Microcalorimeter absorber optimization for 0.2 to 12 keV x-rays

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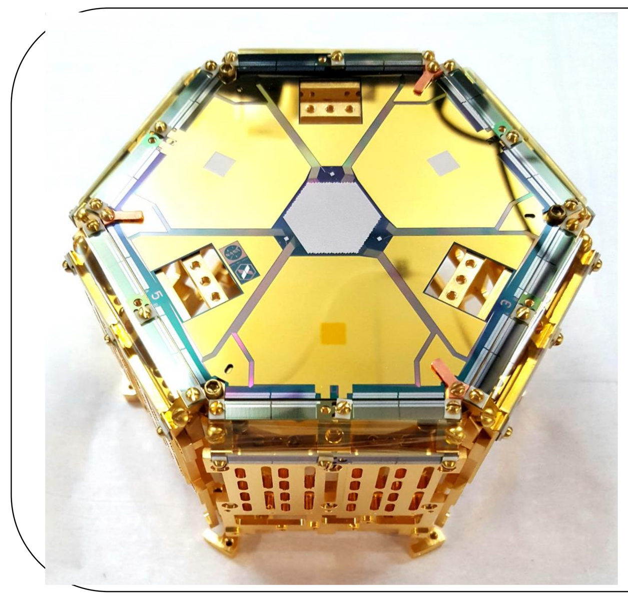
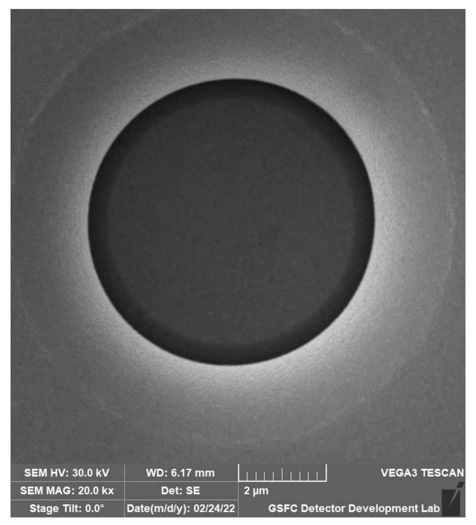
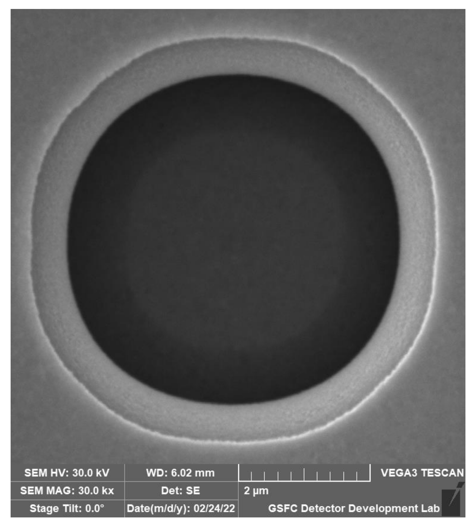
ABSTRACT

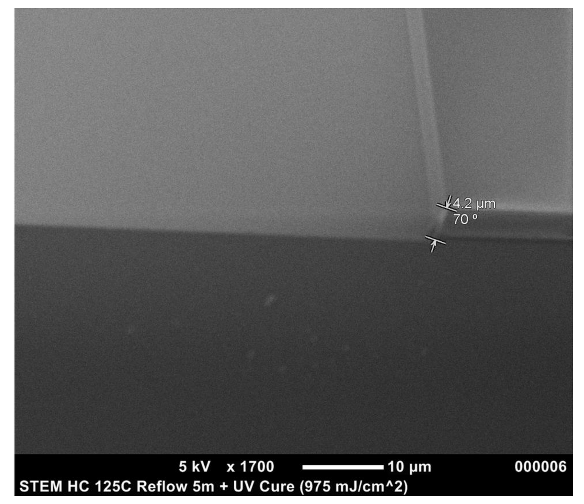


The Advanced Telescope for High ENergy Astrophysics (ATHENA) mission requires high quantum efficiency (QE) x-ray absorption, >90.6% at 7 keV and low specific heat capacity, 0.731 pJ/K. The designed ATHENA x-ray absorbers are cantilevered square tiles (pitch of 317 microns) of 1.05 μm thick Au and 5.51 μm thick Bi electroplated films supported by stems that connect the absorber to the detector below. This work will focus on the design and performance of cantilevered absorbers.

TUNING THERMAL CONDUCTANCE







To tune the thermal conductance of the device and the effect on the normal-to-superconducting transition shape, the stems need to be small diameter and can have a weak bottle-neck connection to the substrate. A funnel shape of the stem using a proximity exposed photoresist mold has been developed to improve the strength of the connections.

Fabrication Flow

- Coat TES and circuit with sacrificial resist
- Pattern stems to cantilever absorbers to TES and evaporate Ti/Au as a seed layer.
- Electroplate 1.0 um Au over entire wafer
- Electroplate 5.1 um Bi over entire wafer
- Pattern streets in thick photoresist and ion mill to define absorber pixels
- Strip photoresist in O_2 plasma

ATHENA QUANTUM EFFICIENCY MILESTONE

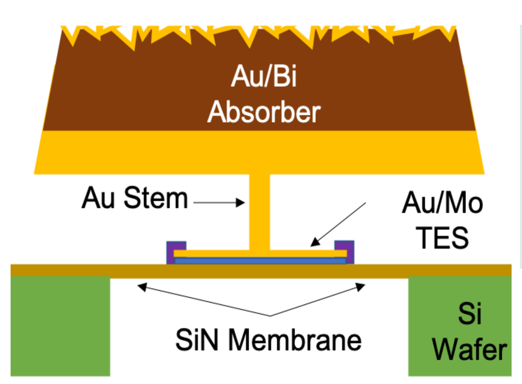


Fig. 1 A diagram of a GSFC TES pixel. Au/Bi absorber is attached to a Au/Mo TES which is suspended by SiN membrane. The absorber has a trapezoidal shape and a rough surface. A thin Au capping layer is added to improve reflectance at 1-20 μm wavelength range.

Athena pixels are being designed to provide full-width-half-maximum (FWHM) instrument energy resolution of ΔE_{FWHM} = 2.5 eV at 7 keV. The total QE requirements for X-IFU are currently 96, 87 and 63% at 1, 7, and 9.5 keV respectively. This includes both the vertical QE and the areal filling factor. To achieve both requirements, Au/Bi absorbers have been chosen to achieve a total pixel heat capacity between 0.8 – 1.4 pJ/K where 1.0 μm Au determines the heat capacity and 5.1 μm bismuth provides the vertical stopping power to capture x-rays of the desired energy.

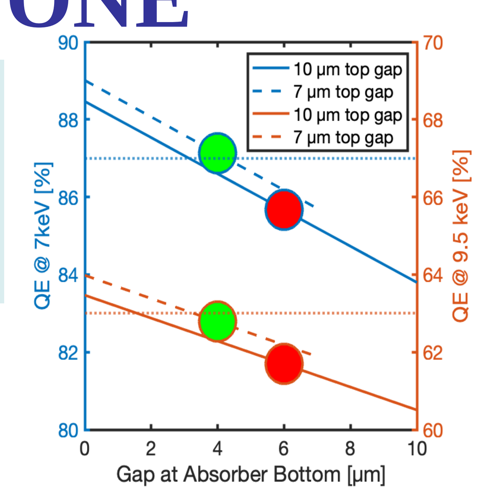


Fig. 2 Quantum Efficiency Requirements for Athena can be met with trapezoidal shaped absorbers and 4 micron gaps between pixels.

Select References and Acknowledgements

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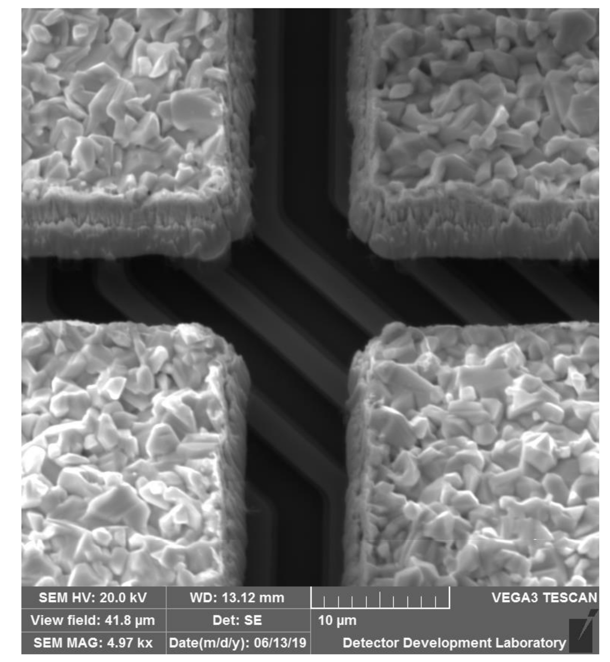
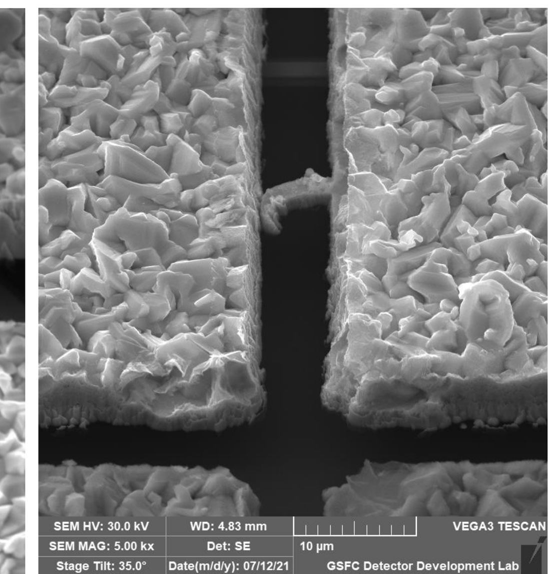
Further requirements on the absorbers include low levels of fine particulate remaining on the substrate after production and zero shorts between absorbers due to incomplete ion milling or trapped fine particular between absorbers. To optimize for post patterning substrate cleanliness and absorber yield, we have examined several methods of absorber fabrication. Three such methods are 1) an ion mill/wet etch combination, 2) a photoresist mold for electroplating followed by wet or dry etch to remove the seed layer, and 3) an electroplating process with leveling to smooth the surface followed by ion mill to separate the absorbers. Because the wet etched experiments were leading to energy resolution degradation through chemical contamination of the bismuth, we only report on the other two methods.

1. Long Ion Mill





Fabrication Flow

- Coat TES and circuit with sacrificial resist
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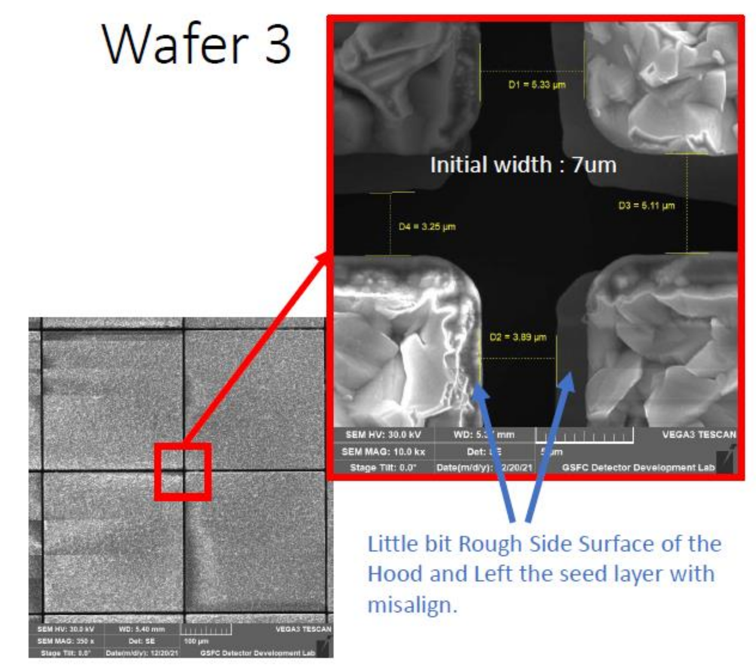
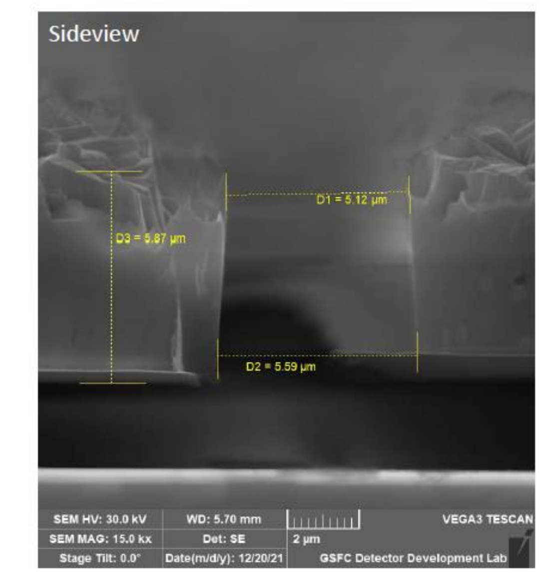
- Strip photoresist in O_2 plasma

2. Plating through Mold

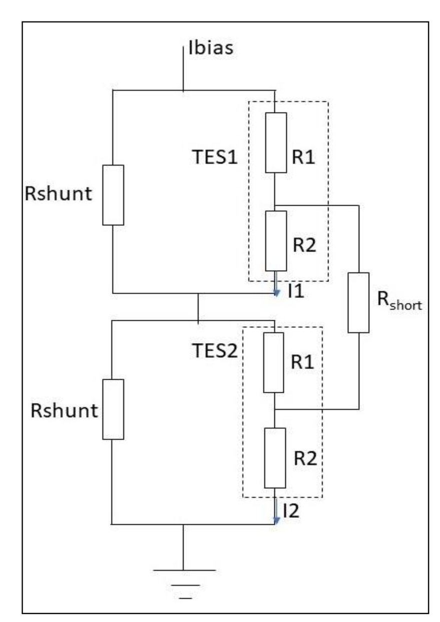




Fabrication Flow

- Coat TES and circuit with sacrificial resist
- Pattern stems to cantilever absorbers to TES and evaporate Ti/Au.
- Pattern PR Mold and Electroplate 1.0 um Au over absorber pixels
- Electroplate 5.1 um Bi over absorber pixels
- Remove PR Mold
- Pattern streets and ion mill through seed layer to separate pixels
- Strip photoresist in O_2 plasma

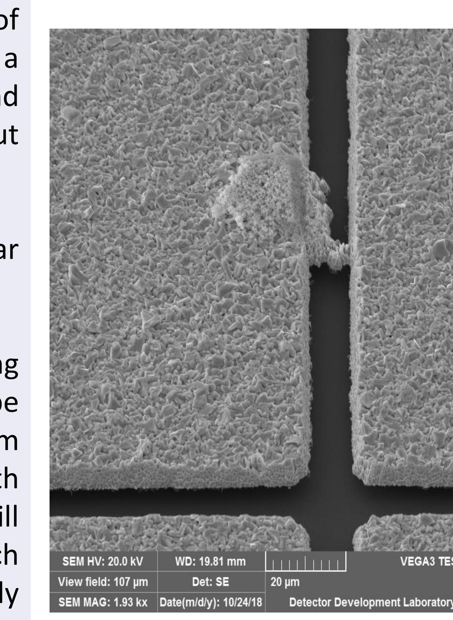
HOW ABSORBER SHORTS DEGRADE PERFORMANCE

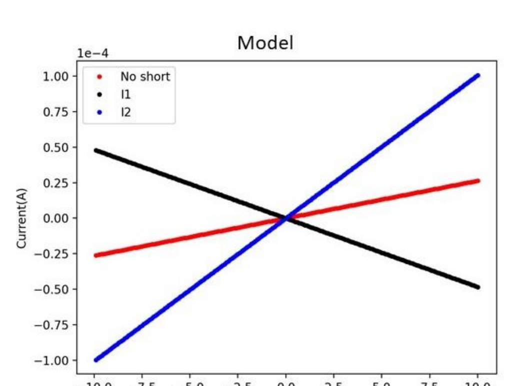


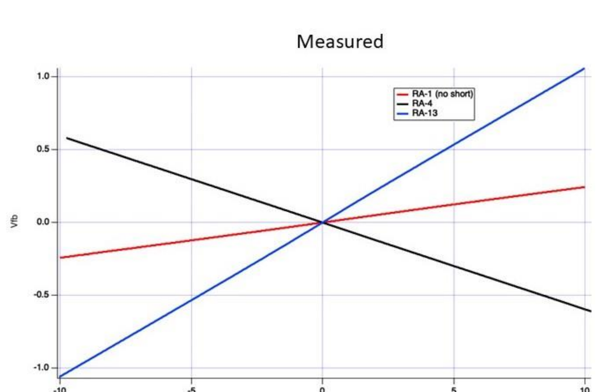
We have measured the effect on TES response of an approximately 5 um diameter Bi grain shorting between absorbers of two neighboring microcalorimeter pixels. The two TES's are both in a single readout column meaning that they share a common TES bias as shown in Fig TBD. Each TES is in parallel with a shunt resistor (Rshunt). Current through TES 1, I1, and current through TES 2, I2 are measured at the points indicated in Fig TBD through inductive coupling to a SQUID readout circuit.

Measurements of the I1 and I2 as a function of Ibias are shown in Fig. (IV curve figure). We observe I1 and I2 have similar magnitude but opposite polarity and both show larger magnitude than a device without an absorber short.

We are able to recreate this observation with a simple circuit model. The resistance of the short between the neighboring absorbers is shown in Fig (Circuit Diagram Figure) as Rshort, where Rshort is estimated to be 2 mOhm. Each TES can be divided into two resistances R1 and R2, where R1+R2= RTES ~ 12 mOhm. The circuit is then shown in Fig (Circuit Diagram Figure). When R1 ~ 11mOhm and R2 ~ 1mOhm the modelled response as a function of Ibias is quantitatively consistent with the measured data as shown in Fig. (Model data), however it is not clear why this ratio of resistance would exist. This will require further investigation. X-ray spectra from these pixels show a highly degraded energy resolution of ~ 1 keV, which shows the importance of removing these pixel shorts. Note, that when one of the shorted pixels is disconnected electrically from the bias circuit the energy resolution of the remaining pixel improves to ~ 6eV.







To match data with ~ 2mOhm short (5um of Bi)
Need R2 = 1mOhm and R1= 11mOhm.