Development of High Resolution Superconducting Detectors for Synchrotron Applications

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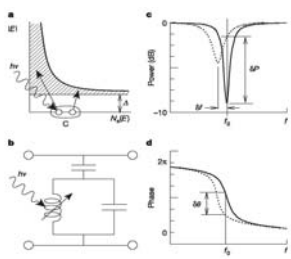
Superconducting detectors operated at temperatures below 1K have demonstrated excellent energy resolution (microcalorimeters) and may enable high temporal resolution and large solid angles of detection with massively multiplexed arrays (microwave kinetic inductance detectors, MKIDs). We have begun a program to deploy each of these technologies at ANL in support of the APS user community. This collaborative effort includes a leader in the MKID field and leverages an ongoing and successful ANL development program in superconducting Transition Edge Sensors. Our poster focuses on development efforts in MKID technology, for which access to CNM capabilities have been invaluable.

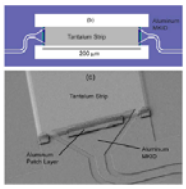
MKID Overview

- The detection scheme employs the monotonic relation between the kinetic surface inductance L_s of a superconductor and the density of quasiparticles generated by photon absorption, *n*.
- We are beginning to develop X-ray MKID pixels. The ultimate goal is deployment of a fast, sensitive, X-ray spectroscopic camera in support of world-class user science at the APS, as well as other light sources.
  - ~1000cps per pixel, overall count rate of 1Mcps
  - Energy resolution: ~12eV at 5.9keV
- Because MKIDs employ a simple, passive multiplexing scheme, there is a clear path forward from single pixel development to the deployment of arrays of >10,000 pixels. This is not true for the principal competing technologies.
- The major fabrication challenges are: 1) to obtain clean interfaces between the absorber and resonator layers, and 2) to fabricate thick absorbers.

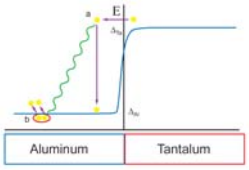
MKID Operation and Design



(a) Photons break Cooper pairs in a superconductor, creating quasiparticles.
(b) Quasiparticles change the inductance of a resonant circuit.
(c) The resonance shifts to lower frequency and becomes broader and shallower.
(d) The density of quasiparticles, which reflects the absorbed energy, can be monitored by measuring the shift in phase of a microwave signal sent through the resonator.

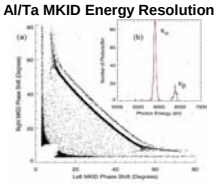


Strip MKID, Mazin et al. (2006)



Quasiparticle trap concept. Here Al is the resonator and the Ta is the x-ray absorber.

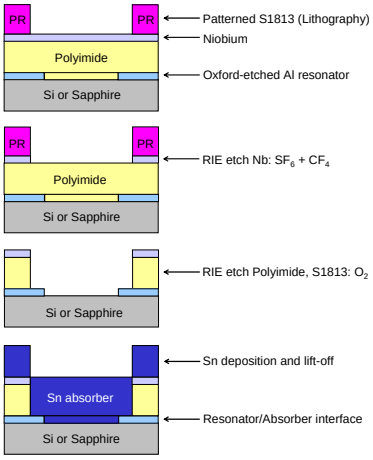
Al/Ta MKID Energy Resolution



Energy resolution of 62 eV @ 5.89 keV of MKID strip detector. The theoretical resolution is about 7 eV. (Mazin et al, 2006)

FABRICATION STRATEGY:

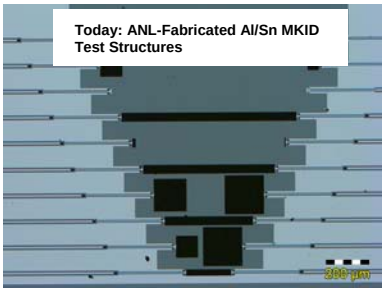
1. Wafer cleaning
2. Resonator deposition (300 nm Al) at MSD
3. Resonator photolithography (MA-6)
4. Oxford ICP-RIE of Al
5. Photolithography for absorber layer by Tri-level liftoff
   - Polyimide/Nb stencil used to prevent organic contamination of the absorber layer during absorber deposition, fabricated using March RIE (*see graphic right*)
6. Absorber deposition (e.g., 1 micron Sn) by thermal evaporation
   - Deposition at MSD and XSD/OFM
   - Plating approaches are being considered
7. Liftoff



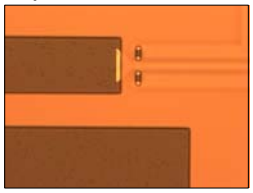
Results & Future Work

Results:

- MKID fabrication at ANL-CNM has begun.
- Initial results are encouraging.



- Technical challenges do exist at several locations:
  - Resonator/absorber interface
  - Quantum efficiency (relating to the absorber quality and thickness)
  - Fill factor of the absorber (e.g., mushroom absorbers)



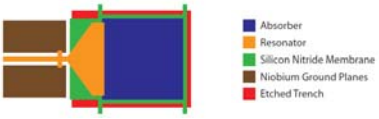
Polyimide/Nb stencil. The Al resonator layer is visible under the Poly/Nb stencil. The tin deposition and liftoff have yet to be done.

Future Work: Explore Bi-Alloy superconductors for absorber (e.g., W-Si, Au-Sn in collaboration with Chian Liu, XSD/OFM)

Material	Atomic Number Z	Transition Temperature	Theoretical Energy Resolution at 6 keV	Attenuation Length at 6 keV
Lead	82	7.2 Kelvin	3.53 eV	1.86 µm
Tantalum	73	4.5 Kelvin	2.79 eV	1.79 µm
Tin	50	3.7 Kelvin	2.53 eV	2.60 µm
Indium	49	3.4 Kelvin	2.43 eV	2.77 µm
Rhenium	75	1.7 Kelvin	1.72 eV	1.31 µm
Molybdenum	42	.92 Kelvin	1.26 eV	2.94 µm
Osmium	76	.66 Kelvin	1.07 eV	1.18 µm

Properties of candidate absorber materials.

Future Work: Membrane-suspended MKID Design



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