Superconducting Transition-Edge Sensor X-Ray Microcalorimeters

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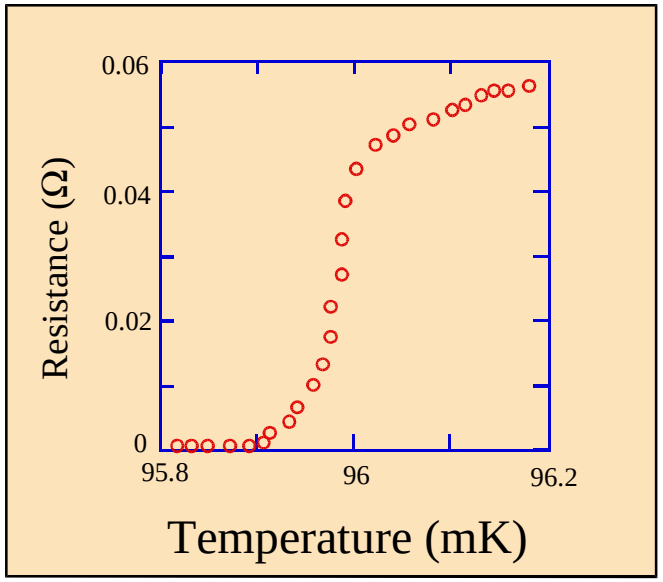
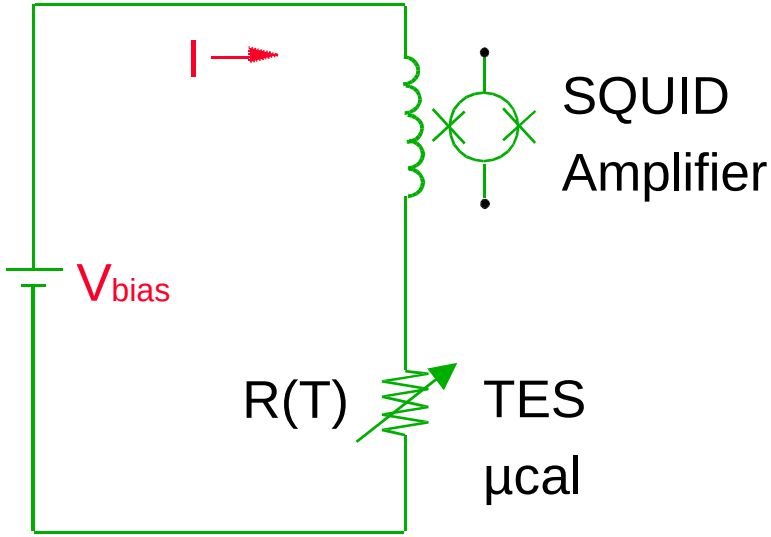
- “Old” detectors pushed to 2 eV at 1.5 keV
- Fully microfabricated detectors 4.5 eV at 6 keV
- Mux developments

Voltage−Biased Superconducting Transition−Edge Thermometers





- Joule power causes each pixel to self−regulate in temperature: Self−biasing allows large format arrays

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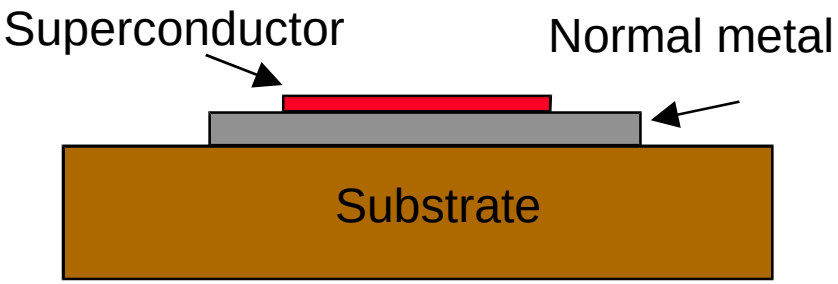
Why Transition−Edge Thermometers?

- Extremely sensitive thermometer
  - High
  - Allows design flexibility for faster response and higher resolution

- Large format arrays
  - Compatibility with microfabrication
  - Low power superconducting amplifiers
  - Possibility of multiplexing

Superconductor / Normal Metal Bilayer Transition−Edge Sensor

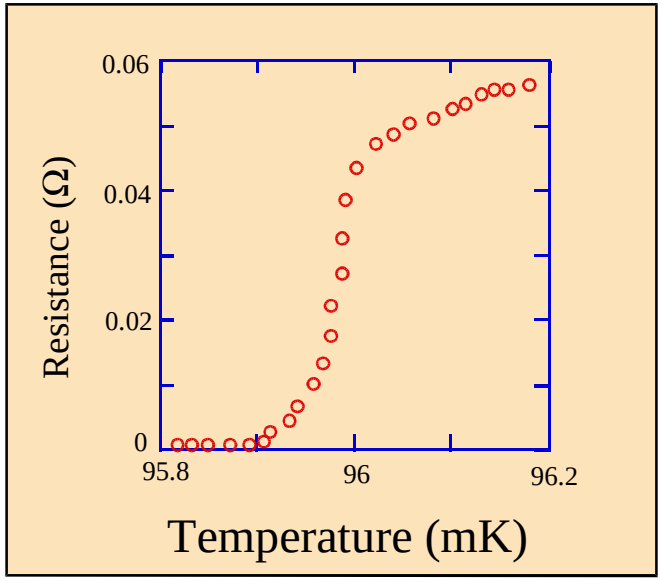
- A bilayer of a thin superconducting film and a thin normal metal acts as a single superconductor with a tunable − the “proximity effect”



- Superconductors in use:

Aluminum	Tc ~ 1.1 K
Molybdenum	Tc ~ .92 K
Titanium	Tc ~ .4 K
Iridium	Tc ~ .14 K

- Sharp
- Reproducible <~ 2 mK
- Tunable



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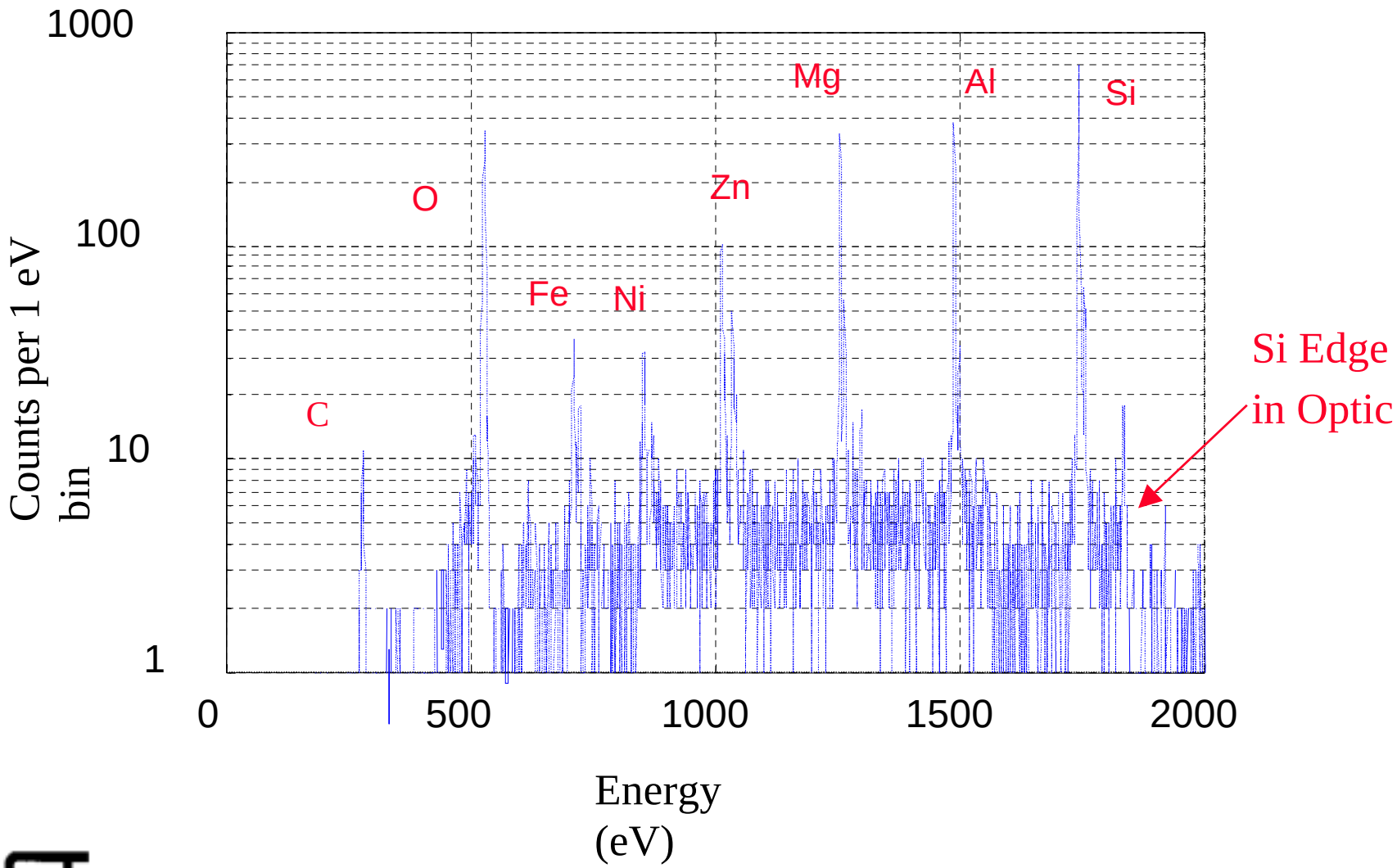
Spectrum of NIST glass with Al−Ag TES microcalorimeter



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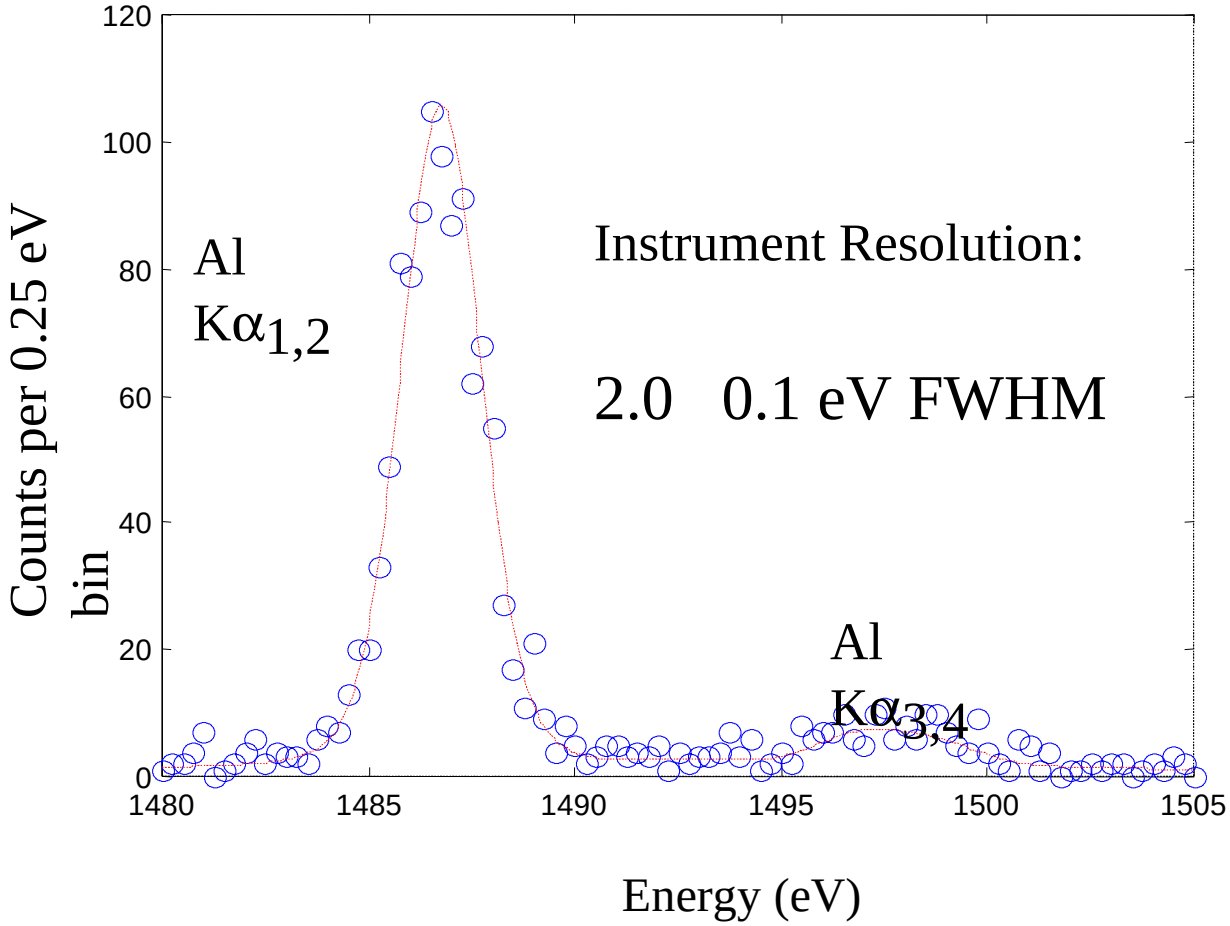
Fit to theoretical Al oxide lines



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New Bilayer materials

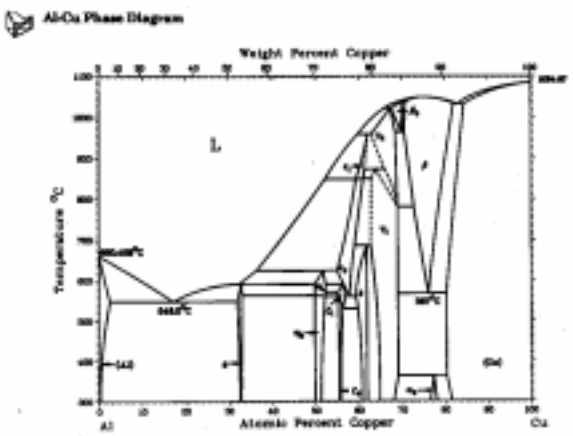
Molybdenum

- Sputters well (but watch the stress)
- Scant oxide formation (good interfaces)
- Thermally stable with noble metals (see phase diagram)
- Chemically inert with noble metals (low corrosion)
- Easy to process (etches well)

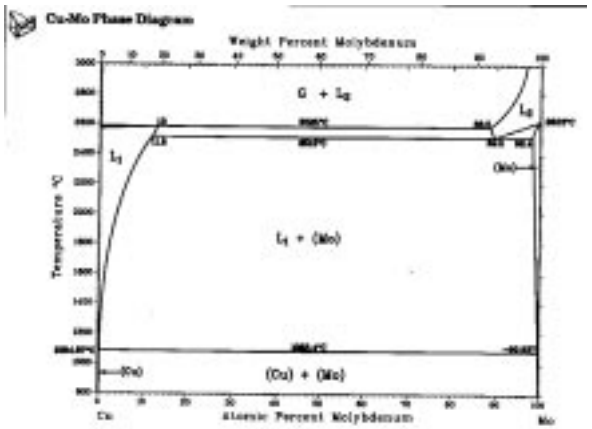
Copper

- Best RRR (compared to Ag, Au) in our sputtering system
- Problem - hard to dry etch (without Cl RIE), wet etch has big undercut

AlCu phase diagram

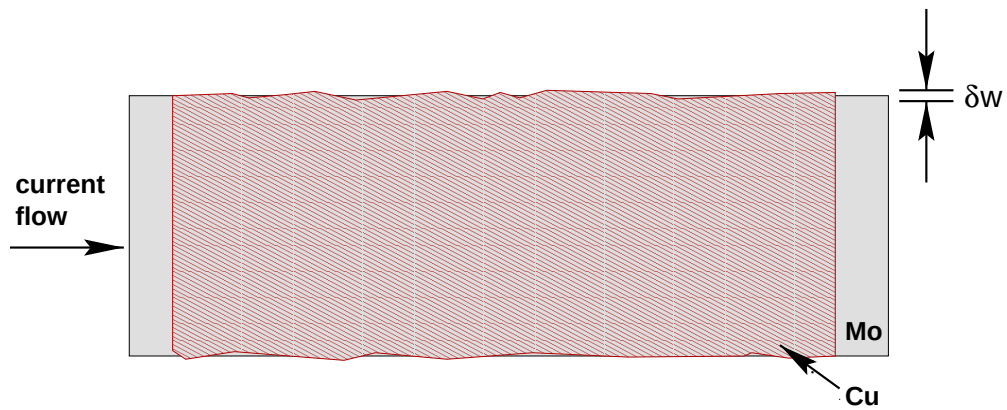


MoCu phase diagram



Critical currents and boundary conditions

- Need uniform j_c for quiet and reliable operation
- Local j_c depends strongly on boundary conditions
- Superconducting boundary conditions give largest j_c and best TES performance
- But ....



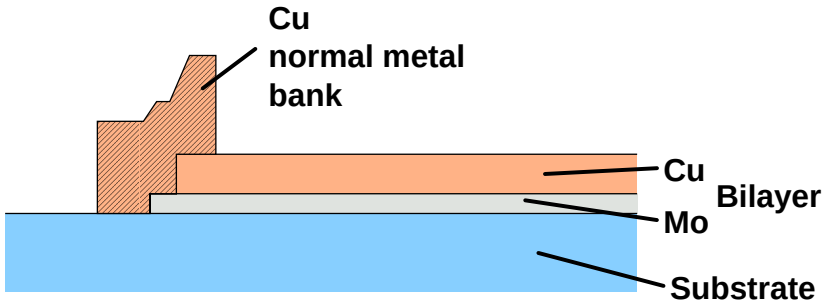
Usadel predicts if δw is $>$ 5 nm, big local T_c and thus j_c variations.

Very difficult to manufacture.

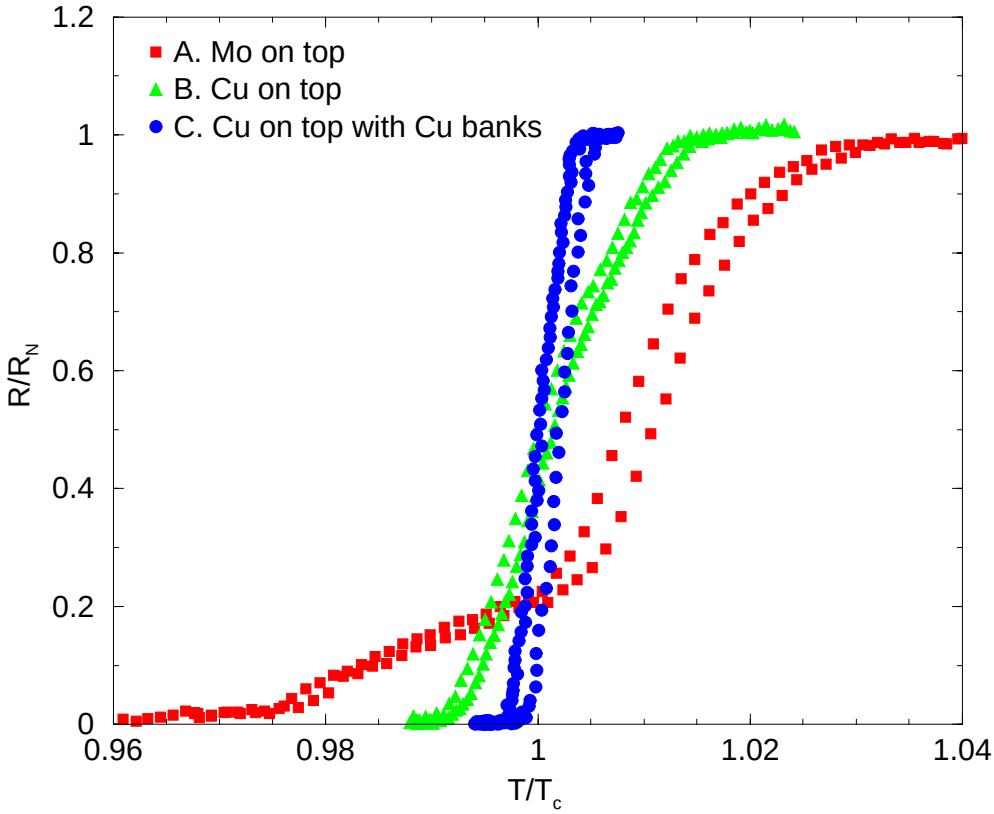
Normal metal boundary conditions fixes this problem.

Normal boundary conditions

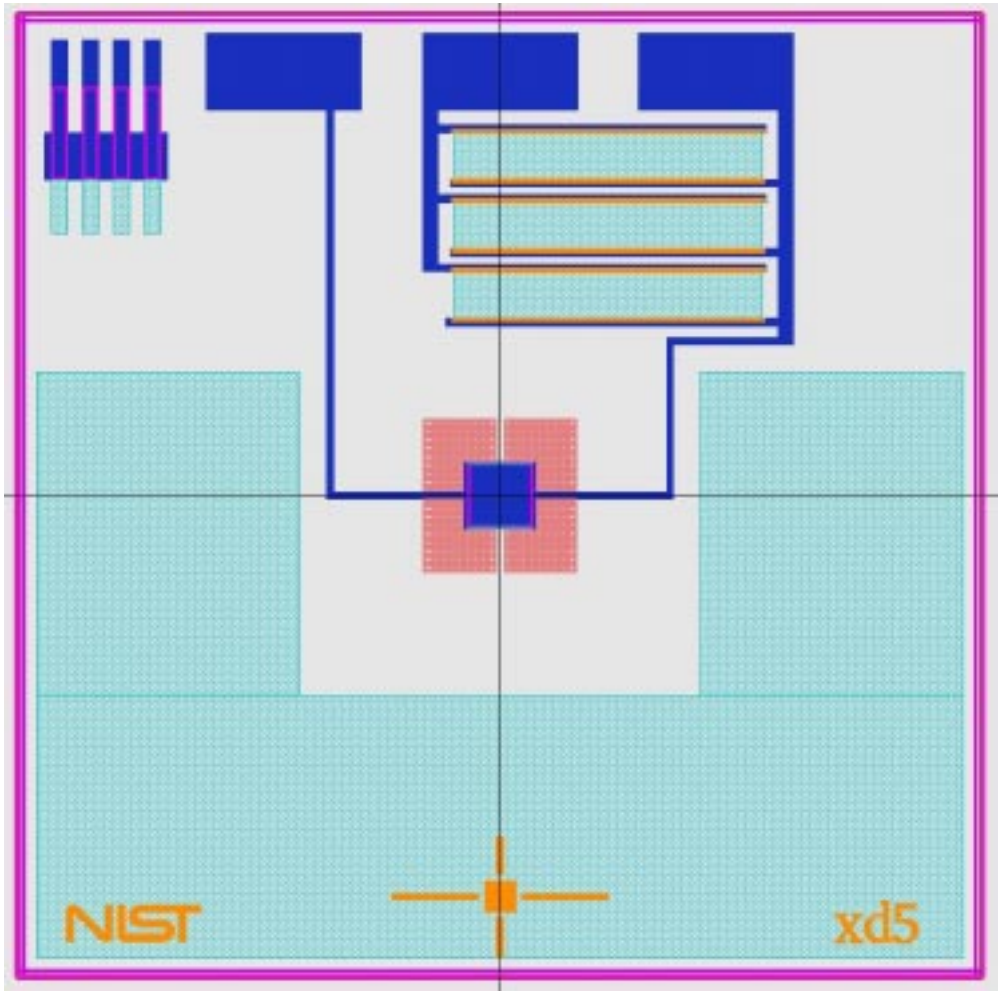
With Mo as bottom layer, normal BC requires additional film

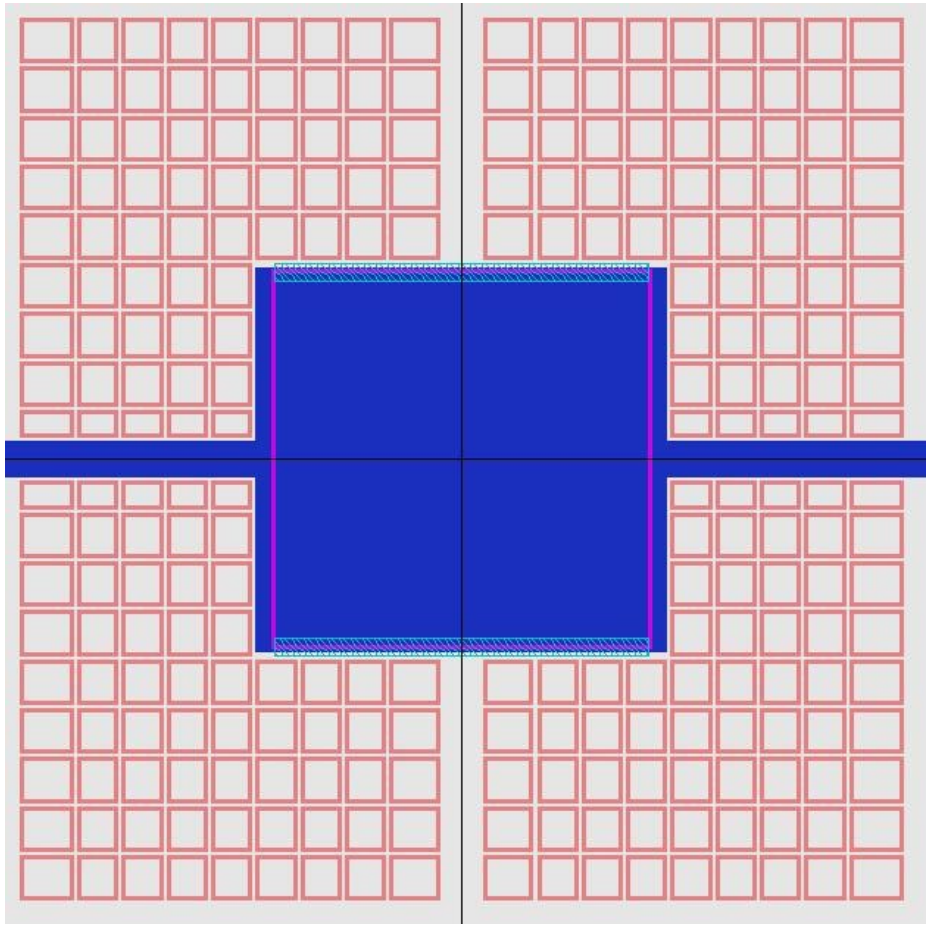


- Light Ar plasma cleaning before deposition of bank
- Bank thicker than d_n to ensure "fully normal"
- Encapsulates bilayer edges (no exposed Mo/Cu interface)



Detector Layout





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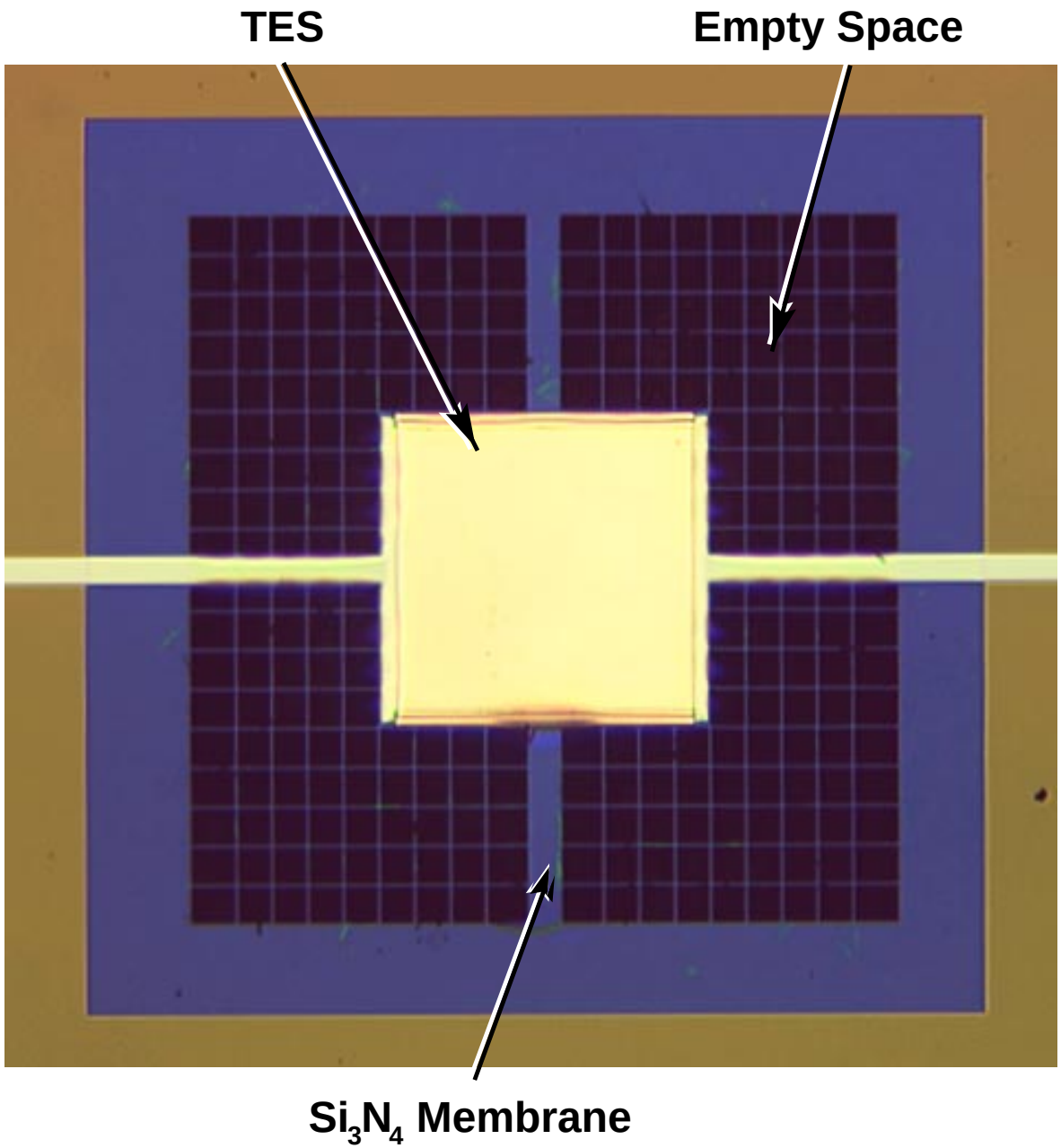
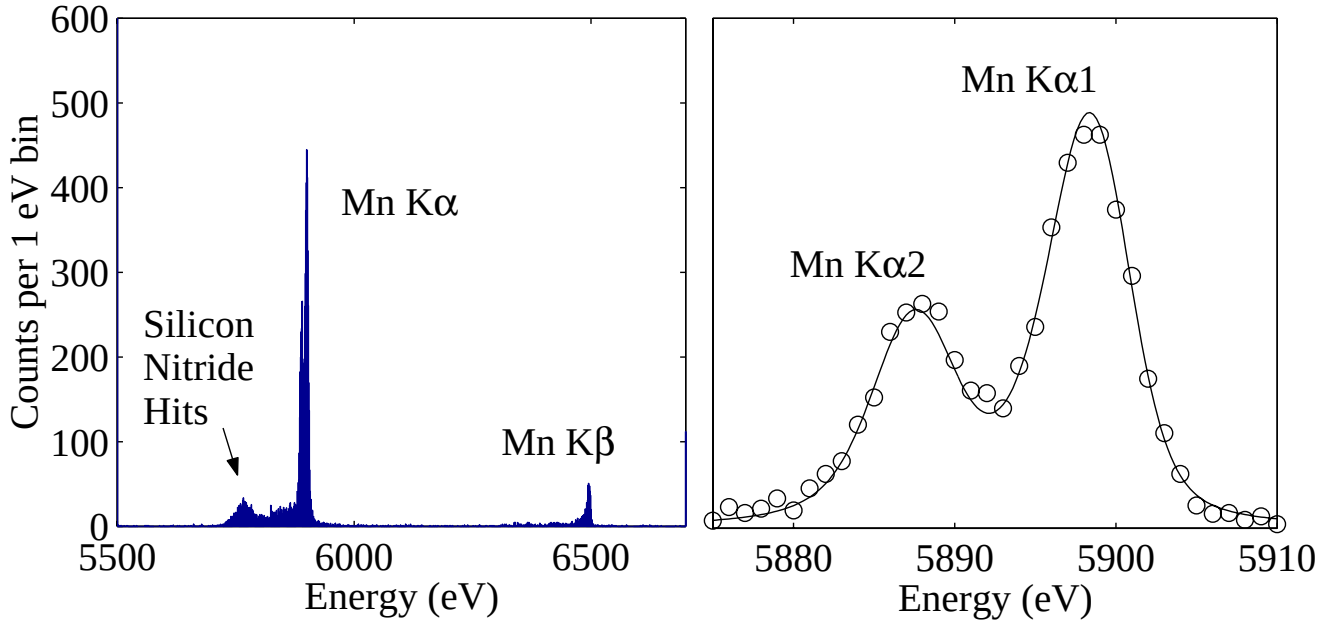

TES
Empty Space
Si_3N_4 Membrane

Results

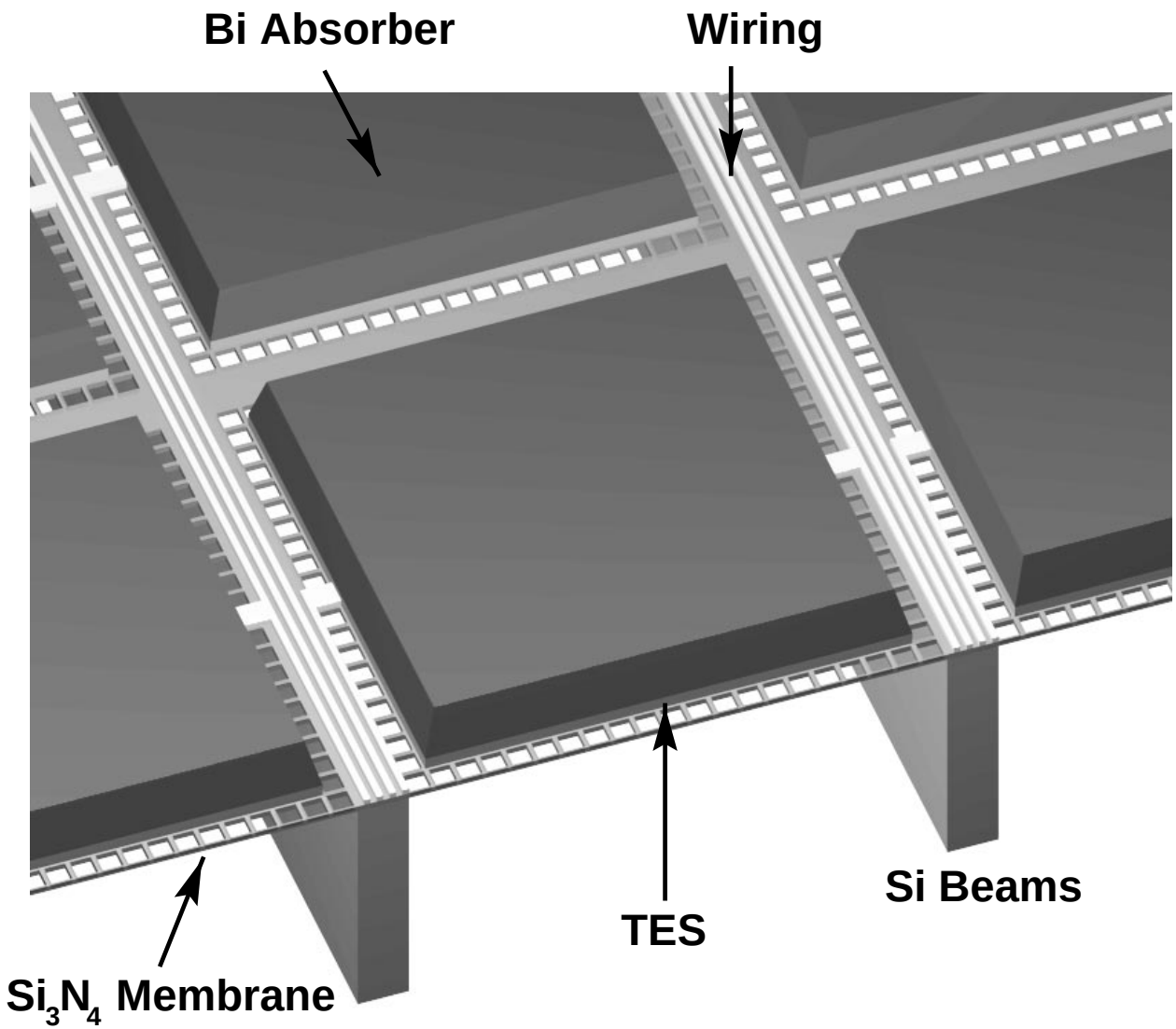
Energy resolution = 4.5 ± 0.1 eV FWHM



What's next?

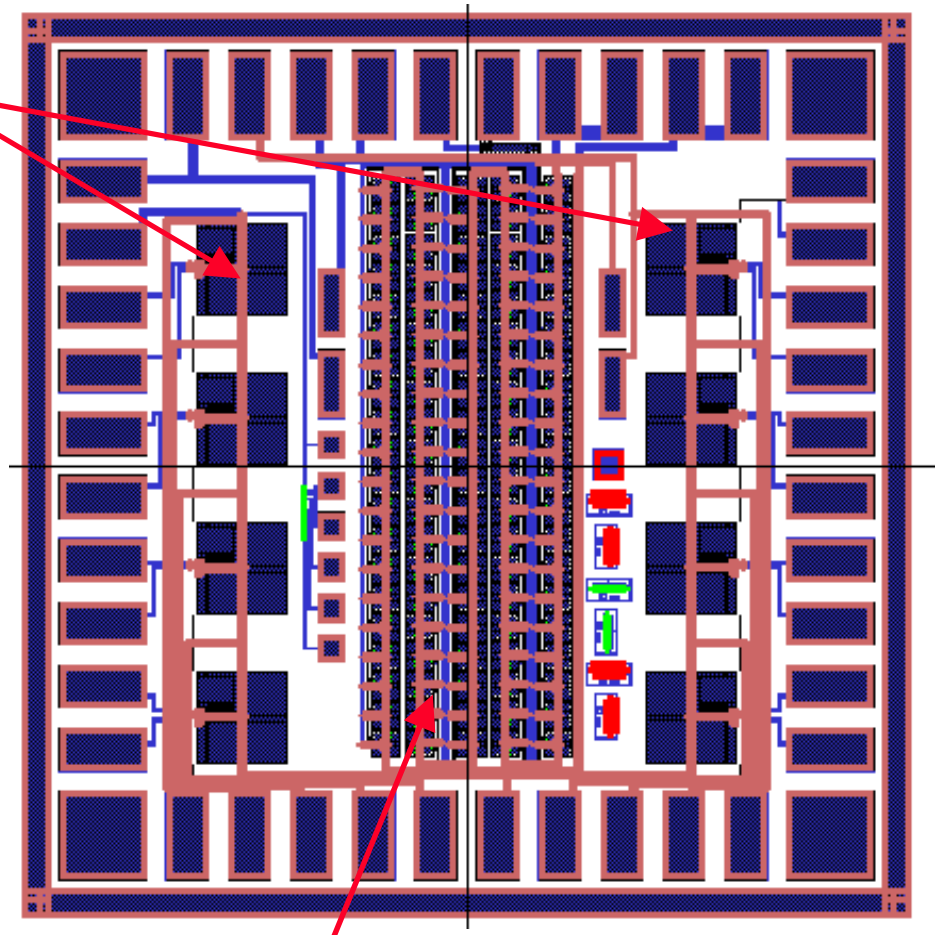
- Improve membrane yield
- Bi absorbers (test structures look good)
- Bi "mushrooms" (NASA GSFC)
- Further optimization (goal of 2 eV at 6keV)

Arrays



SQUID multiplexer design & layout

1 x 8 SQUID multiplexer (one column)



100 SQUID series array

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