Performance of an X-ray microcalorimeter with a 240 μm absorber and a 50 μm TES bilayer

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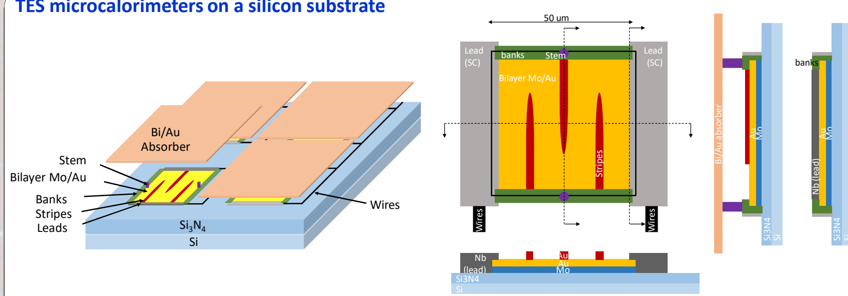
Abstract

We have been developing superconducting transition-edge sensor (TES) microcalorimeters for a variety of potential astrophysics missions, including Athena. The X-ray Integral Field Unit (X-IFU) instrument on this mission requires close-packed pixels on a 0.25 mm pitch, and high quantum efficiency between 0.2 and 12 keV. The traditional approach within our group has been to use square TES bilayers on molybdenum and gold that are between 100 and 140 microns in size, deposited on silicon nitride membranes to provide a weak thermal conductance to a ~50 mK heat bath temperature. It has been shown that normal metal stripes on top of the bilayer are needed to keep the "unexplained" noise at a level consistent with the expected based upon estimates for the non-equilibrium non-linear Johnson noise.

In this work we describe a new approach in which we use a square TES bilayer that is 50 microns in size. While the weak link effect is much stronger in this size of TES, we have found that excellent spectral performance can be achieved without the need for any normal metal strips on top of the TES. A spectral performance of 1.58 eV at 6 KeV has been achieved, the best resolution seen in any of our devices with this pixel size. The absence of normal metal stripes has led to more uniform transition shapes, and more reliable excellent spectral performance. The smaller TES size has meant that the thermal conductance to the heat bath, determined by the perimeter length of the TES and the membrane thickness, is lower than on previous devices, and thus has a lower count rate capability. This is an advantage for low count-rate applications where the slower speed enables easier multiplexing in the read-out, thus potential higher multiplexing factors. In order to recover the higher count rate capabilities, a potential path exits using thicker silicon nitride membranes to increase the thermal conductance to the heat bath.

TES microcalorimeters on a silicon substrate

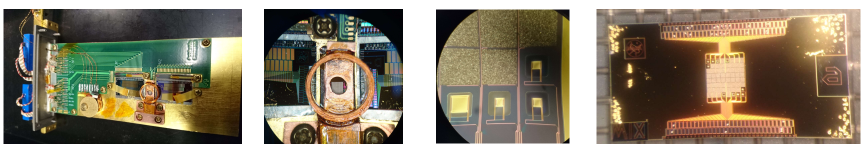


TES: small pixel of 50 x 50 μm^2, Mo (50 nm) / Au (220.3 nm). Pixels tested are usually bigger (from 100 μm to 140 μm)

Absorber: 240 x 240 μm^2, Bi (4.03 μm) / Au (1.49 μm)

Three stripe configurations: stripeless, 1 stripe or 3 stripes. The stripes, in red on the diagram, are shaped in normal metal and are added on top of the bilayer to generate a proximity effect in it.

Experimental set up



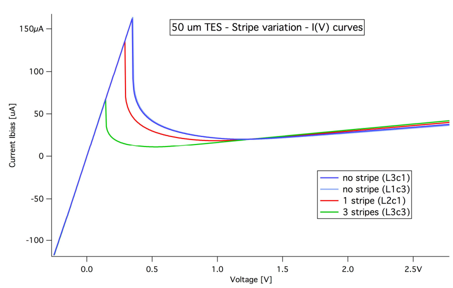
TES Array: Array consisting of pixels on various design, with multiple TES size, normal metal features (e.g. with/without stripes, type of stem, etc …). Here we discuss only the stripe variation.

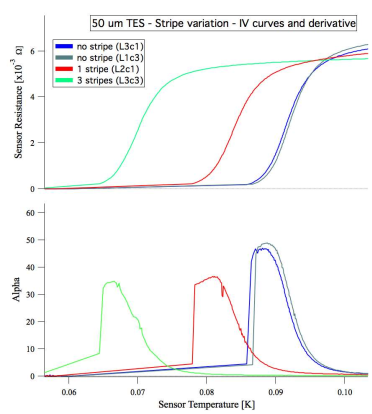
Cryogenics: An ADR fridge is used to cool down to 55 mK, well below the TES Tc, with an rms stability of a few microKelvin

Readout: DC bias, through the SQUID chip on the side of the TES array (two left pictures)

X-ray source: Fe-55 at 8 KBq. Collimated to provide X-rays only to the TES array

Stripe variations impact on the TES behavior





Tests are run on 4 pixels with a TES of 50 μm in size. Two of these are stripeless, one has 1 stripe and the last one has 3 stripes.

- The measured IV curves for these 3 configurations give very good results: very smooth slope, without any kinks or jump in the transition shape
- The addition of stripes decrease the Tc (see table below) and the resolution (see the table below)
- Because of smaller perimeter of the TES, the 50 μm pixel has a smaller thermal conductance compared to larger TES (100 or 140 μm).
- This produces pixels with lower thermal conductance and thus lower count rate capability

Channel	Number of stripe	Tc [mK]	R/Rn [%]	MnKα [eV]	C @ 100 mK [pJ/K]	Pulse τ @ Tc [ms]	G @ Tc [pW/K]	Energy resolution @ 6 KeV [eV]
L1c3	0 stripe	107.3	5	1.58	0.55	6.4	0.75	1.58
L2c1	1 stripe	102.4	5	1.88	0.46	6.2	0.62	1.78
L3c3	3 stripes	76	5	1.87	0.36	8.9	0.29	1.87

➔ These characteristics partially explain the very good results obtained with these pixels.

➔ Usually, adding stripe reduces the noise in larger TES. In smaller 50 μm TES, it can be used to adjust the Tc. The different transition shapes indicate that the small stripeless TES tend to have a more uniform transition.

➔ Increasing the thickness of the membrane could allow to recover a higher count rate capability.

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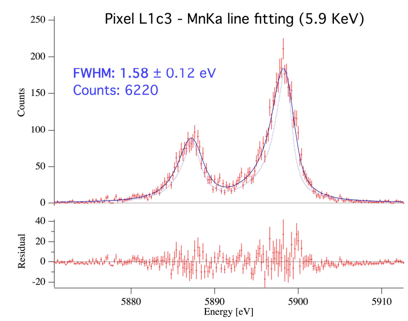
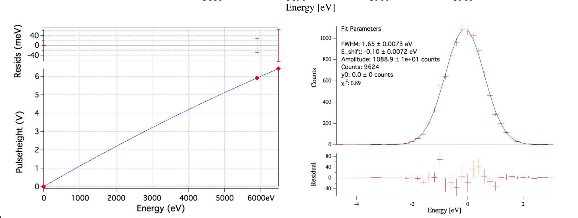
50 μm stripeless - Energy resolution at 6 KeV

The Fe-55 MnKα (5.9 KeV) X-ray source is placed outside of the cryostat and provides X-rays to the entire TES array at a count rante of ~1cps. The energy resolution and properties of each pixel were characterized sequentially. For each spectrum we acquired more than 6000 counts to determine the energy resolution



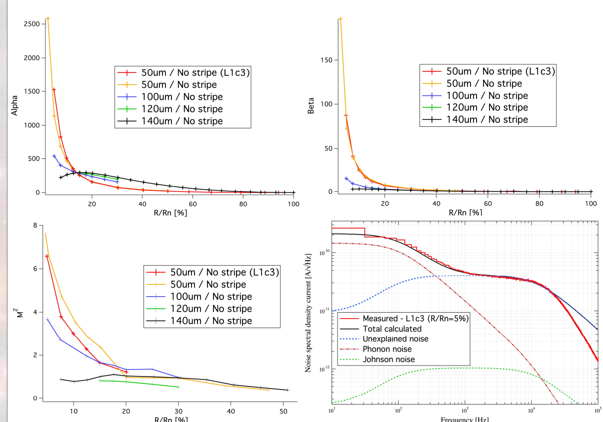


Noise and energy resolution

The key transition shape parameters α and β are derived from the complex impedance measurements and represents the derivatives of the R(T) (eq. 1) and R(I) (eq. 2), respectively. M^2 is an additional noise source, unknown, with the same spectral form as the Johnson noise. It is calculated from the total white voltage noise described by eq. 3.

$$\alpha = \frac{T}{R}\frac{\partial R}{\partial T} \quad \text{(eq. 1)} \qquad \beta = \frac{T}{R}\frac{\partial R}{\partial I} \quad \text{(eq. 2)} \qquad V_n = \sqrt{4k_bT_0R_0(1+2\beta)(1+M^2)} \quad \text{(eq. 3)}$$

Below are given the α, β and M^2 results for the 50 μm TES (L1c3) and other stripeless TES. From this data, we can estimate the total noise, including the unexplained noise.



➔ The combined effect of the transition shape, good linearity and noise for the 50 μm TES (L1c3) results in excellent energy resolution.

Progress and future work

- Best resolution achieved for a 50 μm TES : **1.58 eV** at 5.9 KeV
- Absence of normal metal stripe has lead to more uniform transition shapes
- Small size of the TES leads to lower count rate capability but could be adjust to required time constant through adjustment of the membrane thickness
- This 50 μm design opens up the phase space of possible pixel parameters
- These results provide promising alternative design approaches for the focal plane array of the X-ray Integral Field Unit (X-IFU) of the Athena mission