# Development of Transition-Edge Sensor X-ray Microcalorimeter Linear Array for Compton Profile Measurements and Energy Dispersive Diffraction

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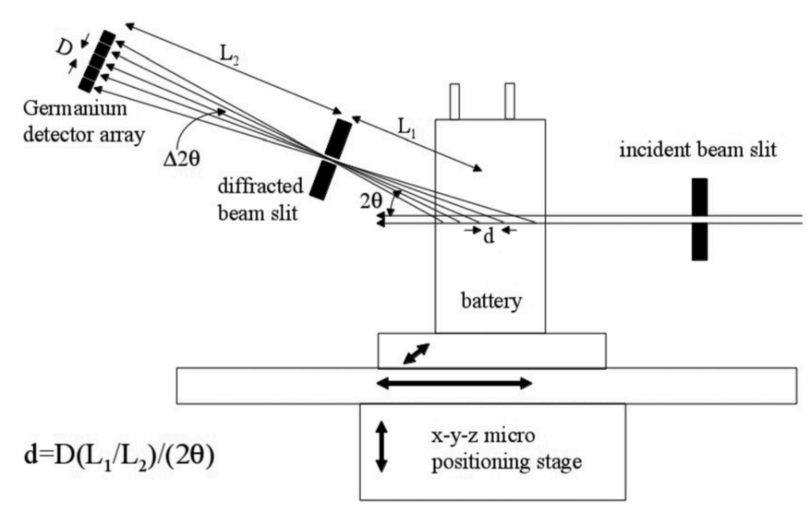
We are currently building a TES X-ray spectrometer for the Advanced Photon Source (APS) at Argonne National Laboratory (ANL) for energies less than 20 keV in collaboration with National Institute of Standards and Technology (NIST). The spectrometer consists of application specific TES sensors for pilot XAFS and XES experiments. We propose to develop and fabricate these TES sensors for the very hard X-ray energy range (20-100 keV). We have recently published an article where we present a design optimization for a linear TES array for energy-dispersive X-ray diffraction and Compton profile measurements [1]. We present our progress on simulation results, preliminary sensor layouts, and proof-of-principle fabrication of millimeter long SiN membranes.

## Introduction

### Energy Dispersive X-Ray Diffraction (EDXRD)

The sample diffraction pattern is measured at a fixed angle by using polychromatic photons and an energy-dispersive detector.

- Compared to angle-dispersive XRD, it does not need sample rotation;
- When a detector with spatial resolution is used, multiple parts of the sample can be measured at the same time;
- The d-spacing resolution is limited by the energy resolution of the detector.




Setup of the EDXRD. Rumaiz, A. K. *et al. IEEE Transactions on Nuclear Science* **61,** 3721–3726 (2014).

### Compton scattering

Current high-resolution Compton scattering experiments are done with crystal spectrometers.

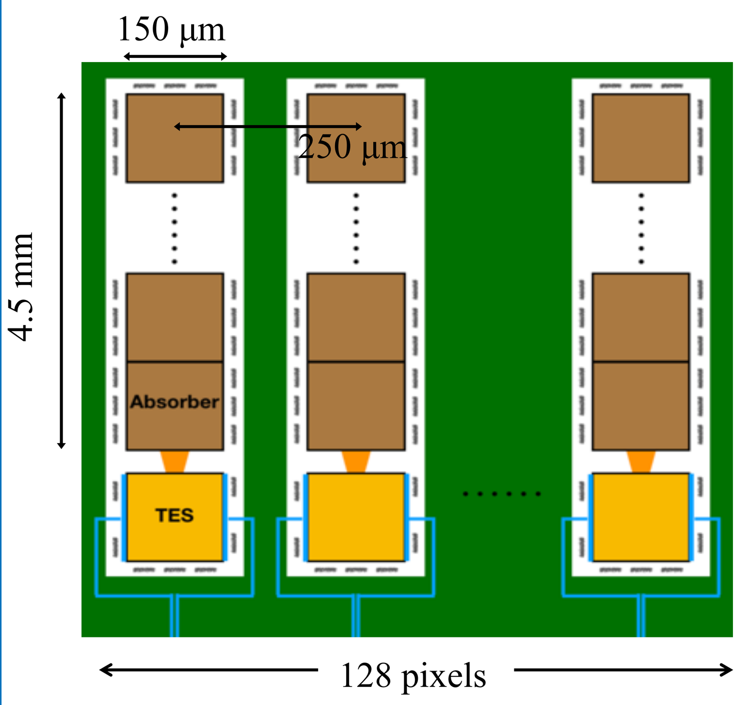
$$p_z = mc\frac{\omega_2 - \omega_1 + \omega_1\omega_2(1-\cos\theta)/mc^2}{(\omega_1{}^2 + \omega_2{}^2 - 2\omega_1\omega_2\cos\theta)^{1/2}}$$

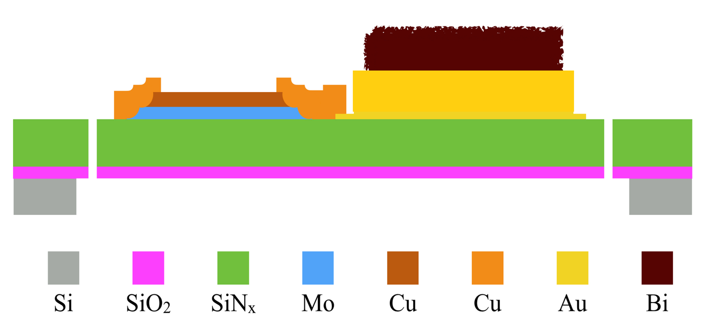
$p_z$ : electron momentum   θ: photon scattering angle
$\omega_1$: incident photon energy   $\omega_2$: scattered photon energy

Both experiments require ΔE < 80 eV @100keV

## Design Optimization

The TES detector offers good energy resolution. The linear array design provides spatial resolution.

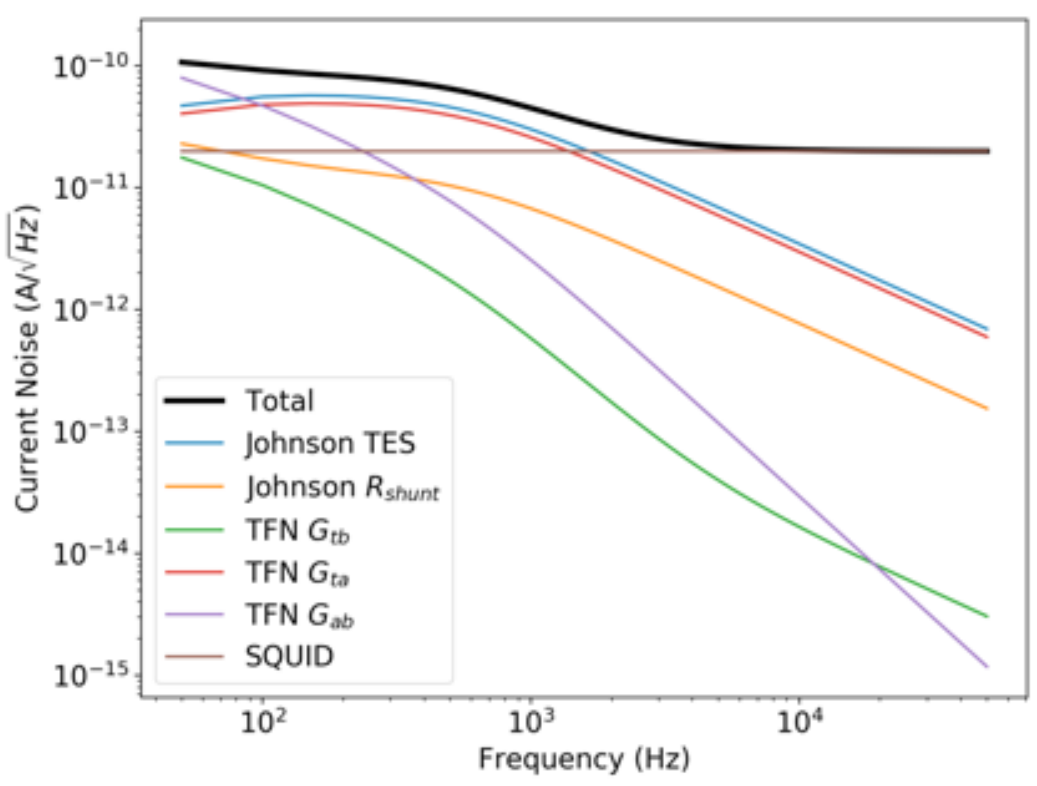



TES:
150×150 µm
Mo-Cu bilayer
Rn = 9 mΩ
Tc = 100 mK
C = 0.2 pJ/K

Absorber:
150 µm×4.5 mm
Au: 20 µm, Bi: 15 µm
C = 100 pJ/K
25% absorption at 100 keV

$G_{total}$ = 2000 pW/K, L = 700 nH, $T_b$=100 mK




Simulated noise spectrum by treating the TES-absorber as two thermal bodies.

**ΔE ~ 21 eV**

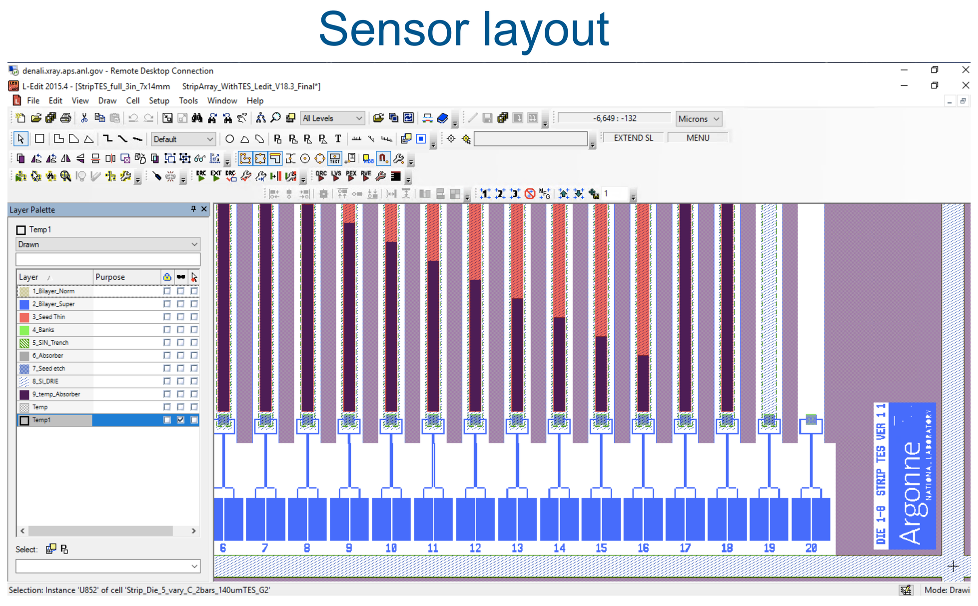
Meets experimental needs

## Fabrication and Characterization

### Fabrication of prototype devices

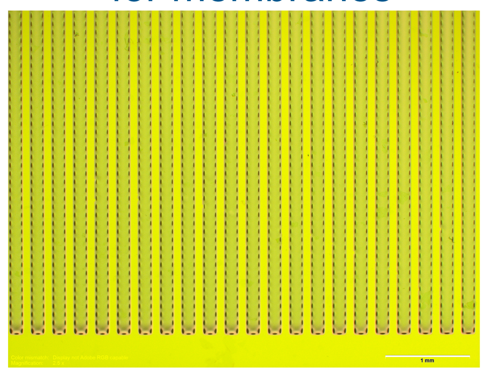
- Each fab run with 8 mask process
- Each 3-inch wafer contains 24 dies, with 20 devices each
- Each die explores different aspects of the device design: $T_C$ and α, G and C

Sensor layout

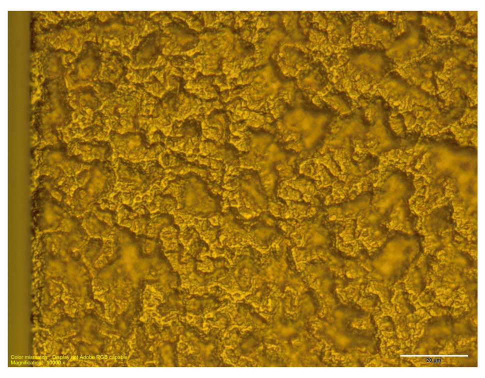


- Use of standard sapphire carrier in Plasmatherm DRIE tool results in complete etch stop of Si due to lower bias seen by substrate.
- Need of mounting bonded wafer stack on Si carrier.
- Need of development of low power slower DRIE etch recipes for reduced heat generation

DRIE process for membranes

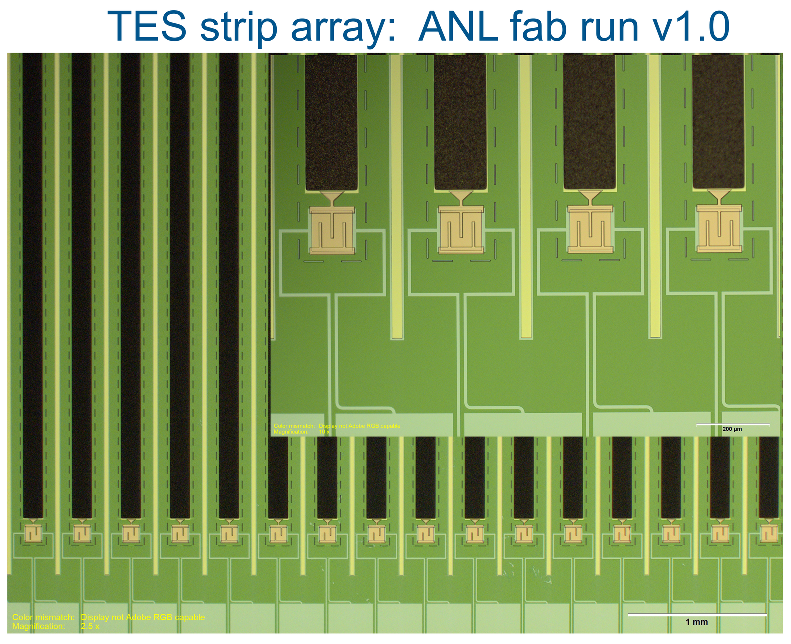


Au electroplating for absorber

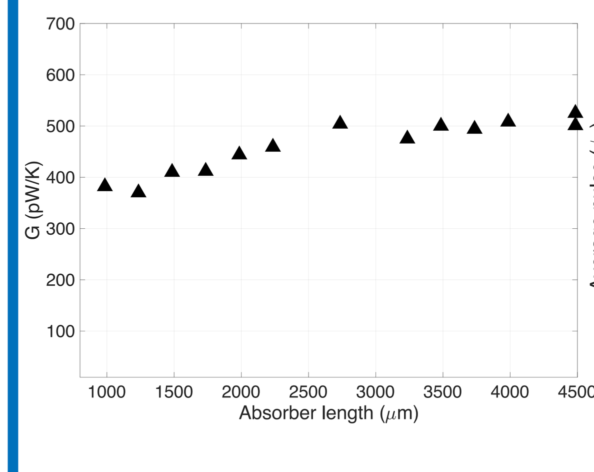


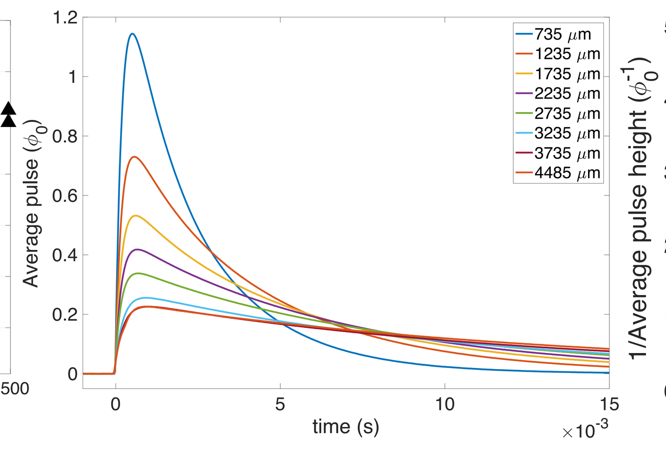
- Total area being plated for full wafer ~ 2.534 cm$^2$ with plating current 1 mA/cm$^2$
- Plating area density = 6.44 %
- ~ 1 µm plating in TechniGold 25E and ~ 9 µm in Neutronex bath

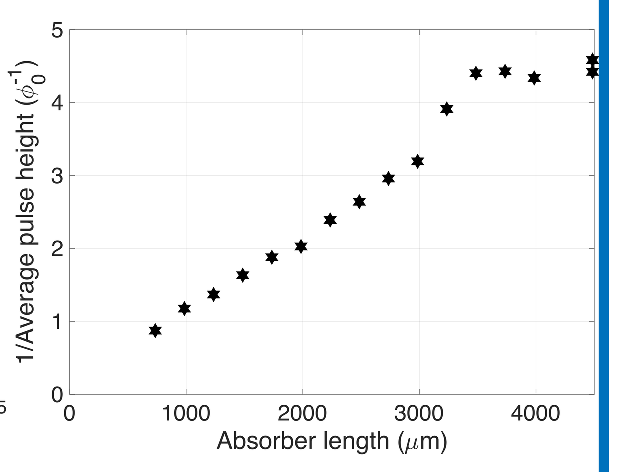
TES strip array: ANL fab run v1.0



### Results and discussions




- Thermal conductance G nearly independent of absorber length suggesting heat flow to the cold bath is dominated by membrane geometry rather than by the absorber area
- Linear relationship of 1/average pulse height, and pulse decay time with absorber length
- Demonstrated minimal unwanted effect of long strip geometry on X-ray pulse response

### Future Work :

- Plan to fabricate next generation devices with a target absorber thickness (20 µm Au + 30 µm Bi) and study energy resolution, quantify effect of position dependence

*References:*

*(1) D. Yan et al; Modelling a Transition-Edge Sensor X-ray Microcalorimeter Linear Array for Compton Profile Measurements and Energy Dispersive Diffraction, (2019)* https://arxiv.org/abs/1902.10047.

*(2) Rumaiz, A. K. et al. A Monolithic Segmented Germanium Detector with Highly Integrated Readout. IEEE Transactions on Nuclear Science* ***61,*** *3721–3726 (2014).*

*(3) Hiraoka, N. et al. A new X-ray spectrometer for high-resolution Compton profile measurements at SPring-8. J Synchrotron Rad* ***8,*** *26–32 (2001).*

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