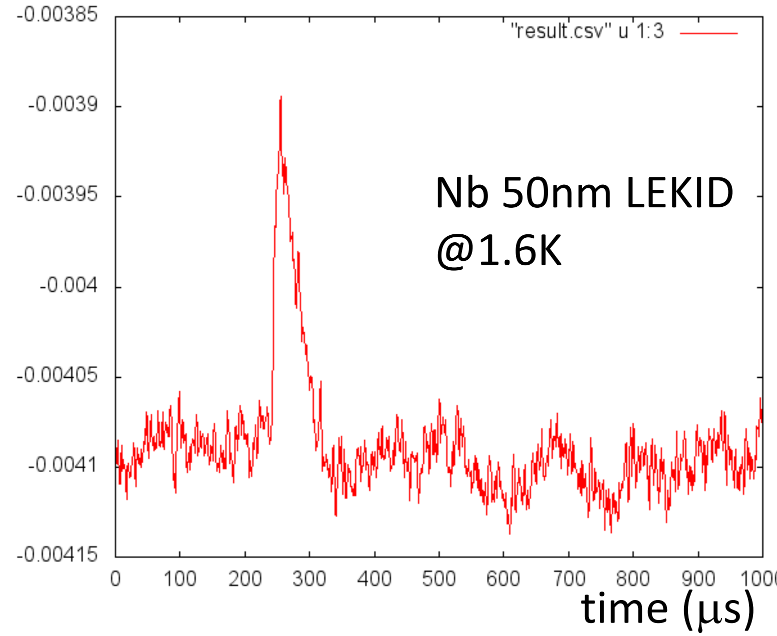
measuring the resonant frequency shift of each resonators $\delta f/f_0$

-1 means peak disappearance

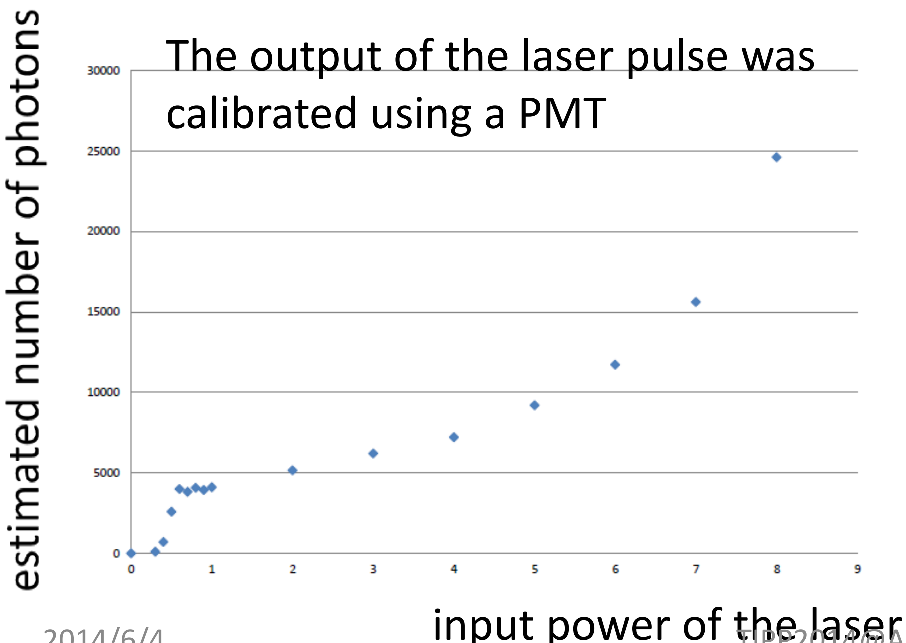
Laser pulse response



10 nsec pulse



The output of the laser pulse was calibrated using a PMT



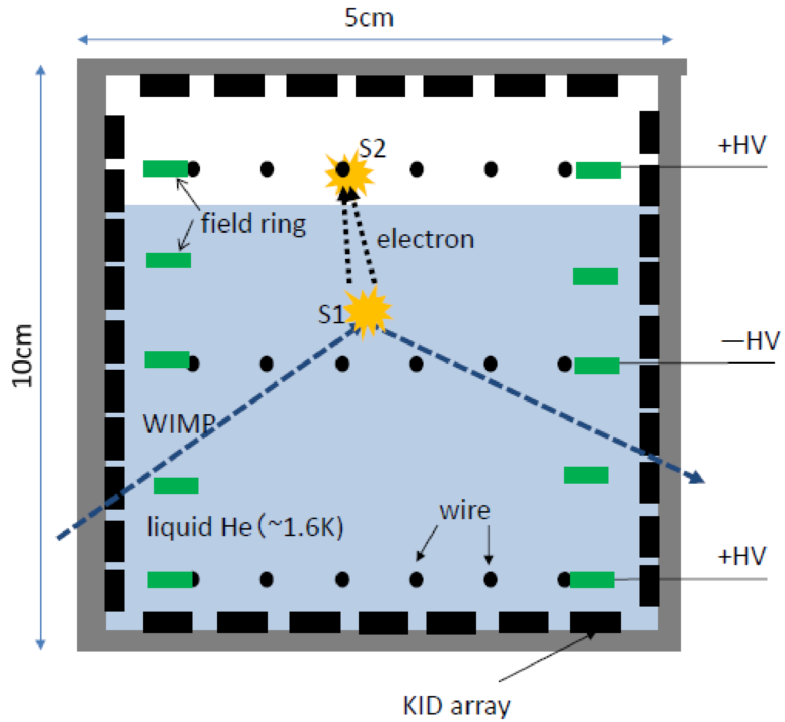
Response of LEKID to 10 nsec laser pulse. We observed nine photons (~17eV).

preliminary

Possible applications

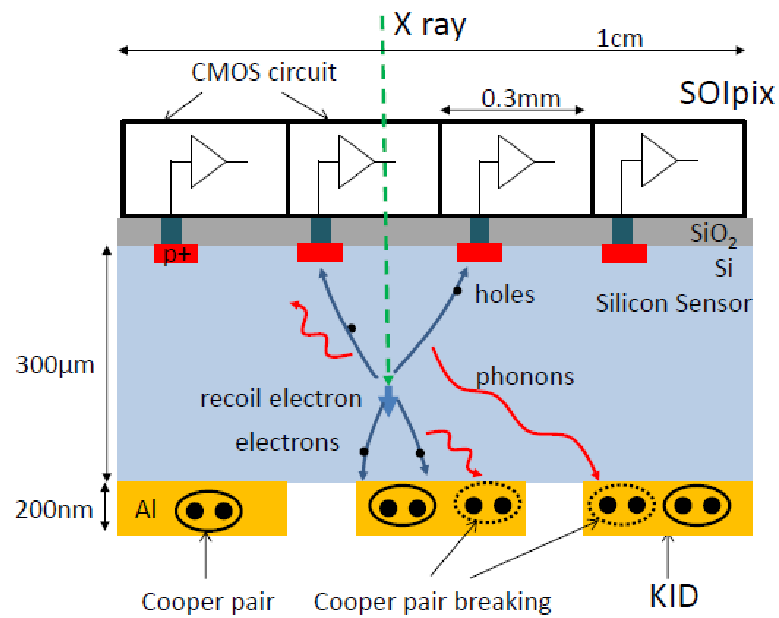
Light dark matter search using liquid helium target

W. Guo and D. N. McKinsey, PRD 87, 115001 (2013)



16 eV scintillation light detection with Nb or NbN KID

High energy resolution X-ray detector in combination with the SOI technology



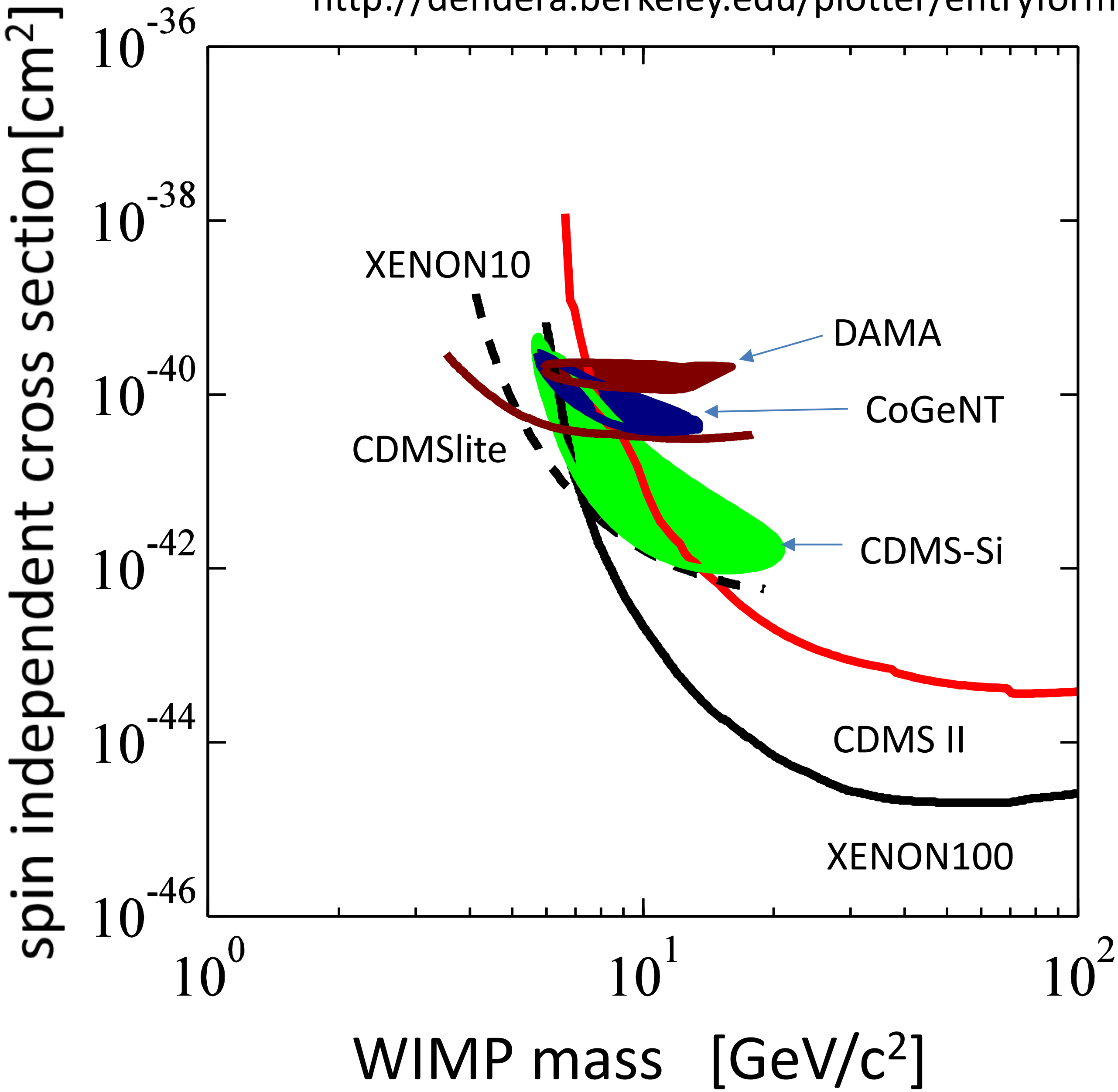
Measuring energy using phonons and position with SOI detector.
We need to develop a low power SOI circuit.

Summary

- We have been developing LEKID for detections of phonons and photons.
  - We successfully observed phonons from the Silicon substrate by irradiating alpha particles
  - Using 660 nm 10 nsec laser pulses, we measured 17eV energy of photons (preliminary).
- We are aiming to apply this detector to;
  - Light dark matter search with liquid He target using 16 eV scintillation light detection.
  - High energy resolution X-ray detector in combination with SOI detector using phonon detection.

backup slides

http://dendera.berkeley.edu/plotter/entryform.html



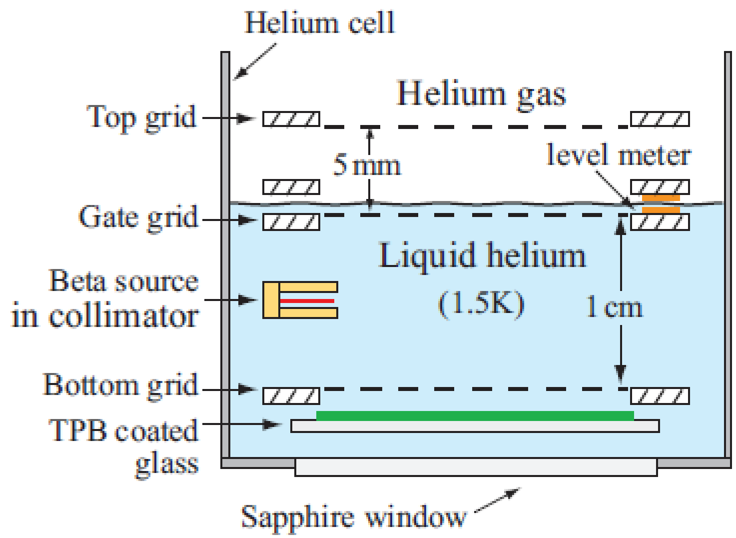
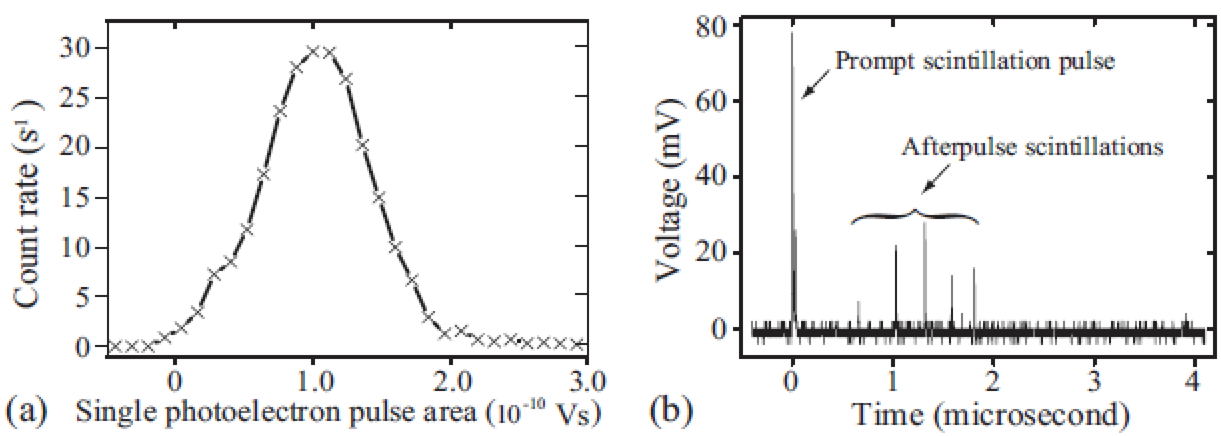
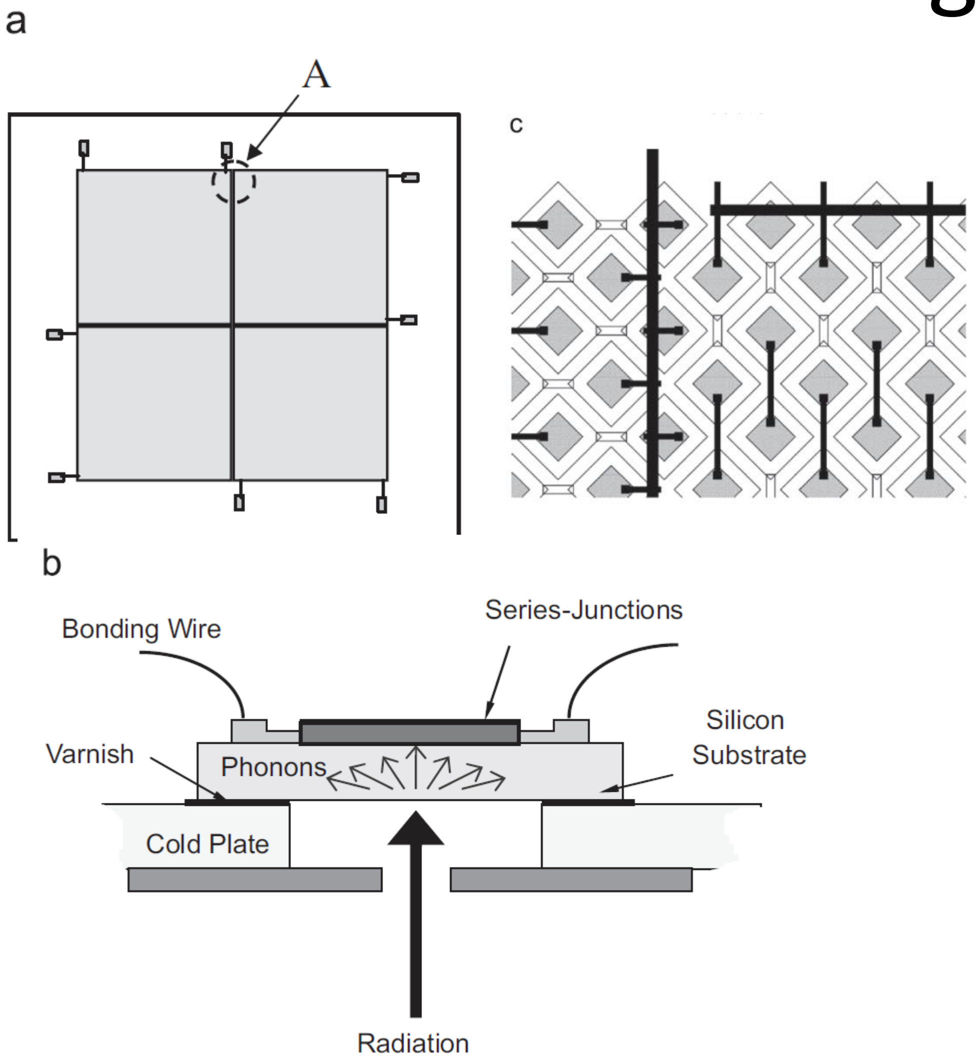


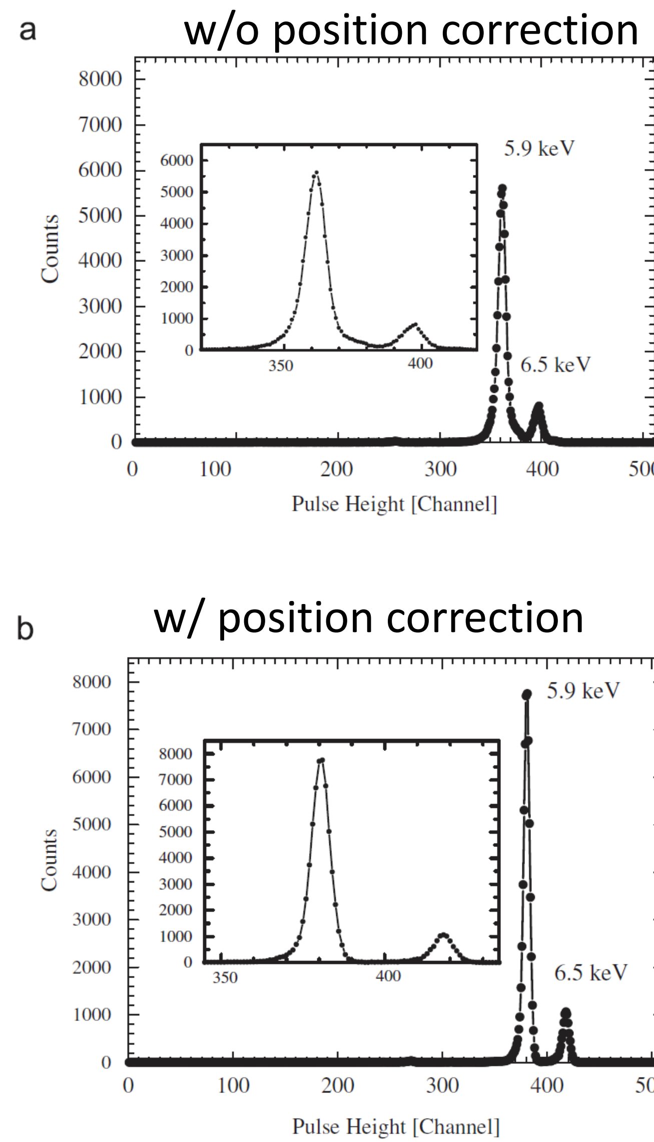
Figure 4. (Color online). Schematic diagram showing the experimental setup.



W. Guo et al., JINST 7 P01002 (2012)

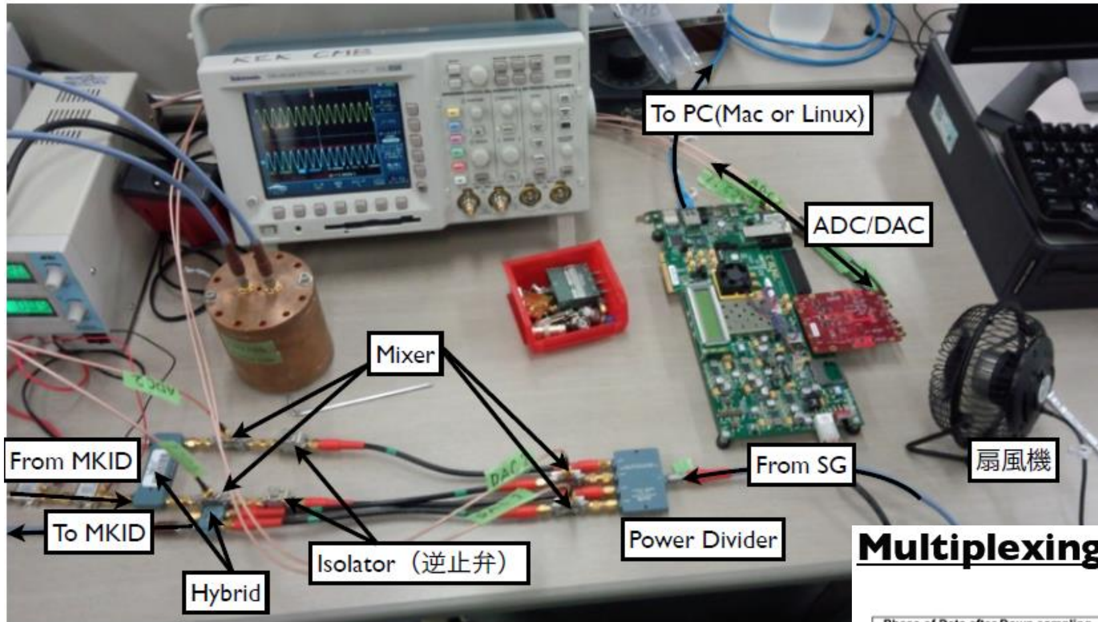
STJ (Superconducting Tunnel Junction)





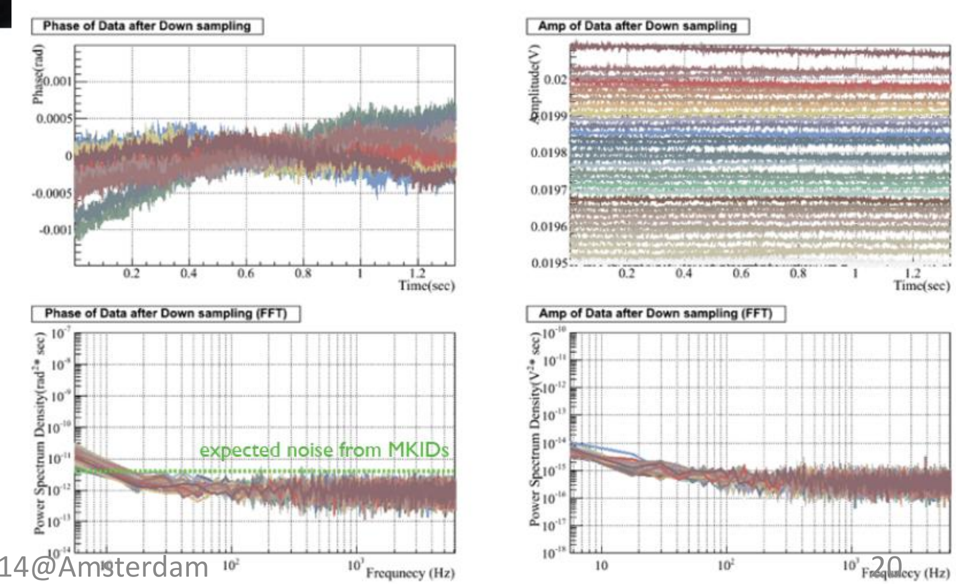
M. Kurakado et al., NIMA 621 (2010) 431-436.

KID multiplexing readout system using FPGA



K. Hattori, Y. Kibe et al., NIMA 732, (2013) 306-310.

Multiplexing with 32 Frequency comb



Material Science at SPring-8 using Compton scattering

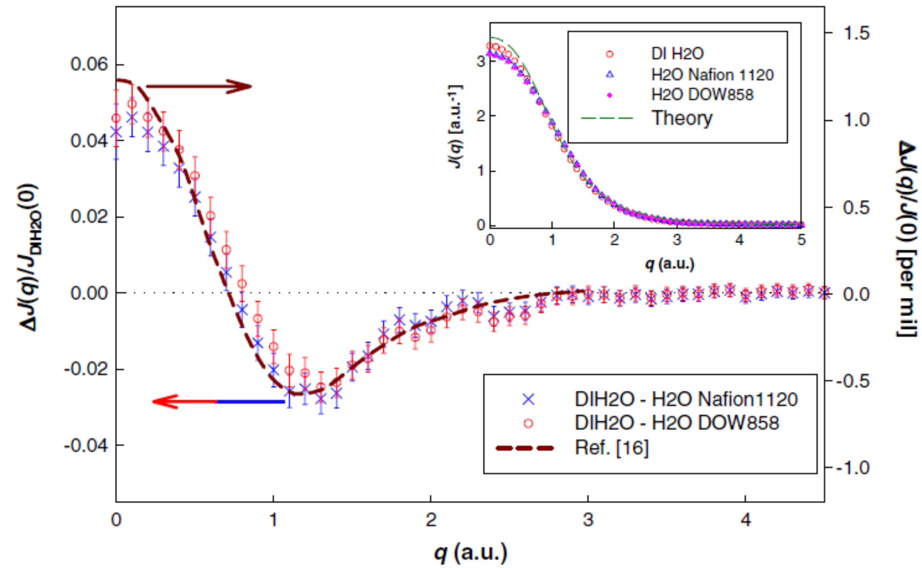
CERN Courier, vol. 53, Sep. 2013.

Weird water

Water confined to scales of around 20 Å has different transport and thermodynamics properties. It now also turns out that even the ground state of electrons is weird. George Reiter of the University of Houston in Texas and colleagues used X-ray Compton scattering to show that the electronic structure of nanoconfined water in hydrated Nafion (a plastic) is not only different from that of regular water but also cannot be explained by conventional *ab initio* calculations. Cells must make use of water in a distinct quantum state from bulk water, so this is likely to have important implications for biology, as well as being of intrinsic interest in physics.

● Further reading

G F Reiter *et al.* 2013 *Phys. Rev. Letts.* **111** 036803.



G.F. Reiter et al., PRL 111, 036803 (2013).