Design and optimization of multi-pixel transition-edge sensors for X-ray astronomy applications


*Corresponding Author: Tel: 1-301-286-3719; fax: 1-301-286-1884; E-mail address: stephen.j.smith@nasa.gov, NASA GSFC / CRESST / University of Maryland Baltimore County, MD 21230, USA

Abstract: Multi-pixel transition-edge sensors (TESs), referred to as ‘hydrams’, are a type of position sensitive microcalorimeter that resides atop large format arrays to detect soft x-rays. We describe designs for the 1st demonstrator absorbers mounted via thermal links to 25-pixel hydras. We discuss thermal performance of 25-pixel hydras and compare to the pixel thermal model. We provide results for 9-pixel hydras including design parameters and measured data. We present pulse shapes for single and multiple absorbers as a function of rise time. We also present measured pulse shapes for single and multiple absorbers for 4-9 pixel designs. Practical implications are described. Future plans include: extending designs to develop the 1st prototype 20-pixel hydras. "Hydrams" could combine single pixels and hydras in one array. (See Bandler et al. PE-46 for further details on "Hydrams")

1) Multi-absorber ‘hydra’ concept.
- Multiple absorbers with different thermal coupling G to 1 readout sensor.
- Sensor could be transition-edge sensor (TES) or magnetically coupled calorimeter (MCC) – hence we focus on TES readout.
- Position dependent pulse-shape from thermal diffusion.
- Designed to increase array coverage with fewer TESs.
- Reduces focal plane array complexity, lower heat loads, less wiring, fewer readout channels.

2) 9-pixel hydra design.
- Arrays presented here are small-pixel designs < 75 μm pitch for high angular resolution.
- 8 x 8 arrays of 4 and 9 pixel hydras have been developed.
- 35+35 μm Mo/Au bilayer TES.
- 65×65 μm electroplated Au x-ray absorbers, 5 μm thick. Provides 98% absorption at 6 keV.
- Absorbers are cantilevered above substrate and TES for high fill factor.
- Fabricated on thick Si wafers with embedded Cu heat sink layer.
- ~ 500 mm Au thick, few μm wide links couple the TES to the absorbers.

3) 4 and 9 pixel hydra.
- 9-pixel hydra layout

4) 4 and 9 pixel energy resolution.
- ΔE scales approximately with √(number of pixels).
- 4 pixel array ΔE < 10 eV at 1.5 keV.
- 9 pixel array ΔE < 15 eV at 0.2 keV.
- 4 pixel hydra ΔE = 3.0 eV at 1.5 keV.
- 9 pixel hydra ΔE = 3.6 eV at 1.5 keV.

5) Position sensitivity.
- Position determined from rise-time.
- Thermal links designed using a finite element model to calculate the pulse shapes and noise.
- Pulses match well with numerically simulated.
- Hits in exposed links between absorbers have been identified.

6) 20-pixel hydra designs.
- Extending designs to develop the 1st prototype 20-pixel hydra.
- These designs utilize a hierarchical structure using trunks and branches that make it easier to design and lay out, but require more complex position discrimination algorithm.
- 3rd design iteration consisting of 5 clusters of 4 absorbers, where each cluster is individually coupled to the TES (schematic below).
- The absorbers are 4.2 μm Au on a 50 μm pitch.
- TES is 25x200 μm².
- T_TES = 80 mK.

7) 20-pixel hydra results.
- Measured average pulse shapes (right) qualitatively agree with simulations.
- The 5 clusters each with 4 pixels have different characteristic pulse shapes.
- Additional pole in rise time requires 2nd order parameter for pre-equilibrium signal.
- Different algorithms under study for determining optimum position.
- Example shown here uses 2 rise time metrics: τ_C and τ_T, determined from 50% and 90-50% of the pulse peak. Two X-ray data runs at different energies: Mn-K (6.4 keV) and Cr-K (5.4 keV).
- Good position discrimination performed on most pixels down to < 2.5 keV.
- However, due to very fast rise time and low sampling rate (only 4 data points on rise of fastest pixels), position discrimination between fastest pixels (cluster 4).
- ΔE_{mean} evaluated using crystal monochromator.
- ΔE_{mean} = 3.39 ± 0.18 eV including all 20 pixels, already surpassing 5 eV goal for Lynx.
- Future plans include:
  - Extend design to 25-pixels for Lynx baseline design.
  - Optimize design to match fastest pixel with matched wave front readout bandwidth.
  - Test large scale arrays with multiplexed microwave micro readout.
  - Design hydras with 25 μm pixel pitch to better match Lynx 0.5 arc-second goal.