High-density arrays of x-ray microcalorimeters for Constellation-X






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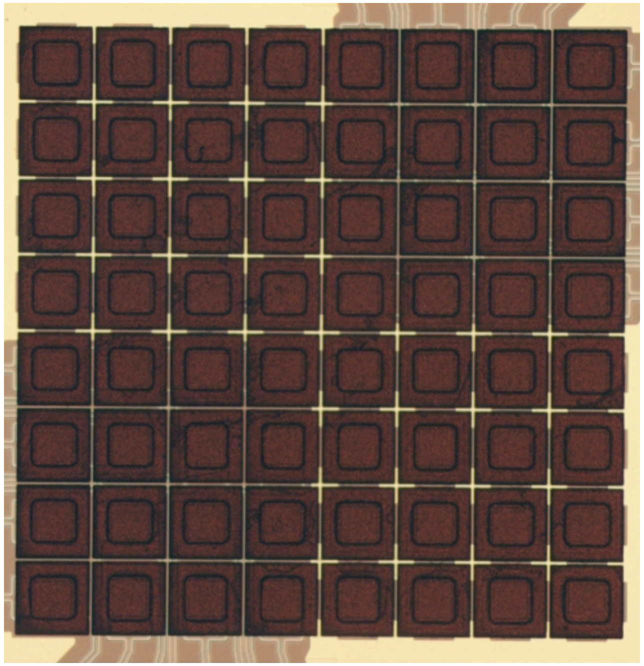
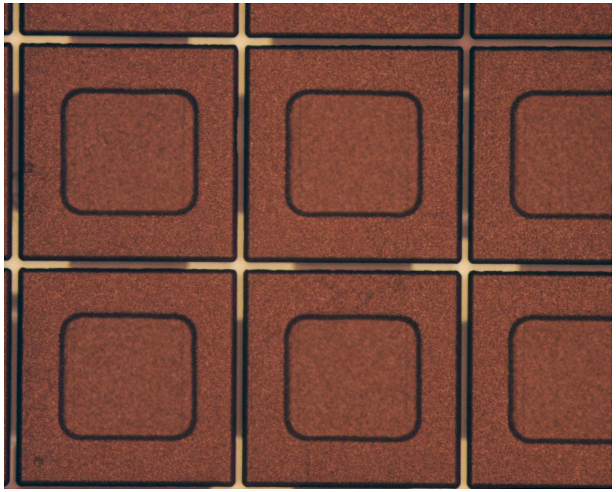
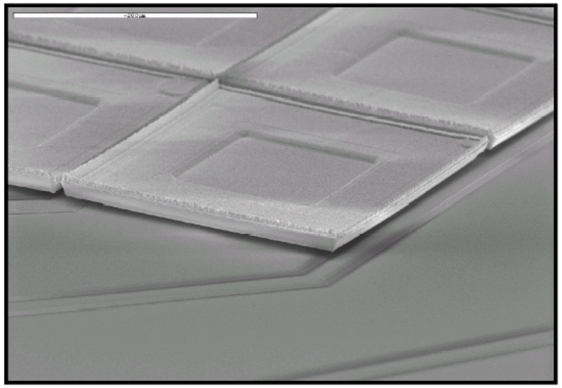
Standard 8x8 arrays

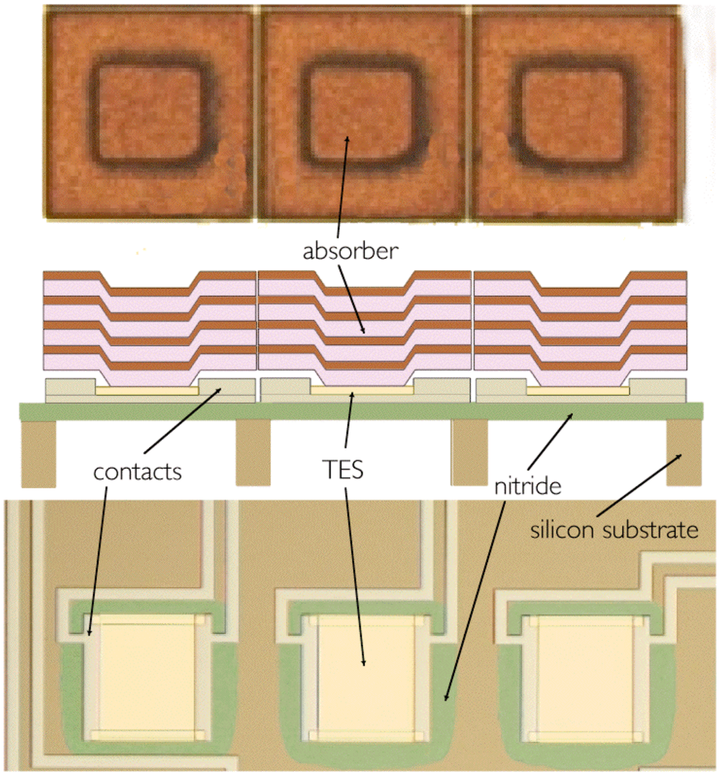


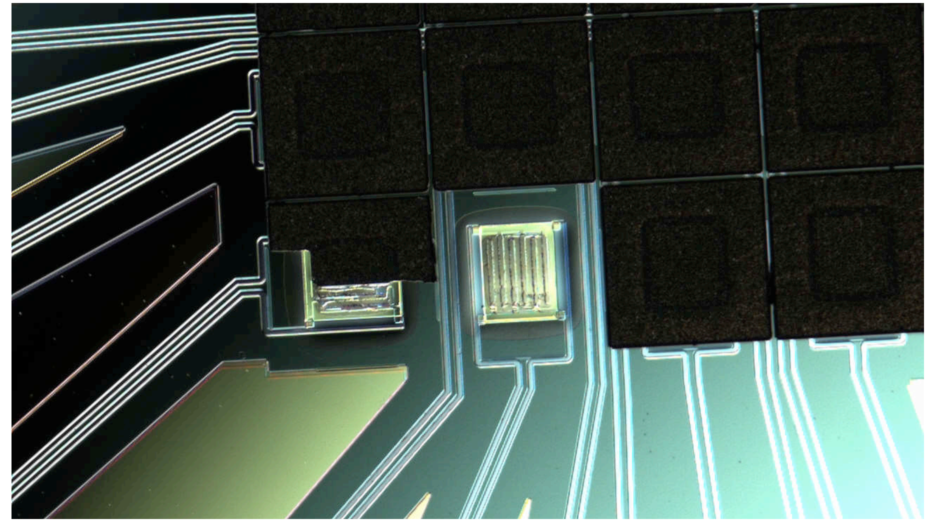


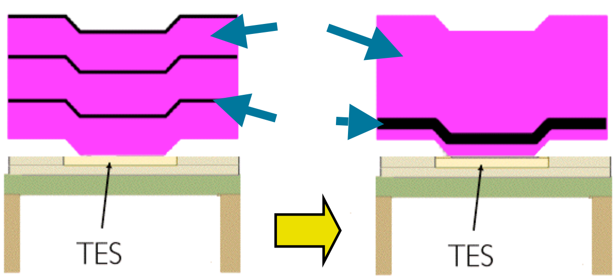
- Mo/Au TES
  - Electron-beam deposited
  - $T_c \sim 0.1$ K
- Bi/Cu absorber
  - High Z semi-metal
  - Normal metal to tune C and aid thermalization
- Matched to Constellation-X reference design
  - 0.25 mm pitch
  - 92% fill factor, 95% QE at 6 keV



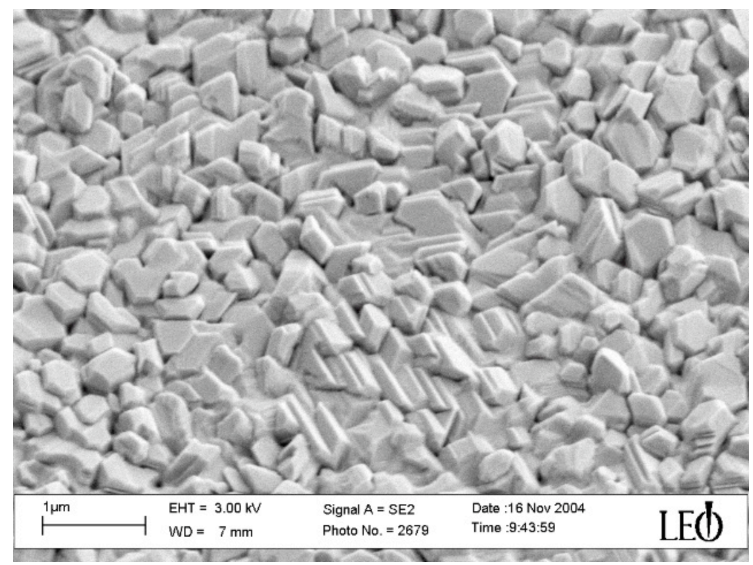
Array components



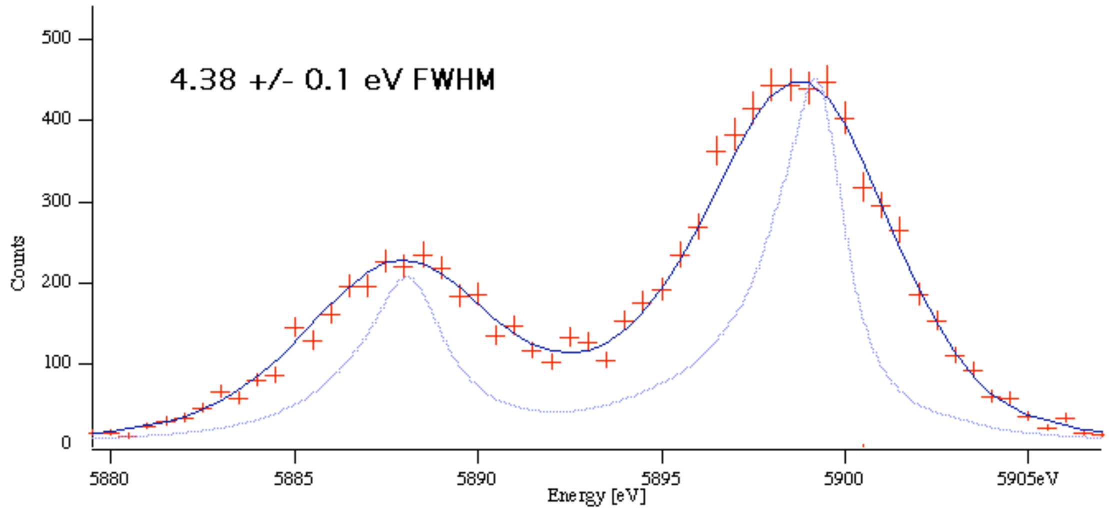




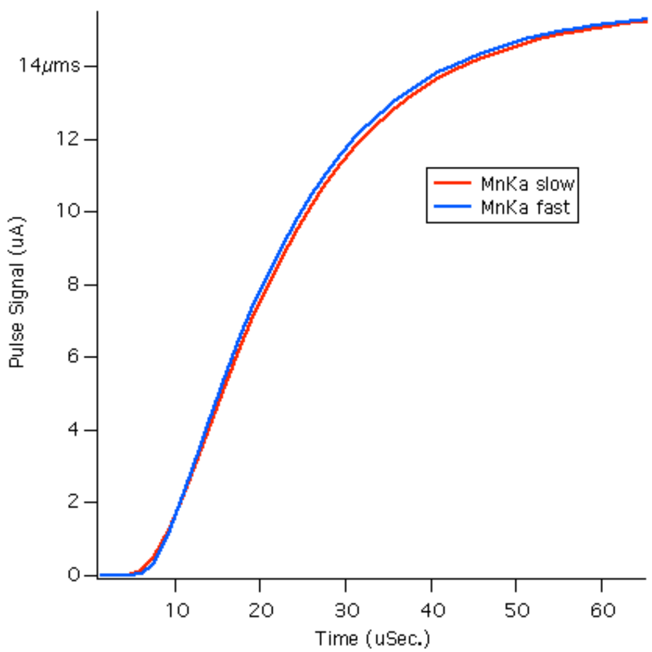
0.6 microns Cu
6.5 microns Bi

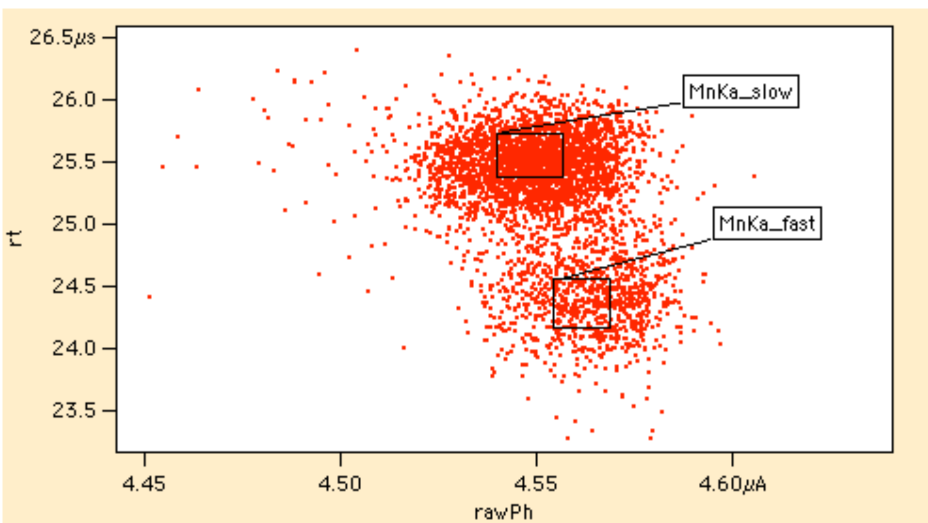


Performance of traditional bismuth absorbers



- 4 - 5 eV resolution at 6 keV on several arrays with first wafer after absorber redesign (redistributed Cu into one thick layer)





Interface issues

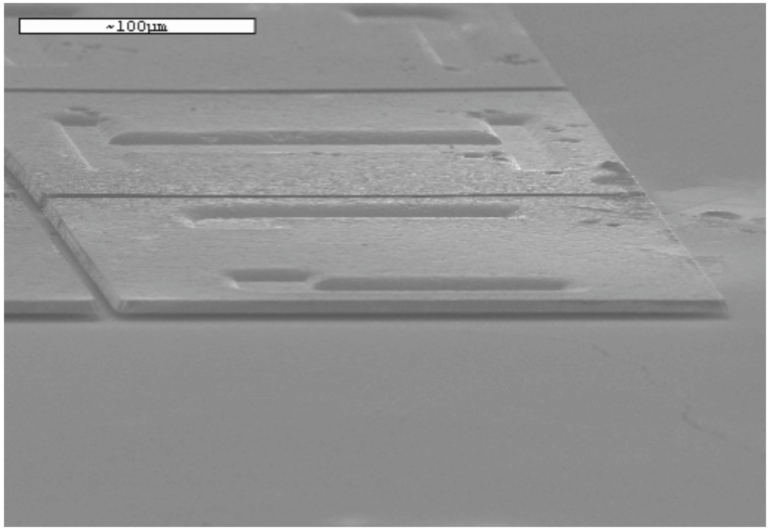
- Subsequent wafers did not match 4 - 5 eV performance
- Formation of BiAu intermetallics at the interface & diffusion of Cu through the Bi into Au of TES altered Tc uncontrollably
  - Good devices were immune to such interface chemistry, even when subsequently annealed
- Because of the variable nature, we have investigated designs that would prohibit damage to the critical interface

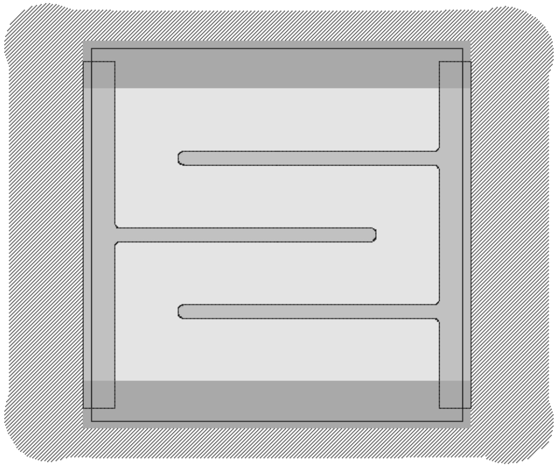
Potential Barrier layers at interface

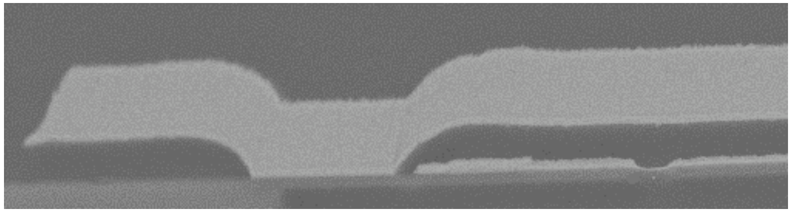
- Ge
  - Compatible with Bi to > 120 °C, but not with Au
- Mo
  - Compatible with Bi & Au. E-beam tends to put down normal-conducting film if substrate not heated, but actual T_c (and its impact on the underlying TES) too hard to control
- SiO, AlO Insulating films not necessarily bad
  - Open holes to normal-conducting (non-sensing) regions of the TES
  - Or phonon connection between metals with good e-ph coupling

New Absorber Attachment Method - Vacuum gaps

- Absorber makes contact only at normal-metal features or out on the membrane (for support)
- Contacts placed to avoid diverting current away from the sensor
- Permits deposition of good smooth thermalizing layer first
- Permits use of highly conducting absorbers, even superconductors







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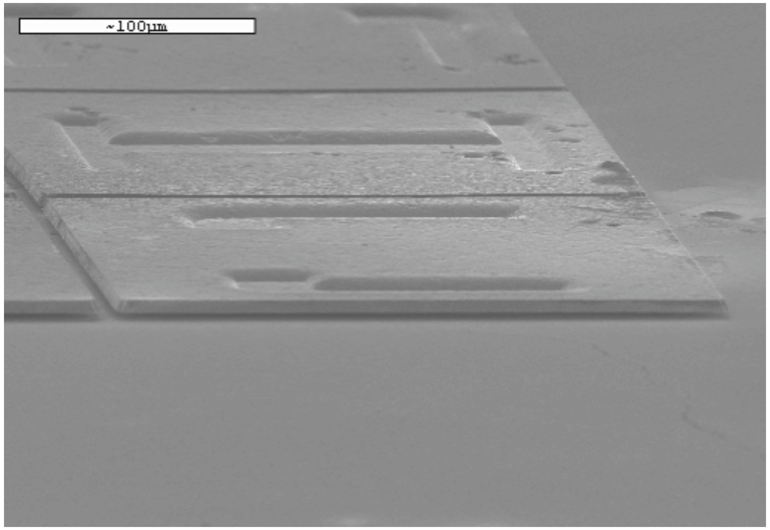

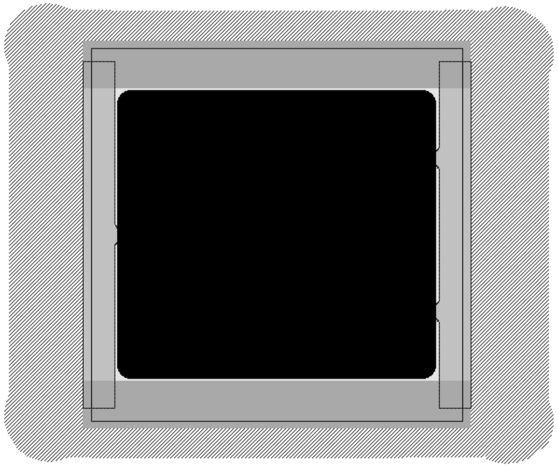

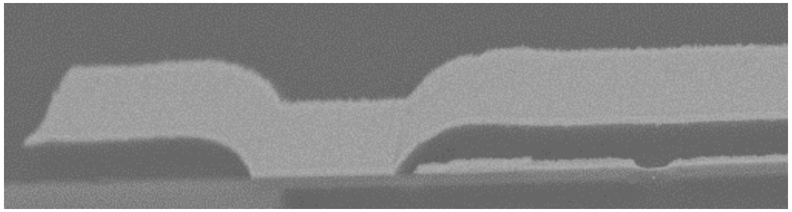

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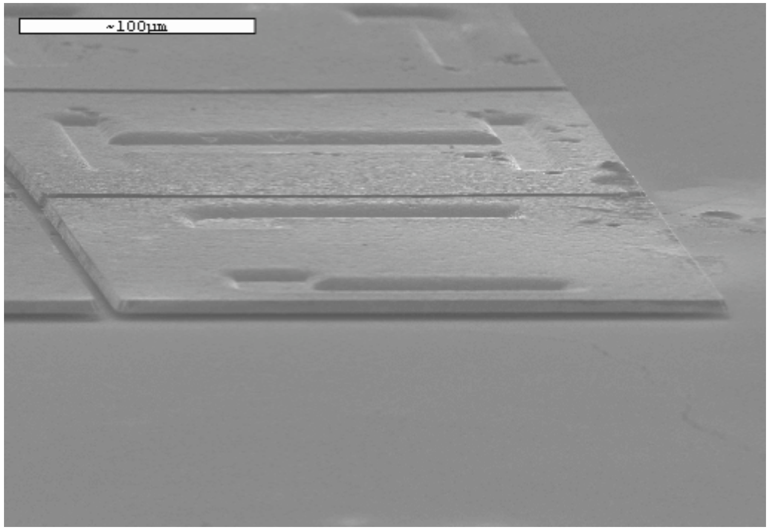

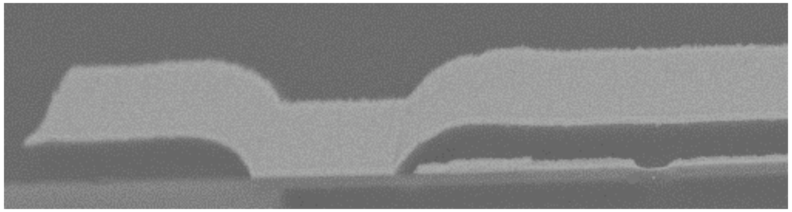

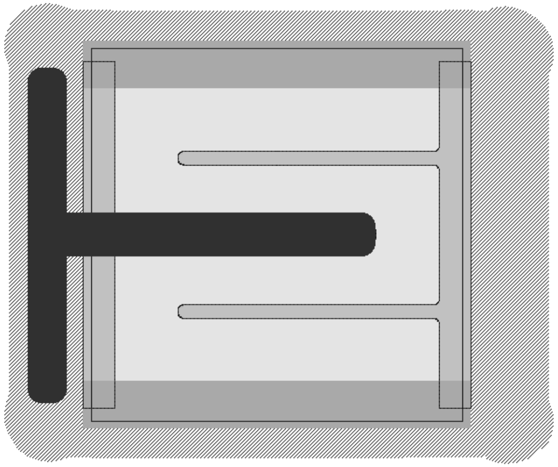

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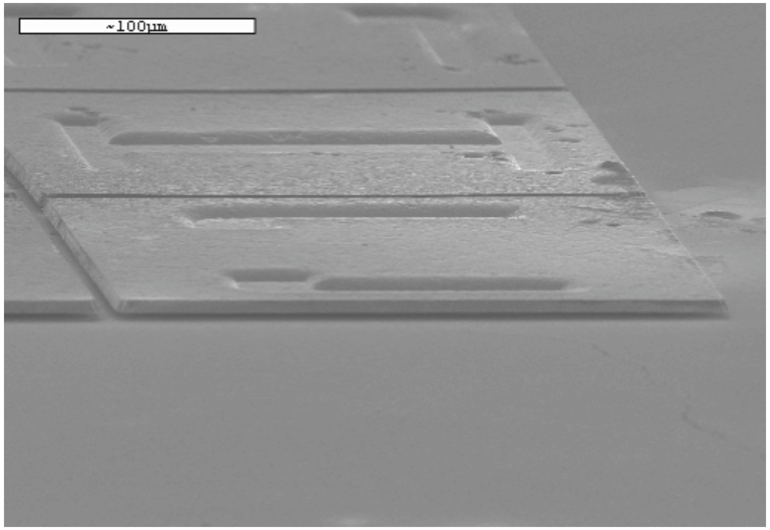

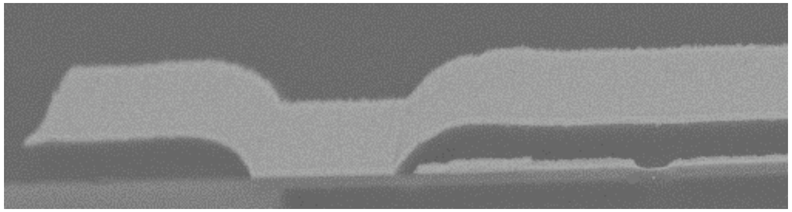

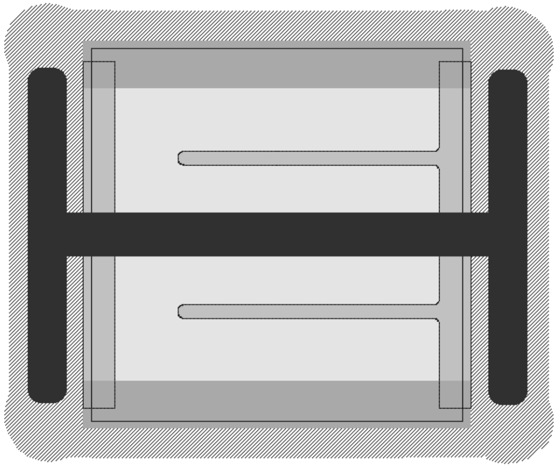

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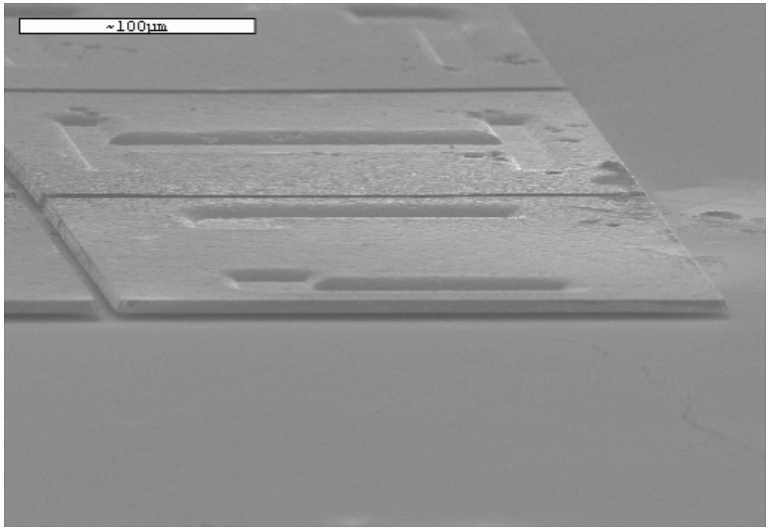
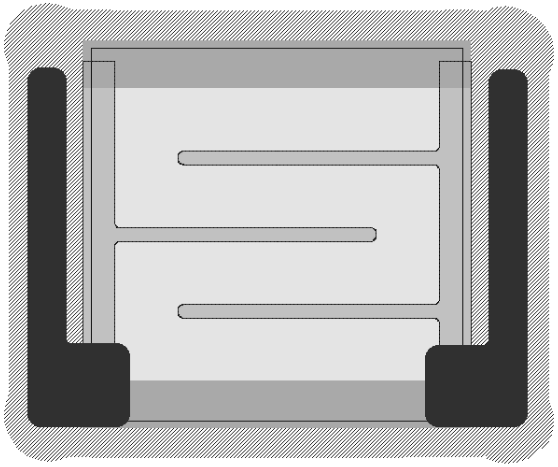
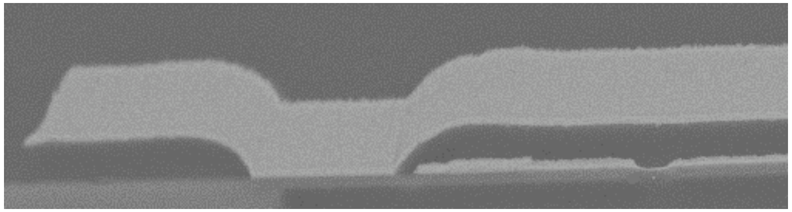
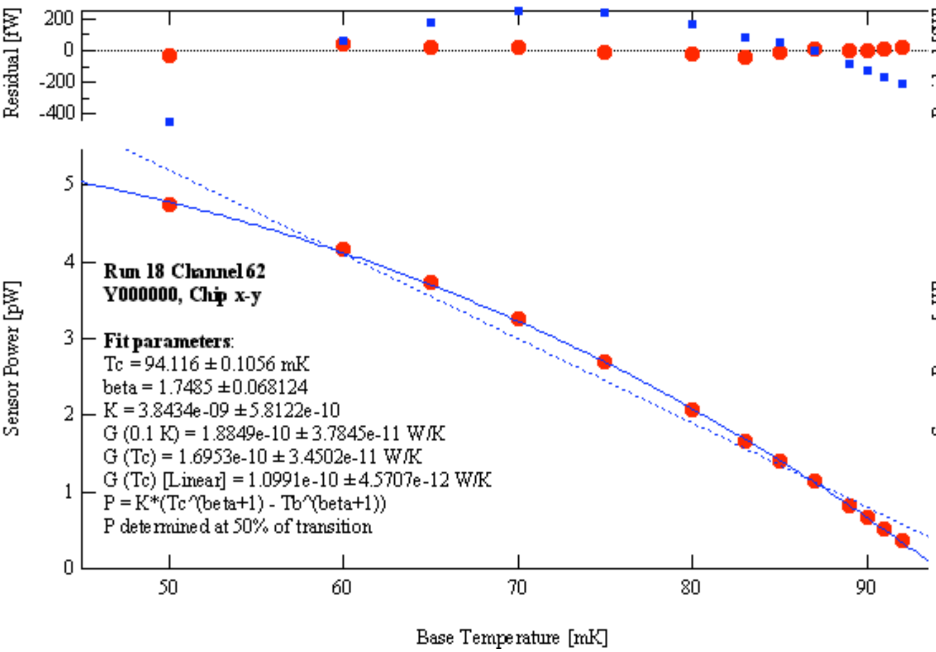
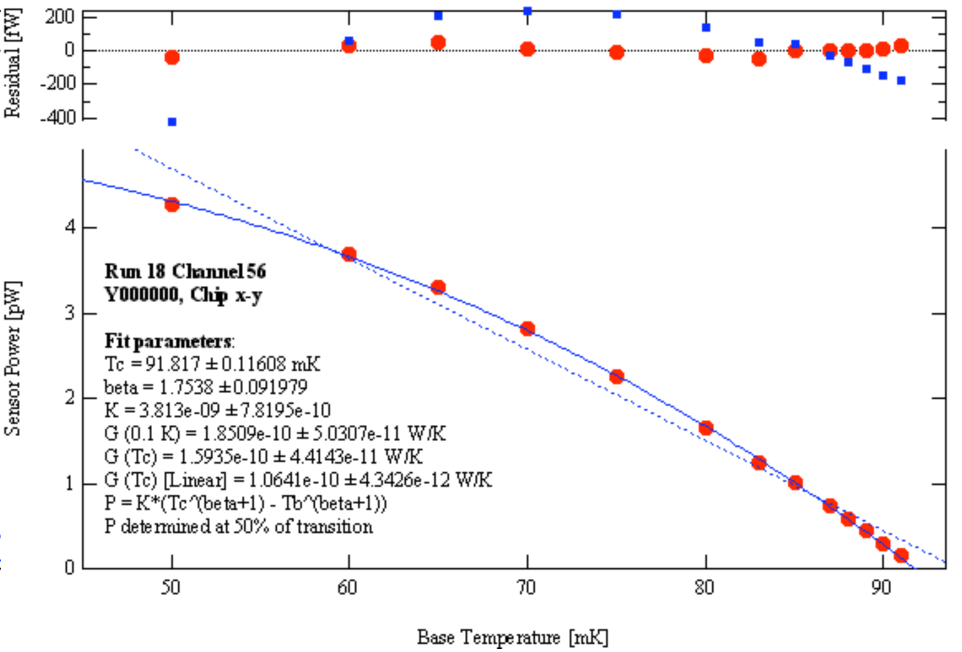


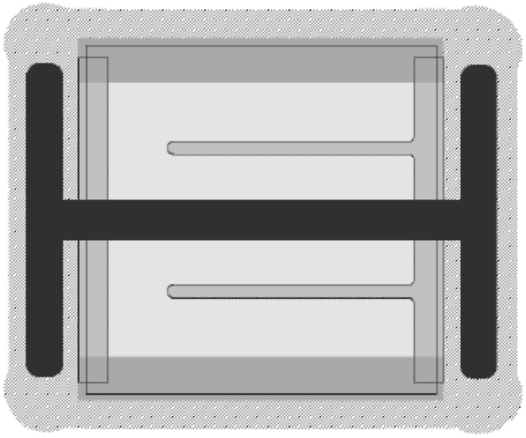


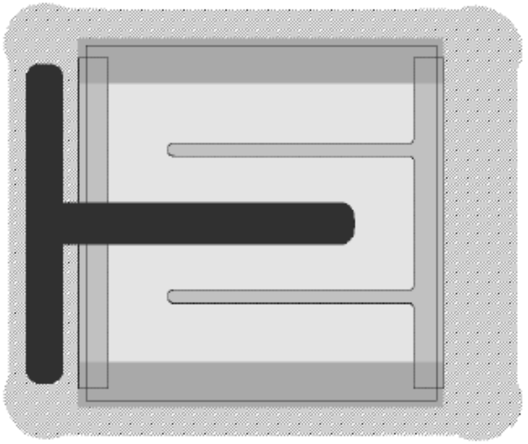


Thermal Conductance Measurements







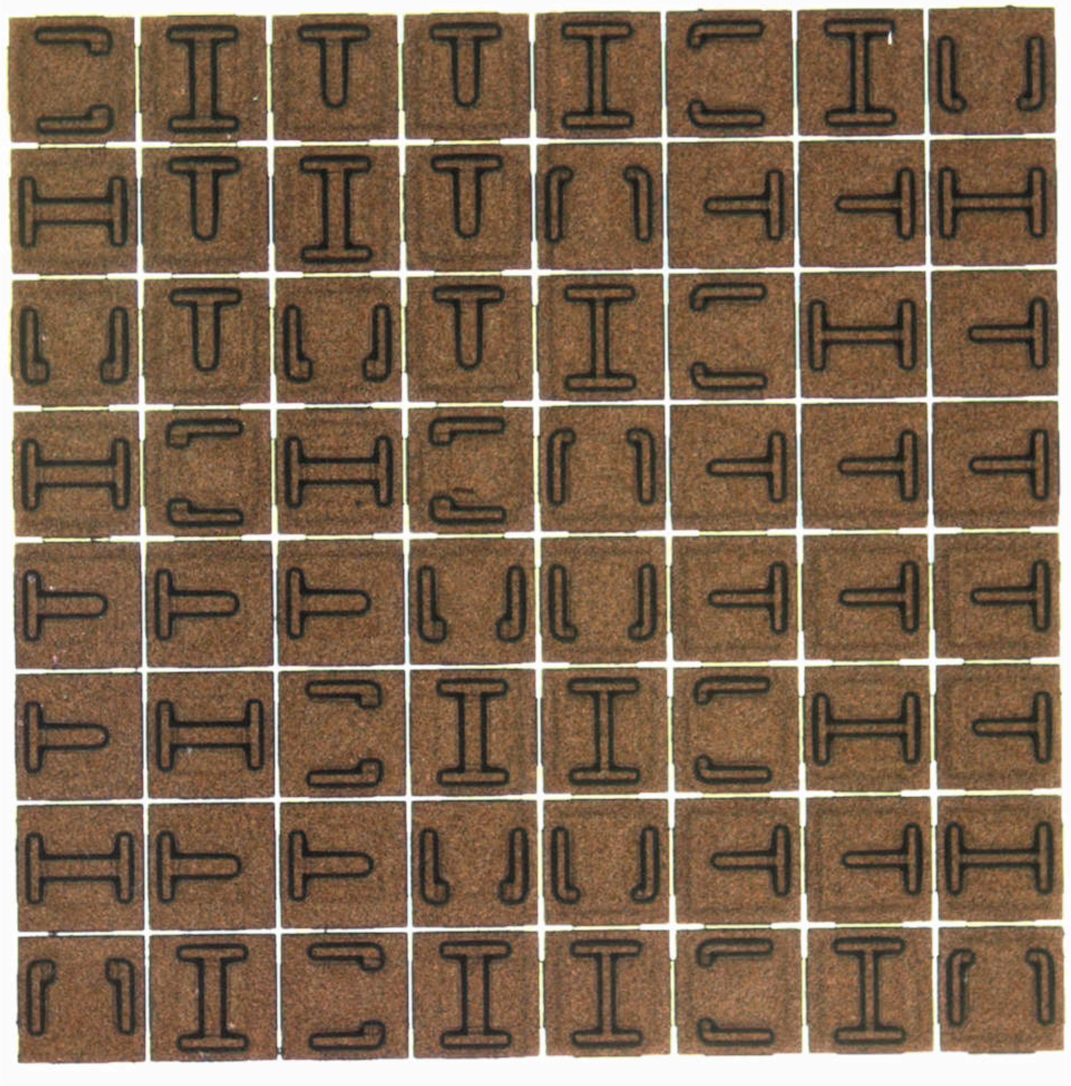


G(0.1) = 1.9 x 10^{-10} W/K for 1um membrane

–In range obtained for conventional design

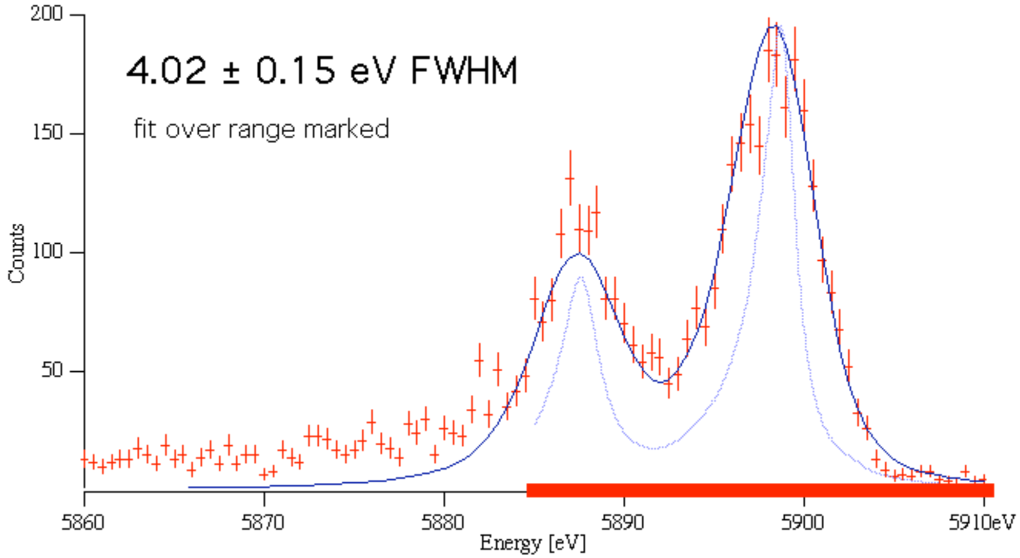
Vacuum Gap Arrays with BiAu absorbers

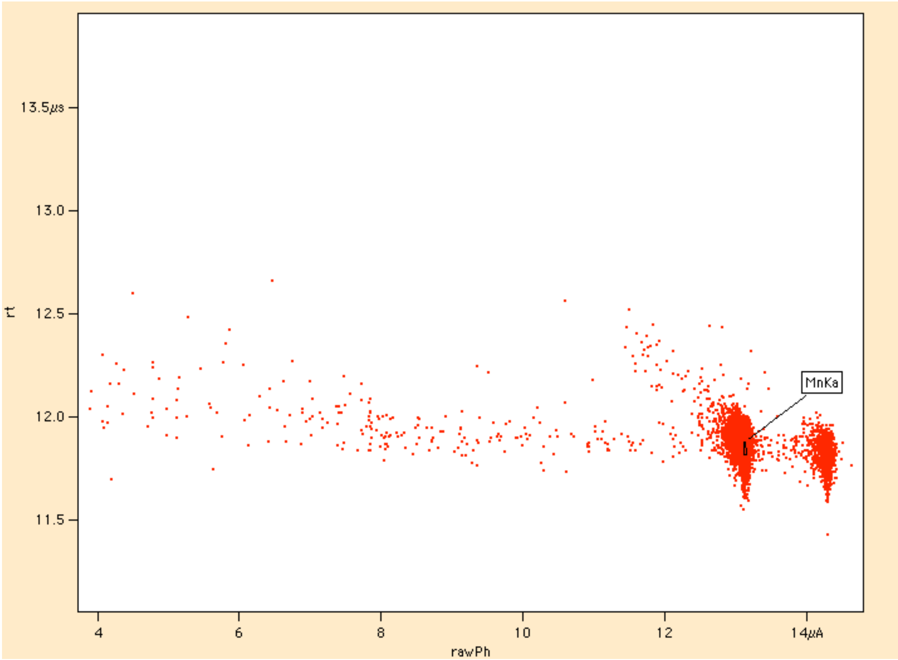
- Have made arrays with evaporated BiAu absorbers
- For fabrication details - see poster "Cantilevered X-ray Absorbers for Close-Packed TES Detector Arrays" – Ari Brown
- Investigating electroplated BiAu absorbers



Au/Bi results ("T" and "H" designs)

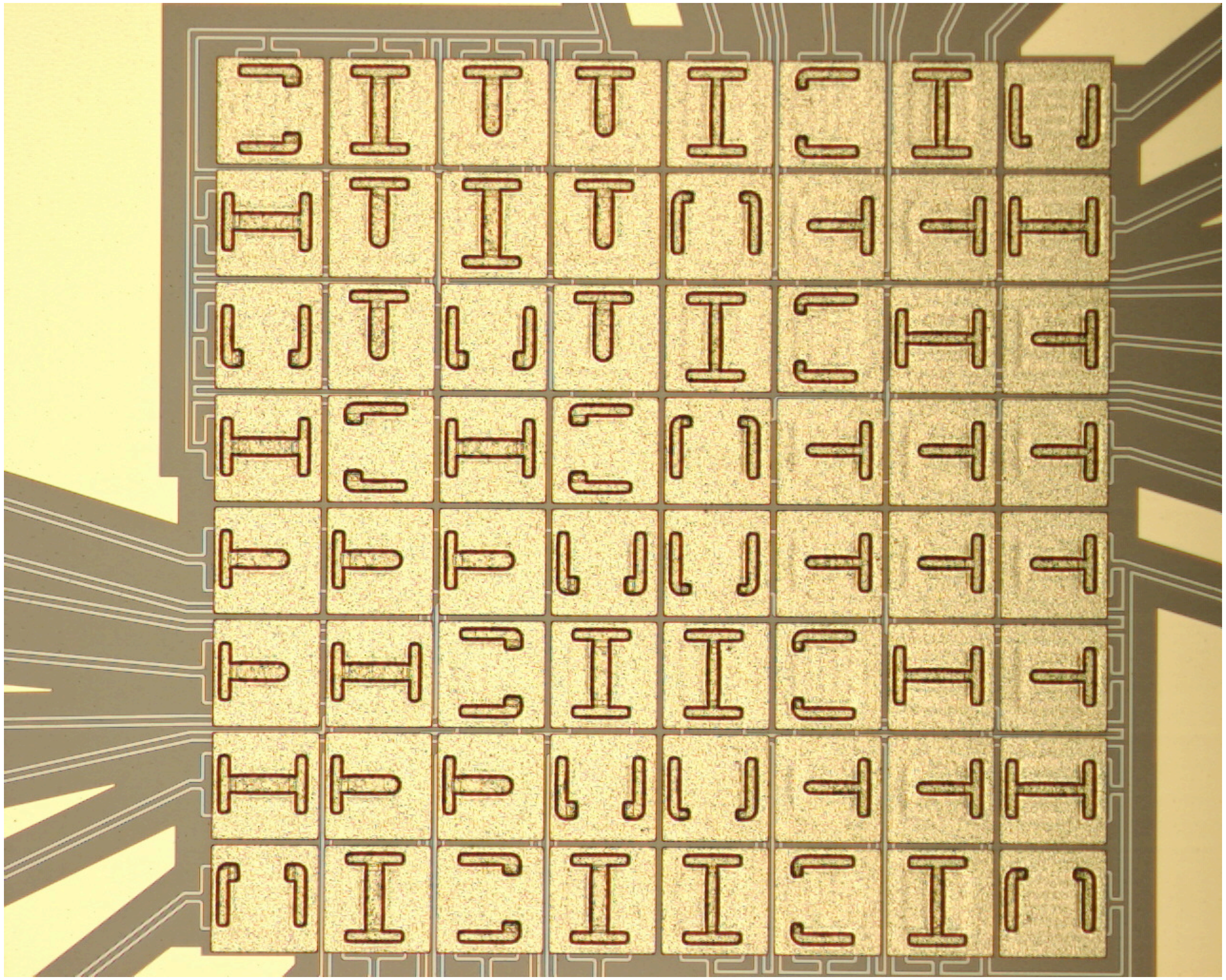
- Three devices with 4.0 - 4.5 eV resolution at 6 keV
  - ~15% of the counts in a low-energy shoulder
- All three spectra appear to have tails
- Arrays of TESs with BiCu absorbers showed no signs of tails.
- In both designs, so not consistent with loss to the membrane
  - Electrical conductivity factor of 2 higher than Bi/Cu/Bi devices
  - But extent of cantilevered regions much greater





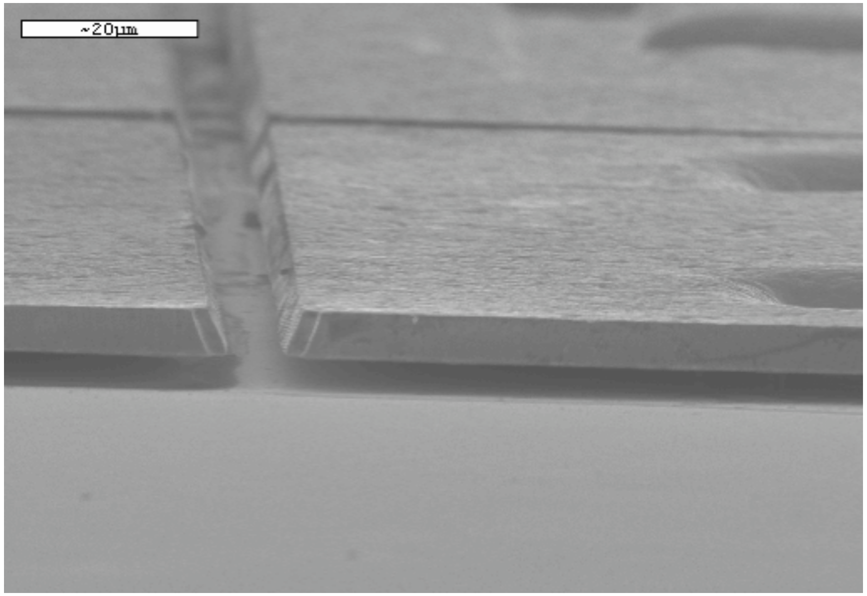
Gold Absorbers

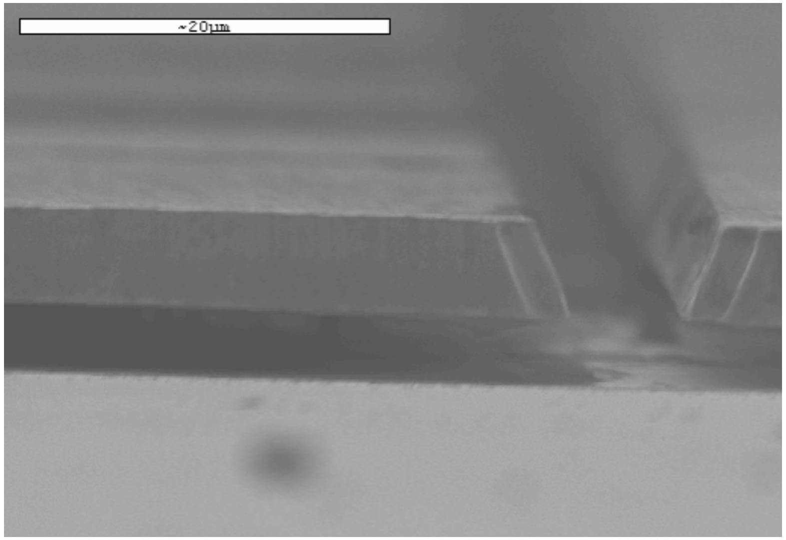
We have successfully fabricated "all-gold" absorbers with overhangs



- 0.2-μm evaporated Au seed layer
- 4 μm thick electroplated gold
- Ion-milled

See poster "Cantilevered X-ray Absorbers for Close-Packed TES Detector Arrays" – Ari Brown

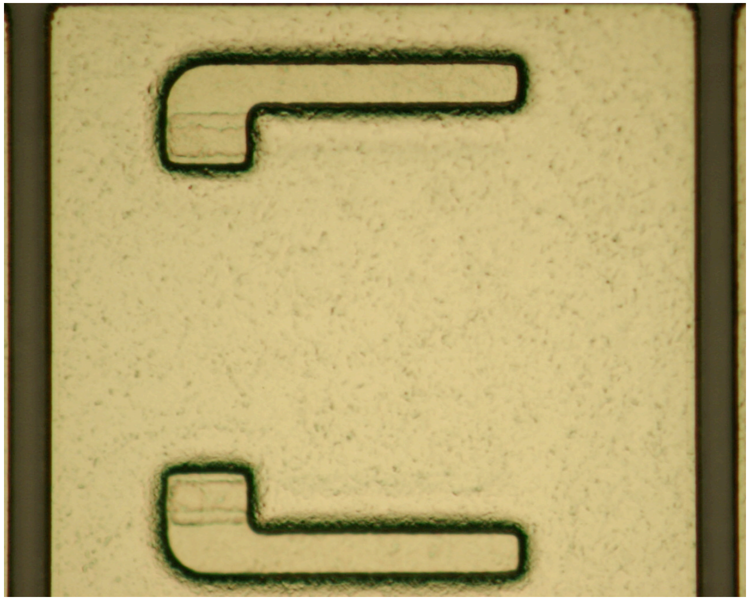




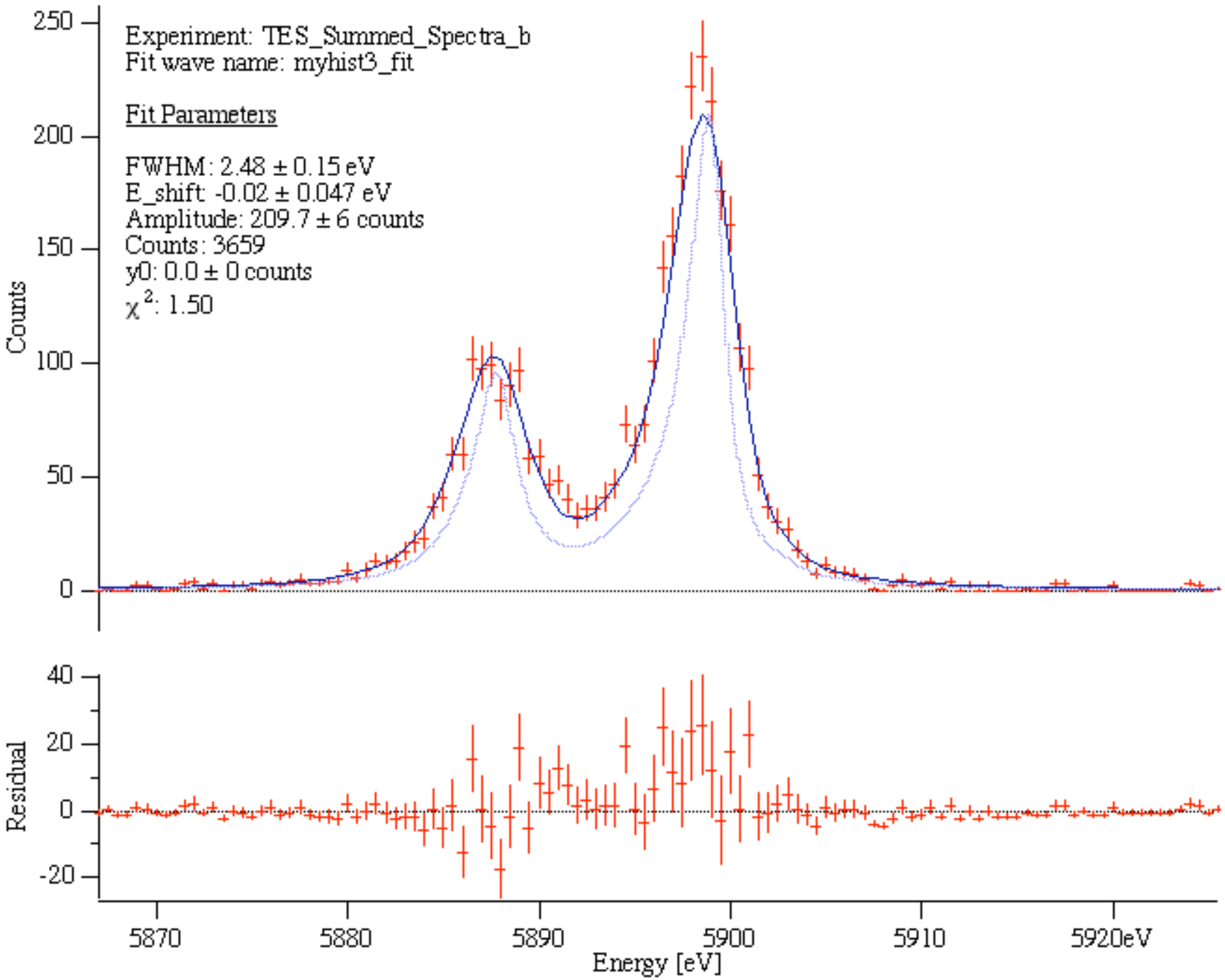
Gold RRR = 45

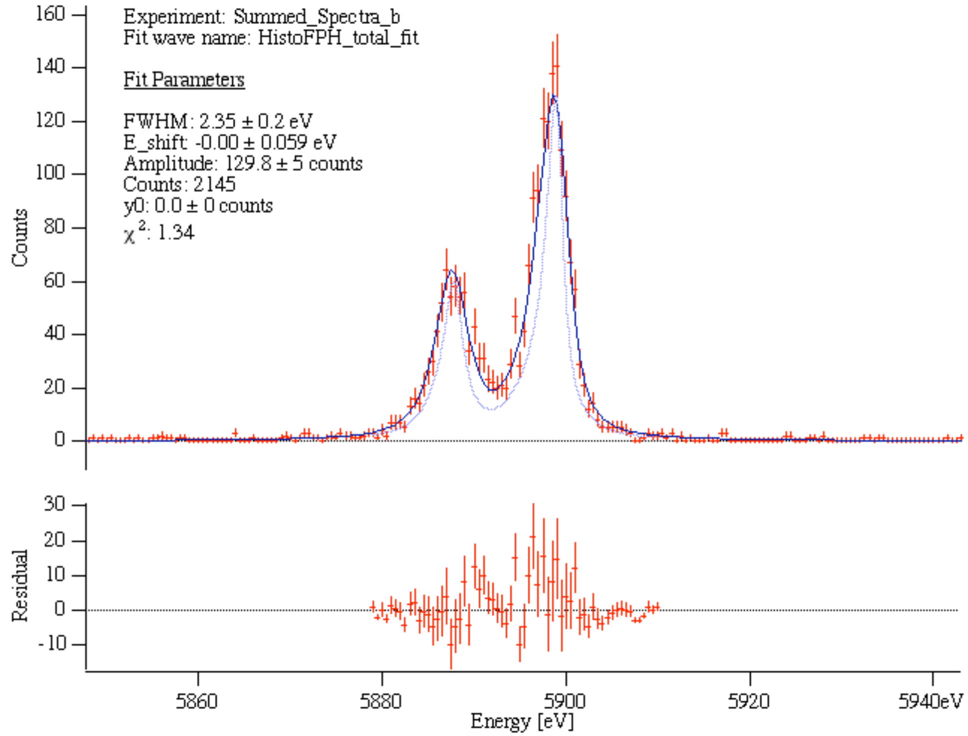
Grain size ~ 10 to 100 microns

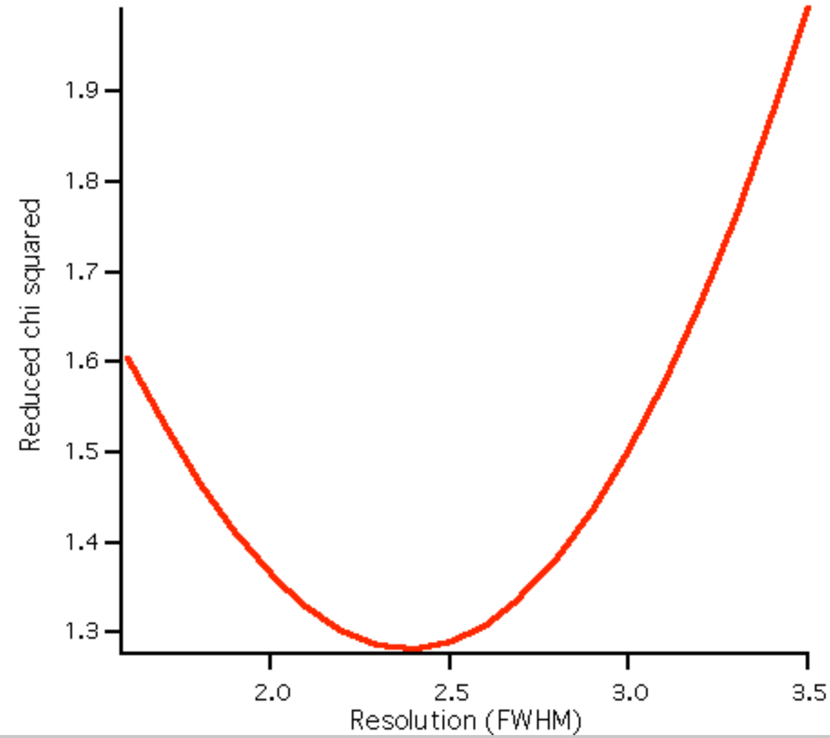
Factor of 4 higher heat capacity than other designs - offset by simpler and better behaved system



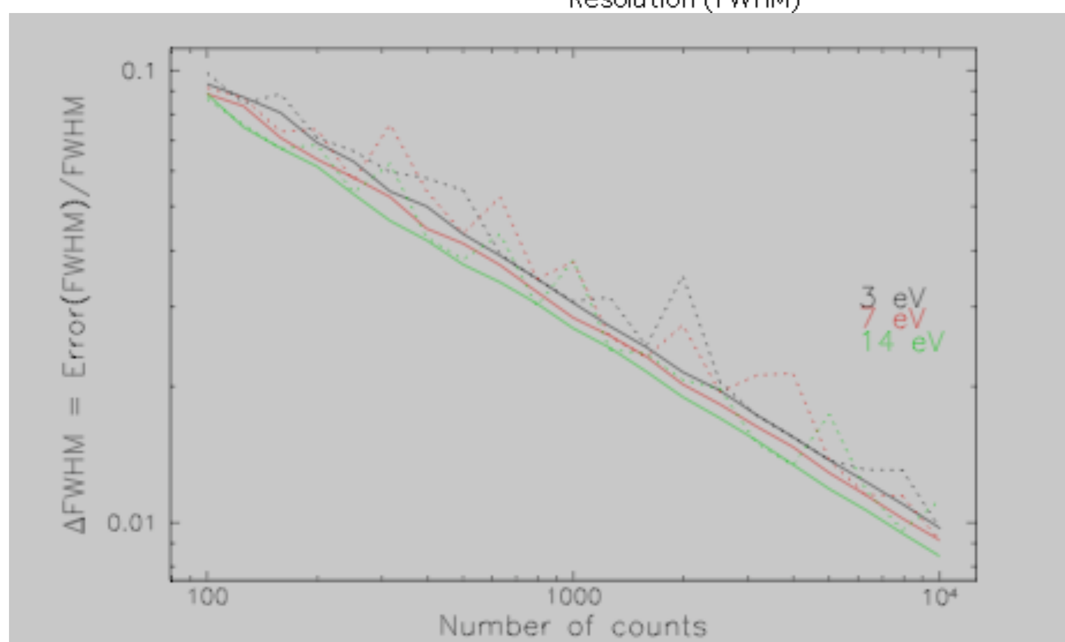
Initial results with gold absorbers encouraging - 2.5 eV +- 0.15 eV :



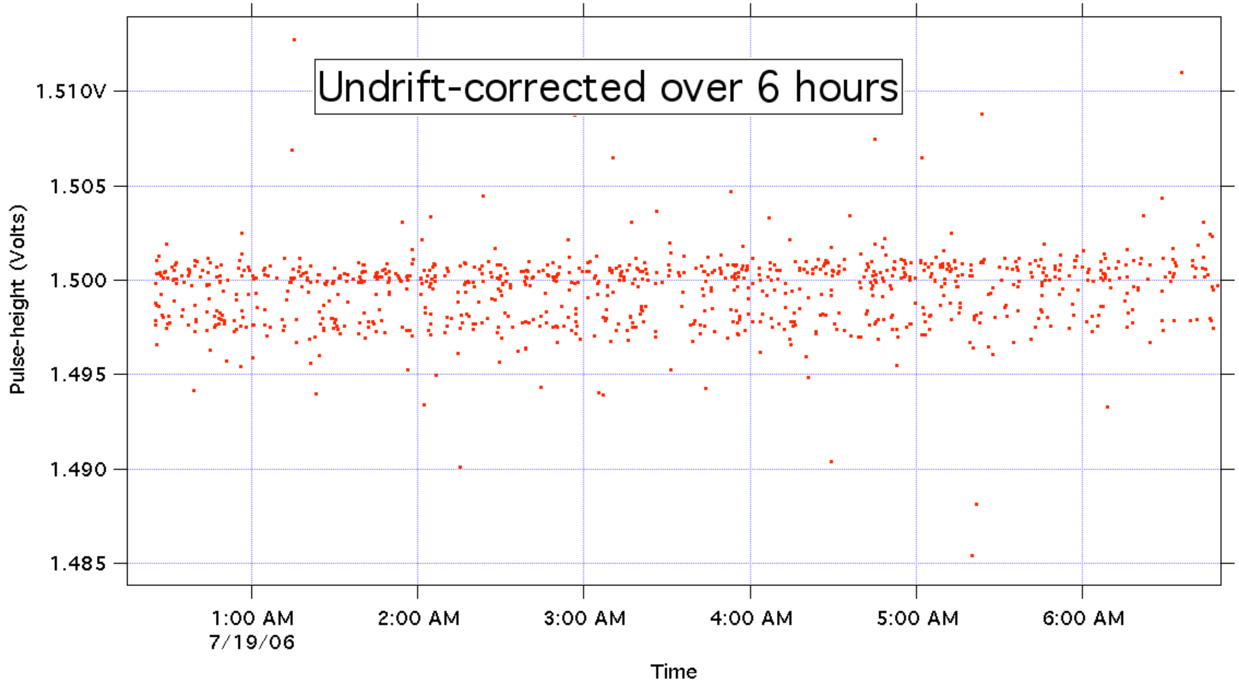




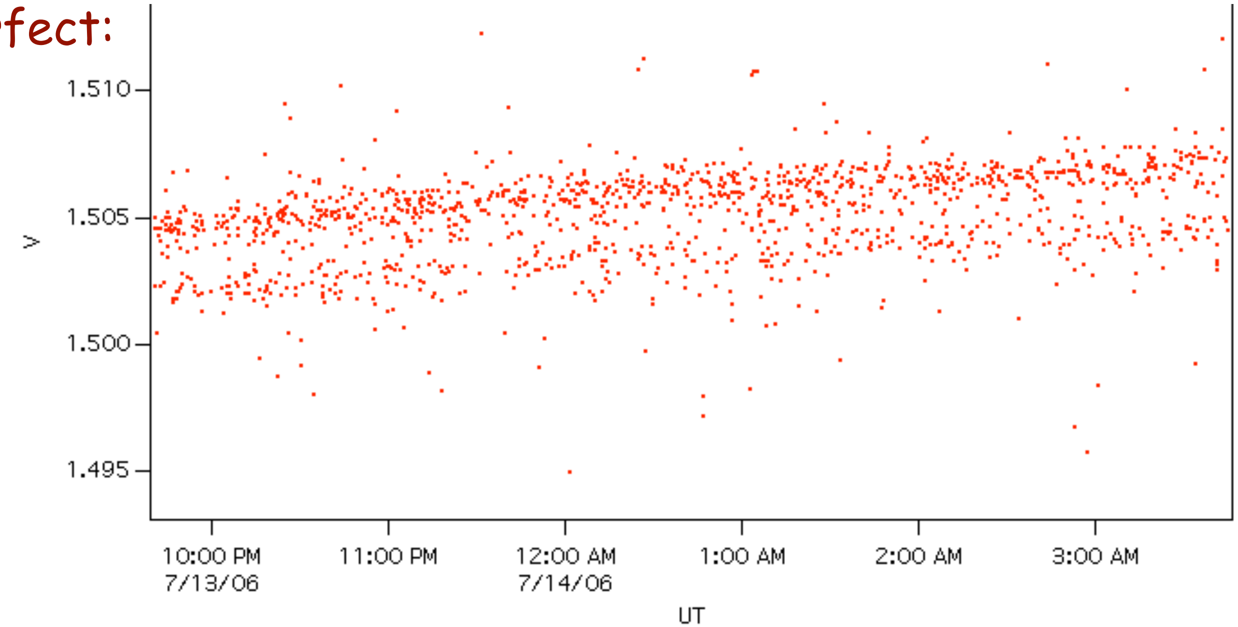
- 8 Lorentzian model for Kalpha lines
- Simulate data with Voigt profile for all lines, assuming either 3, 7, or 14 eV FWHM (Gaussian) and 0.5 eV bins
- Fit data, allowing only FWHM to vary, using CASH statistic (takes into account low counts)
- Solid line is shows error range on error (1 sigma)



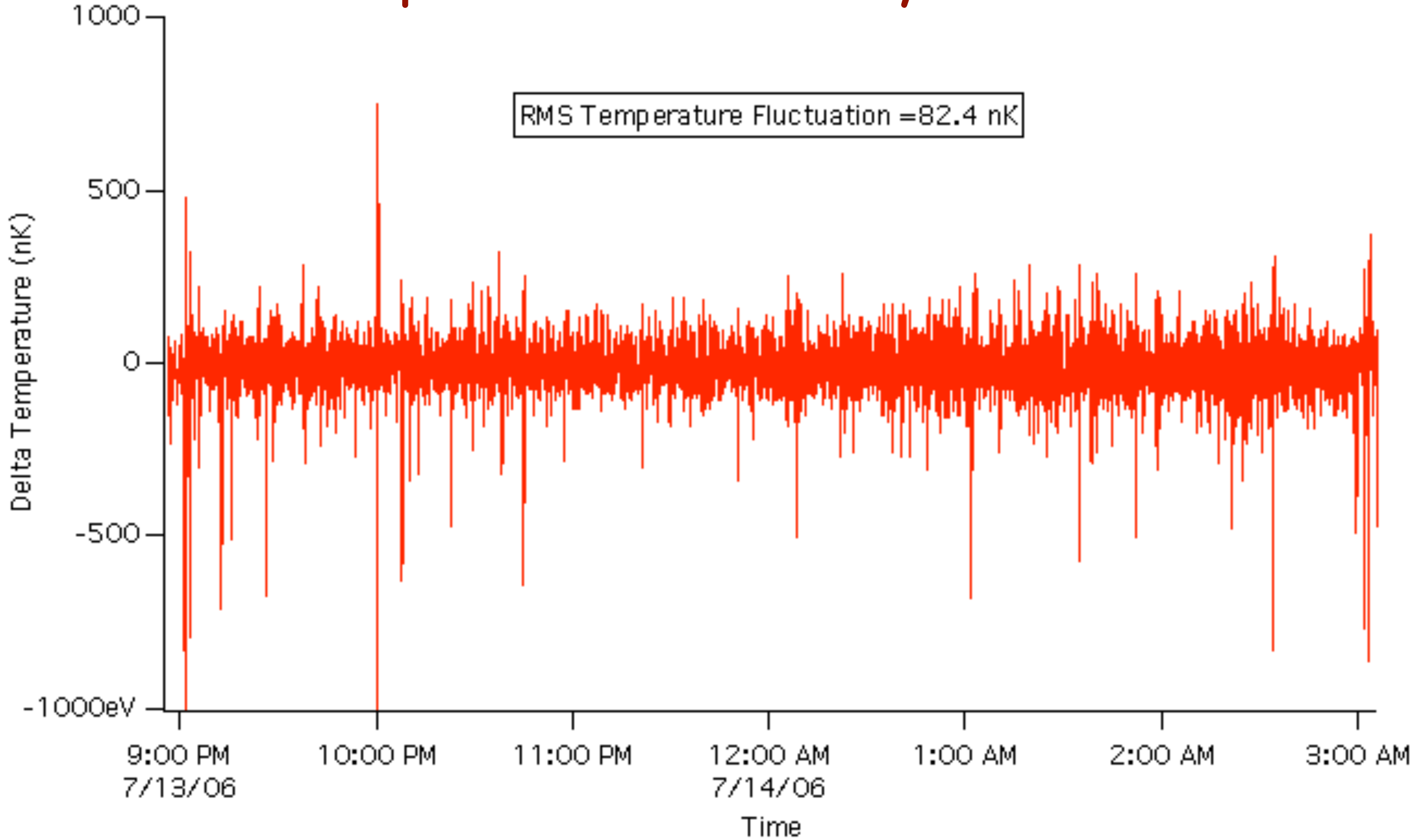
Gain Stability :



Not always perfect:

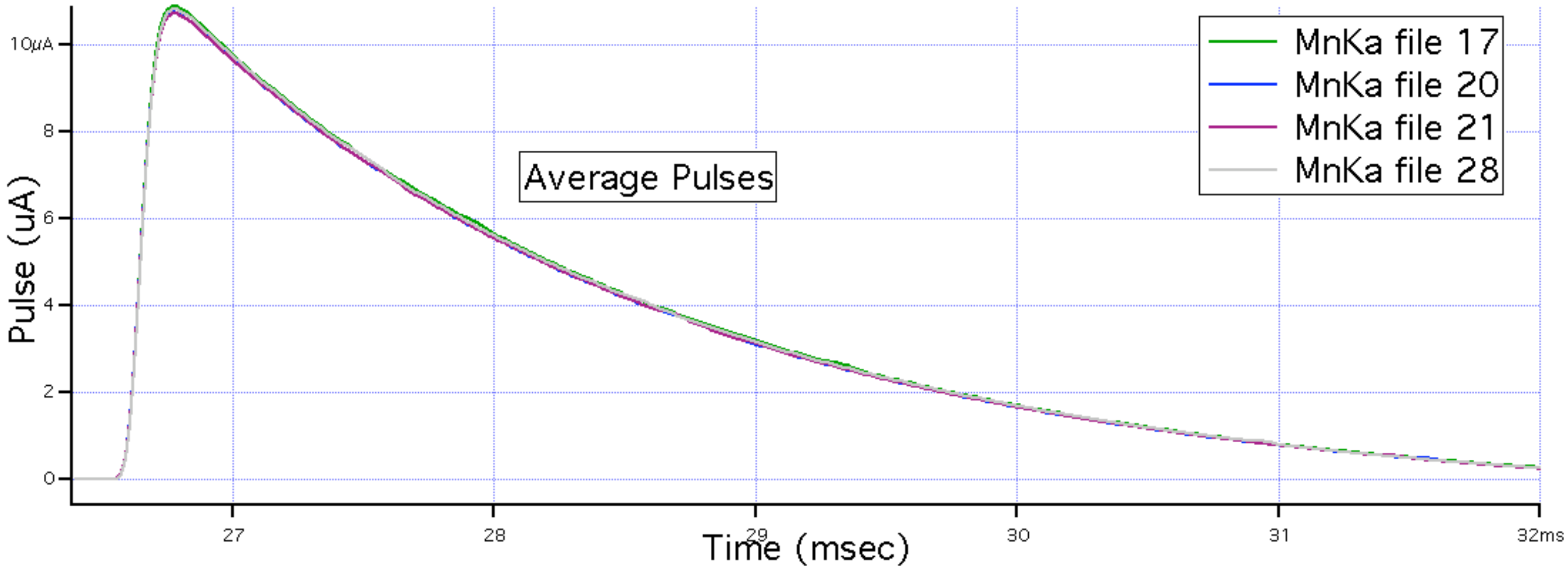


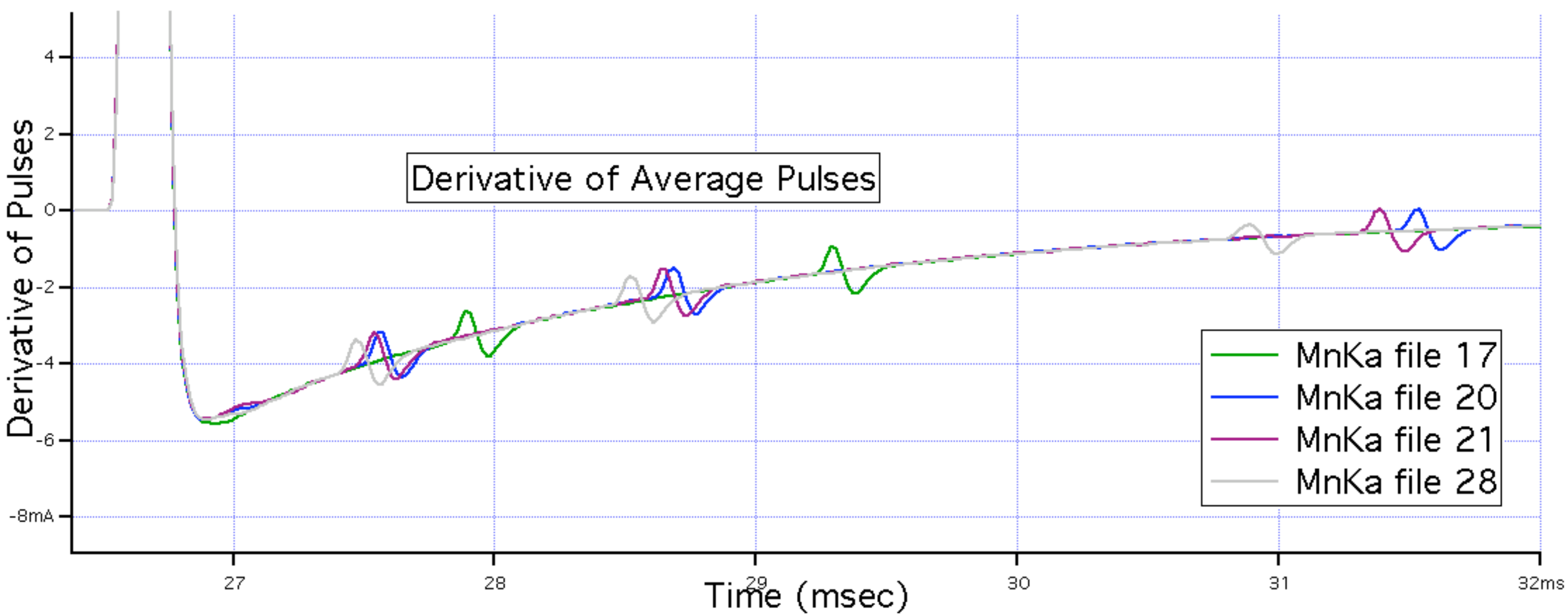
Temperature Stability :



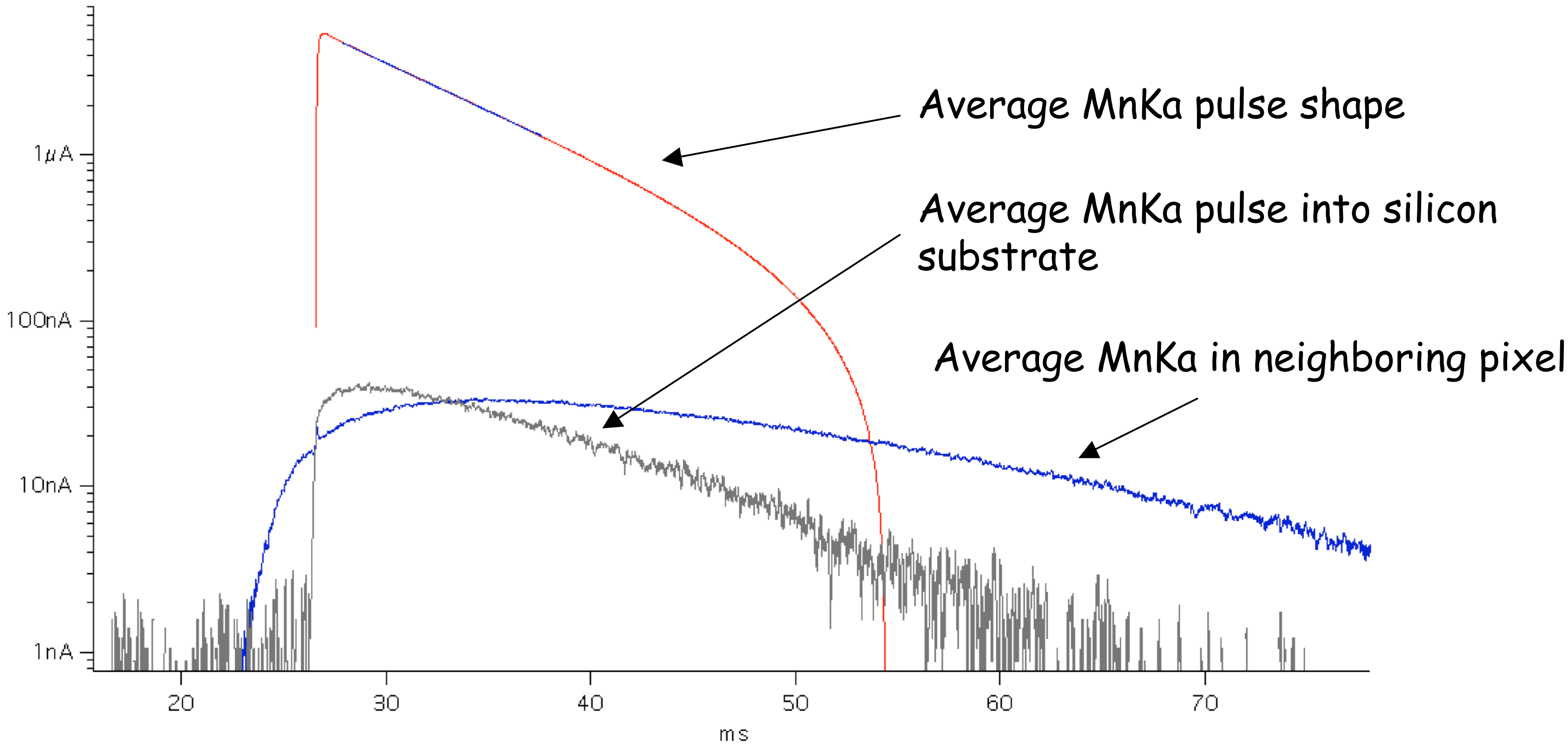
- Temperature stability ~80 nK rms at 50 mK
- Thermometer: GRT
- With temperature "spikes"
- As sensitive as ~ 1 eV per uK
- Typically veto pulses if temperature spike is greater than 2 uK.

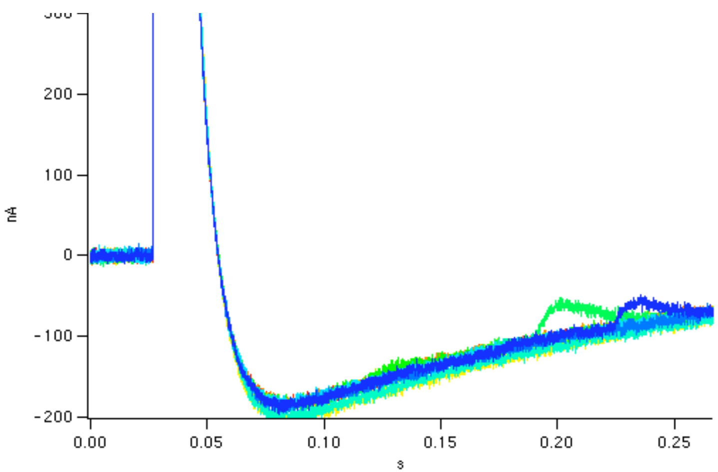
Small, minor "blips"





Thermal Cross-talk





Examples of a few individual thermal cross-talk events

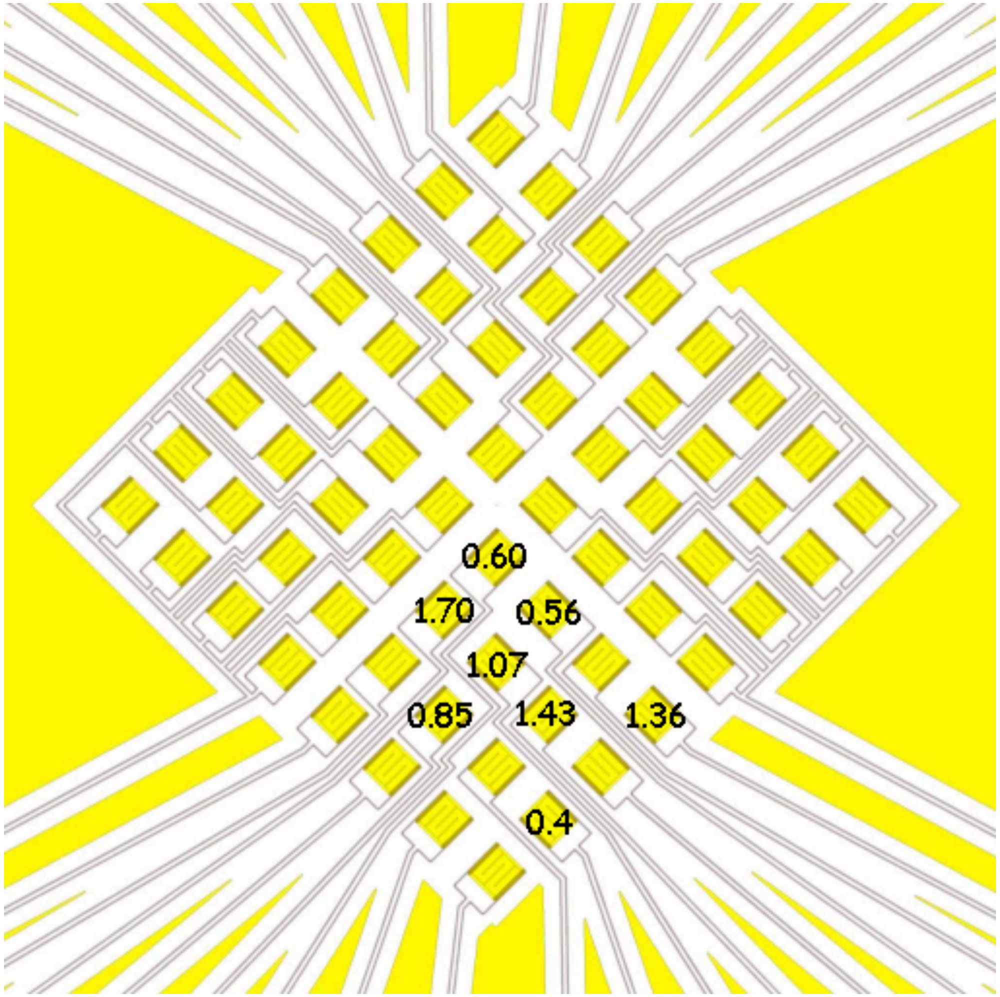
Characterization :

- Devices with bismuth and gold absorbers have been fully characterized

- For details see talk tomorrow:

"Characterization of x-ray microcalorimeters for Constellation-X" - by Naoko Iyomoto

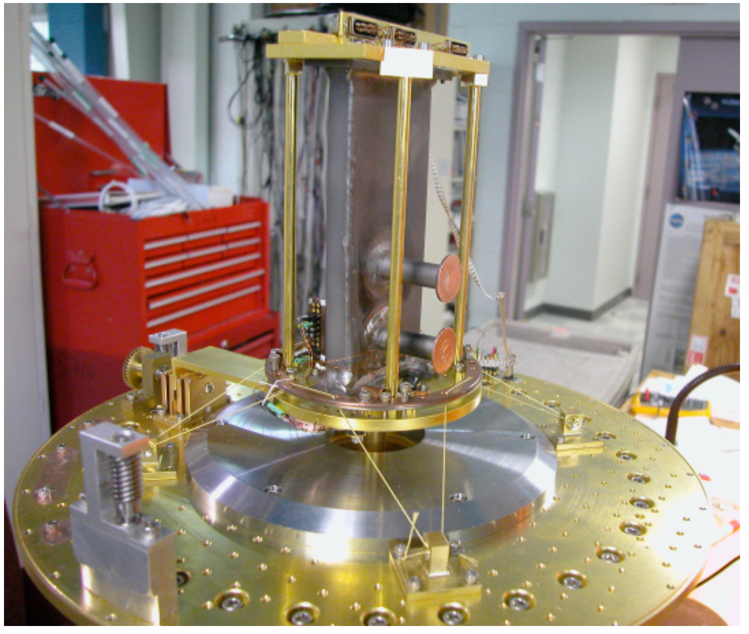
Magnetic field dependence for this array

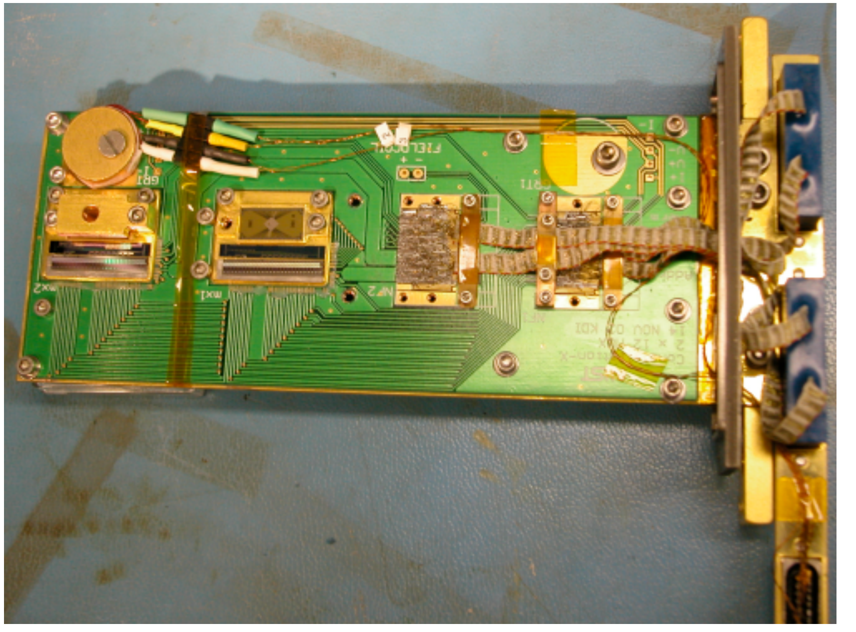


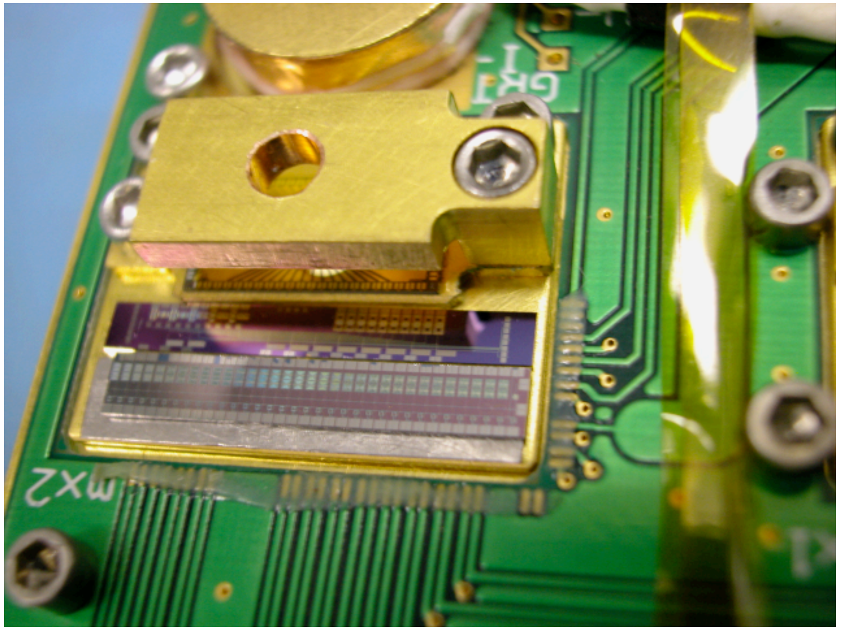
Optimum field : Units=Gauss
TES pitch = 250 um

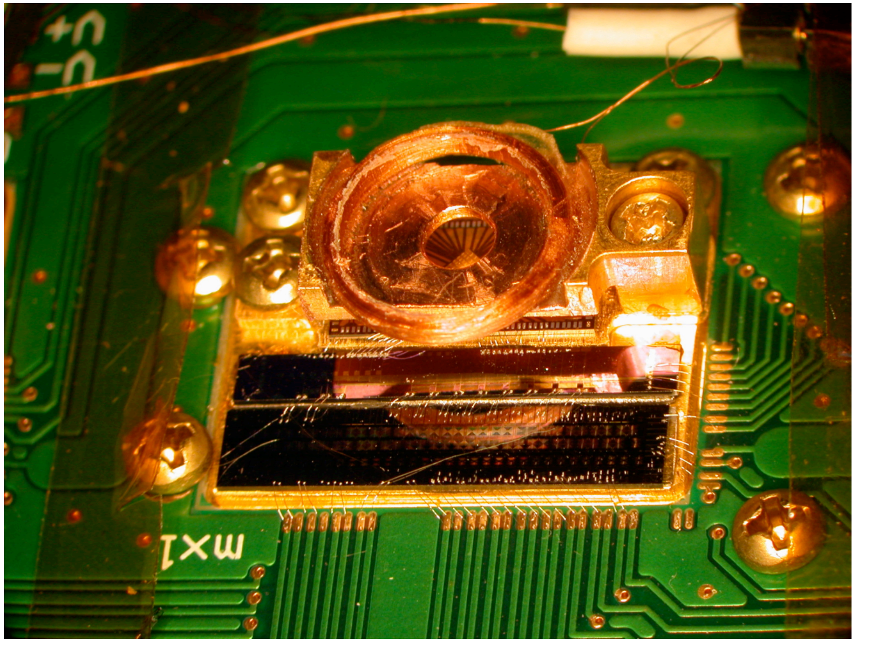
- Without magnetic field, Tc variable, and transitions "kinky"
- Maximum Tc (=78 mK) from varying magnetic field
- Spatial variation of field required to maximize Tc steeply varying
- Field always in one direction
- Without cancellation fields, Tc ~ 63 mK to < 45 mK
- TES arrays without absorbers have uniform Tc = 78 mK
- Local field in Nb box typically <10mG

Pictures of experimental set-up:

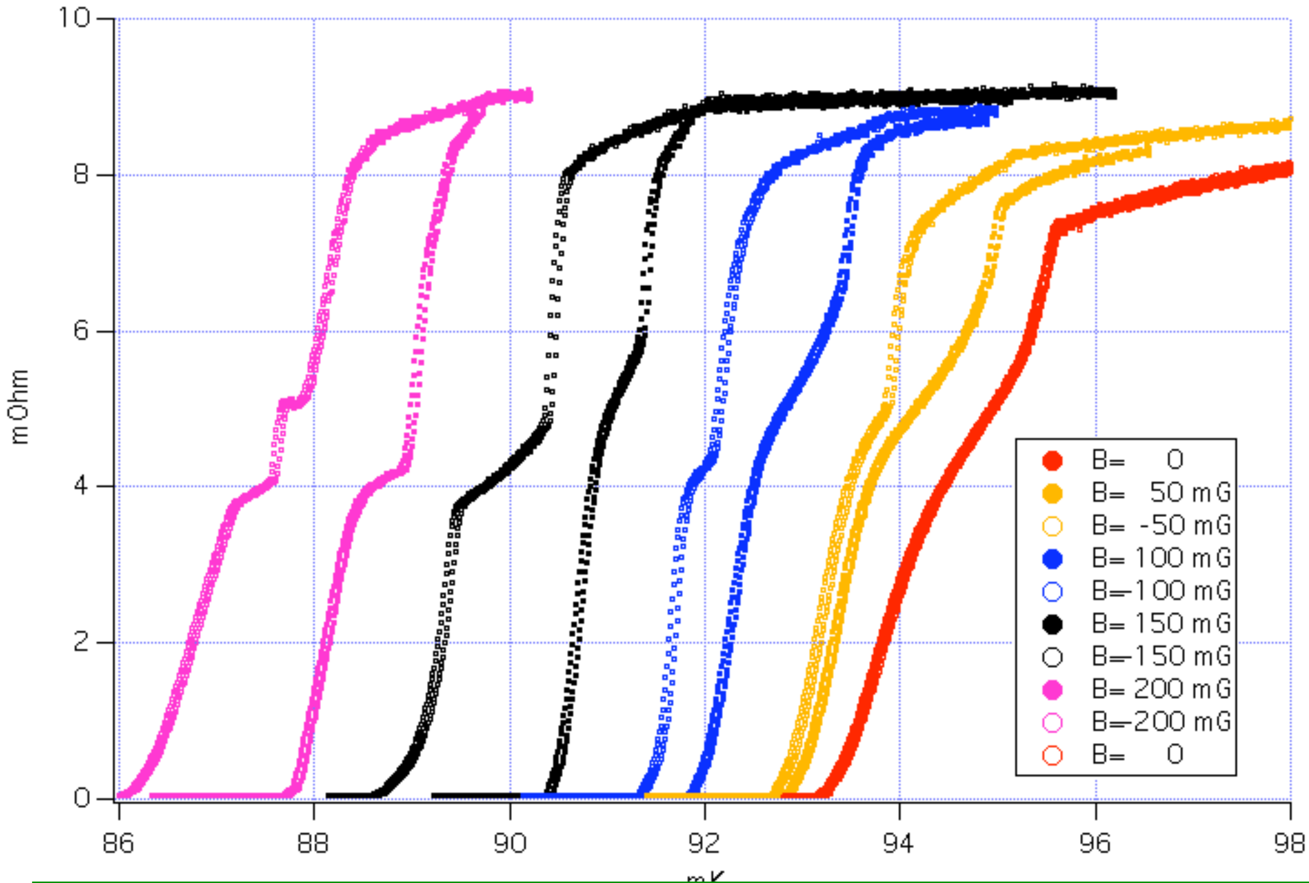








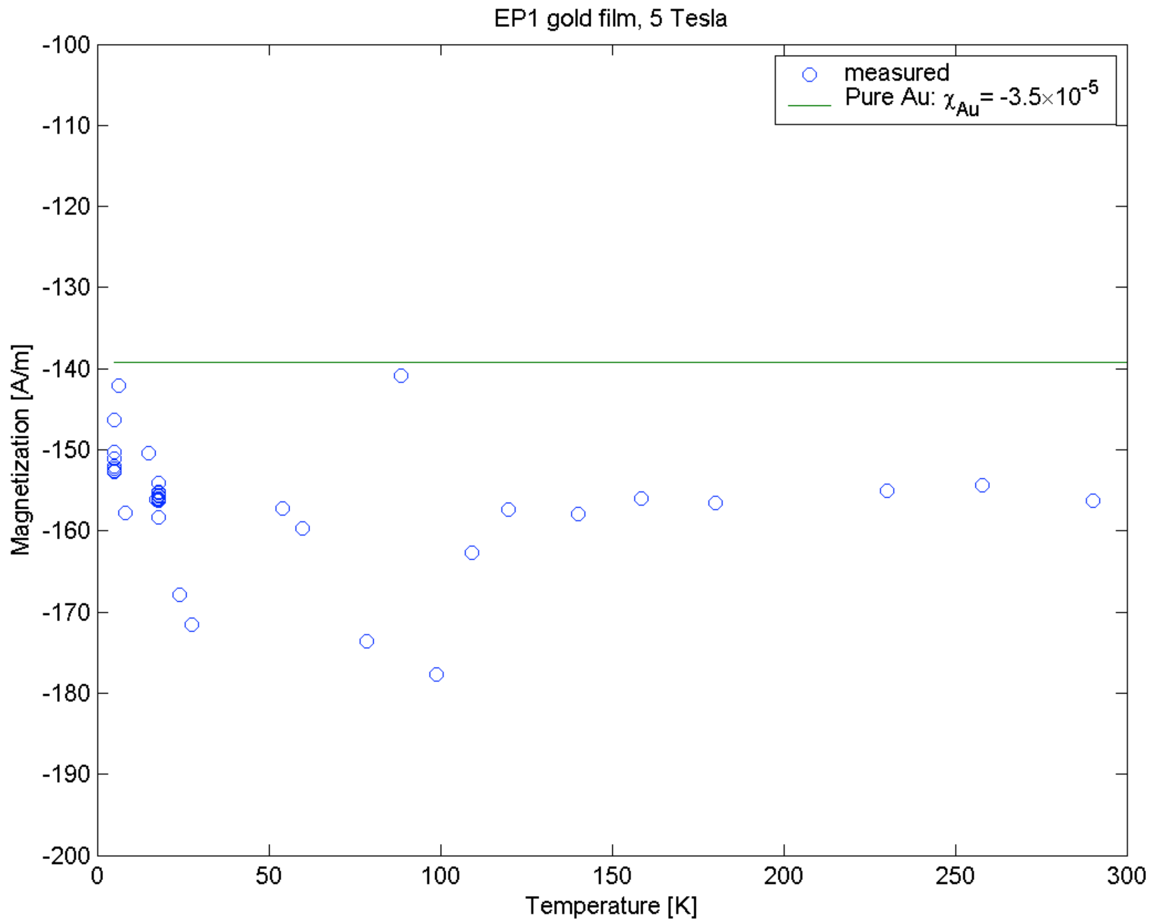
Field dependence of Tc with pixels with bismuth absorbers :



- Transition shapes tends to vary with field
- Residual field < ~ 10 mGauss
- Tc shifts ~ 1 mK / 40 mGauss
- Tc shift amidst previous gold array consistent with ~ 1 Gauss !

No measurable ferromagnetic impurities:

Magnetometer measurement:



Also : No ferromagnetic impurities seen during X-ray Photoelectron Spectroscopy (XPS) analysis (< 0.01%).

Purity of electroplating solution - 4 9's

But ……

- For H=1 Gauss at a distance ~ 1 um away from an absorber a cluster of ~ 5×10^7 spins are needed.

- This requires the iron concentration in this region is about 1 part in 10^7 - undetectable in the XPS measurement.

- Magnetization of the bulk electroplated gold from this spin concentration ~ 10^{-4} cgs, or 0.1 A/m

  << diamagnetic magnetization of conduction electrons in a field of 5 T - by 3 orders of magnitude

- Magnetic stirrer used in electroplating solution

- Magnetic “particles” found near electroplating set-up

Ferromagnetic impurities are the likely cause of inhomogeneous magnetic fields amidst array

Conclusions:

New attachment technique between TES and absorber has been successful

Arrays with gold absorbers have demonstrated excellent energy resolution at 6 keV

Apparent inhomogeneous magnetic field amidst array - origin believed to be understood

Next steps :

Eradicate field inhomogeneity

Add heat-sinking gold (in preparation)

Important principle :

Link between absorber & thermometer

- Can mask effects of position dependent thermalization in absorber
- Adds thermal fluctuation noise

Noise from a decoupled absorber high for TES's

- is more important for higher α devices with most the the heat capacity in the absorber

⇒ Link between the absorber and thermometer tuned to the absorber thermalization time

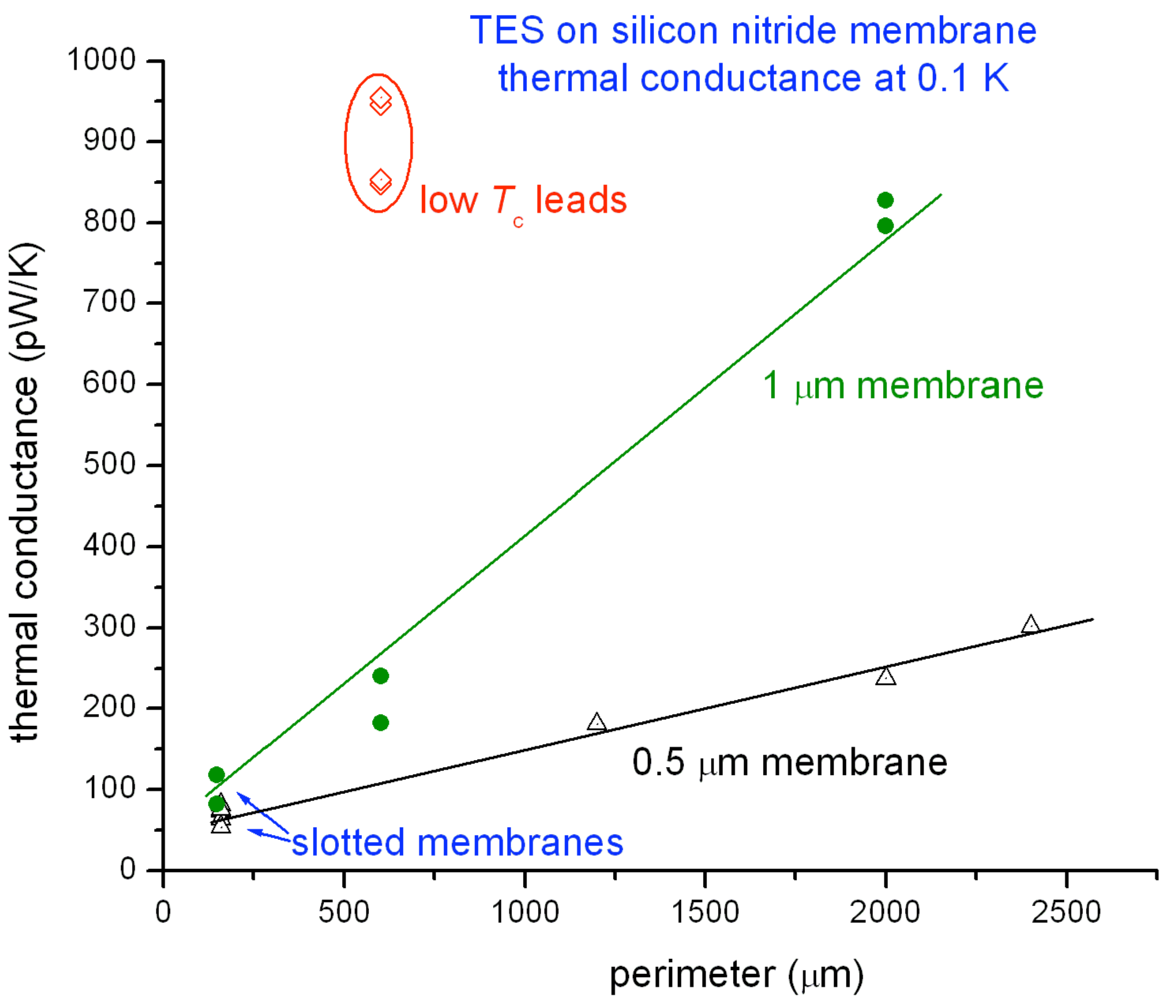
Leads

Mo/Au only in region of TES + Nb overlapping contacts
adequate step coverage difficult - low R contacts

Mo/Au in TES and leads + extra Mo added to leads to increase T_c
Trilayer T_c too low - electron thermal conductance too high

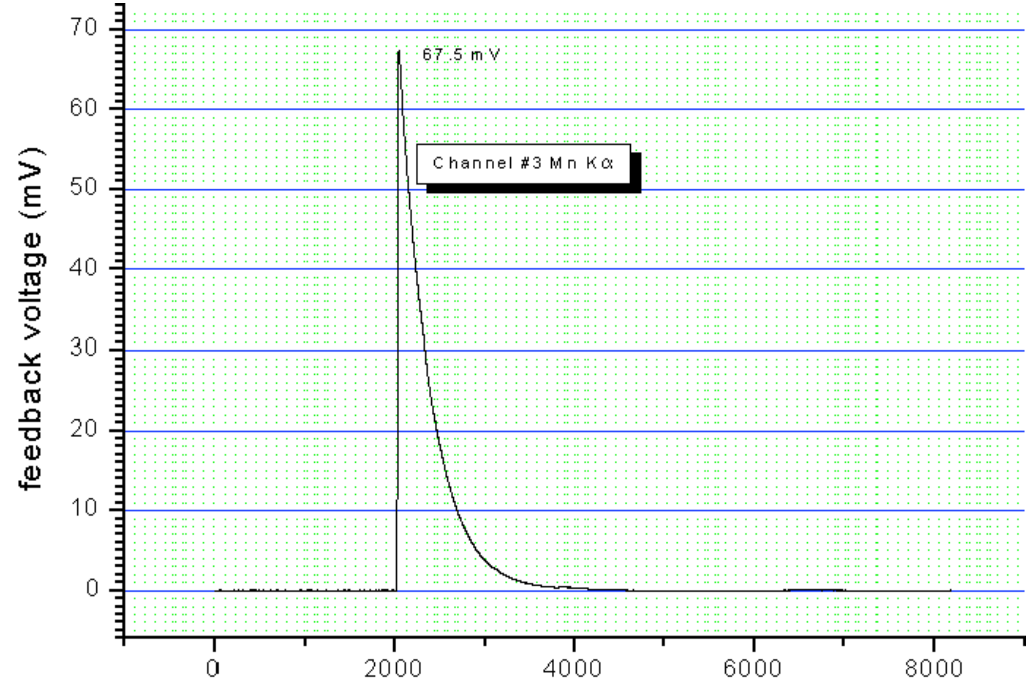
Mo/Au in TES and leads - Au removed from contacts using ion mill.
Works well !

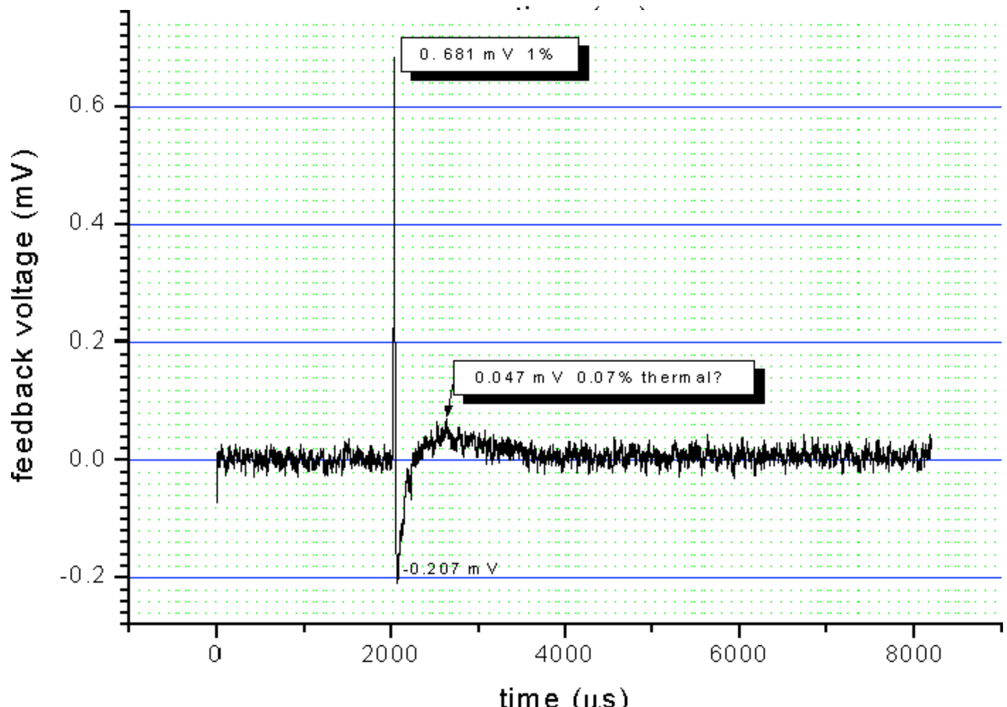
Thermal coupling & perimeter



Crosstalk in 5x5 arrays

- Thermal crosstalk < 1/1000
- little electronic crosstalk in band
- Averaged hundreds of measurements to see crosstalk





Thermal crosstalk in recent 8x8 arrays:

* Highest crosstalk observed in center pixels	~1.3% - High !
* Lowest crosstalk observed in edge pixels	~0.15%
* 2nd nearest neighbor crosstalk	~0.03 %
* 3rd nearest neighbor crosstalk	~0.01 %