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 0.15 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 strips 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 thermal conductance and thus potential higher multiplexing factors. In order to recover the thermal conductance to the heat bath, 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.

TES microcalorimeters on a silicon substrate

Experimental set up
TES Array: Array consisting of pixels on various design, with multiple TES size, normal metal features (e.g. with/without strips, 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

Stripes variations impact on the TES behavior
Tests are run on 4 pixels with a TES of 50 μm in size. Two of these are stripes, 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

<table>
<thead>
<tr>
<th>Channel</th>
<th>Number of stripe</th>
<th>Tc [mK]</th>
<th>R/Nox [%]</th>
<th>MnK [eV]</th>
<th>C @ 100 mK [pA/K]</th>
<th>Pulse G @ Tc [pW/K]</th>
<th>Energy resolution @ 6 KeV [eV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3c3</td>
<td>0 strip</td>
<td>107.3</td>
<td>5</td>
<td>1.58</td>
<td>0.55</td>
<td>0.94</td>
<td>1.58</td>
</tr>
<tr>
<td>L2c3</td>
<td>1 strip</td>
<td>102.4</td>
<td>5</td>
<td>1.88</td>
<td>0.64</td>
<td>6.2</td>
<td>0.62</td>
</tr>
<tr>
<td>L3c3</td>
<td>3 strips</td>
<td>76</td>
<td>5</td>
<td>1.87</td>
<td>0.36</td>
<td>8.9</td>
<td>0.29</td>
</tr>
</tbody>
</table>

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 stripesless TES tend to have a more uniform transition.

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

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. M² 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.

\[ α = \frac{\Delta T}{R(T)} \] (eq. 1)
\[ β = \frac{\Delta T}{T} \] (eq. 2)
\[ M² = \sqrt{\Delta V² R(T)}(1 + 2β(1 + M²)) \] (eq. 3)

Below are given the α, β and M² 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 strip 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

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

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

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 rate of ~2cps. 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

Pixel 1L1c3 - MnKα line fitting (5.9 KeV)
50 μm / No stripe (L1c3)
50 μm / No stripe (1Lc3)
100 μm / No stripe
100 μm / No stripe (L1c3)

NOISE & ENERGY RESOLUTION

Coordinates: 34° 51’ 08.3” N / 118° 01’ 55.1” W