Dynamic characterization of cryogenic optical photon detectors with Ir/Pt bilayer transition edge sensors

W. Armstrong[1], G. Benato[2,3], C. Chang[4,5,6], B. K. Fujikawa[3], K. H. Hafidi[1], R. Hennings-Yeomans[3], R. Huang[2], G. Karapetrov[7], Yu. G. Kolomensky[2,3], M. Lisovenko[8,9], L. Marini[2], Z. E. Meziani[1], V. Novosad[1,8], J. Pearson[8], T. Polakovic[1,7], B. Schmidt[3], V. Singh[2], S. L. Wagaarachchi[2], G. Wang[8], B. Welliver[3], V .Yefremenko[8], J. Zhang[8]

[1]Physics Division, Argonne National Laboratory, [2]Department of Physics, University of California, Berkeley, [3]Nuclear Science Division, Lawrence Berkeley National Laboratory, [4]Kavli Institute for Cosmological Physics, University of Chicago, [5]Department of Astronomy and Astrophysics, University of Chicago, [6] High Energy Physics Division, Argonne National Laboratory, [7] Physics Department, Drexel University, [8] Materials Science Division, Argonne National Laboratory, [9]Nanoelectronics Department, Sumy State University, Sumy, Ukraine

CUORE and CUORE Upgrade with Particle ID (CUPID)

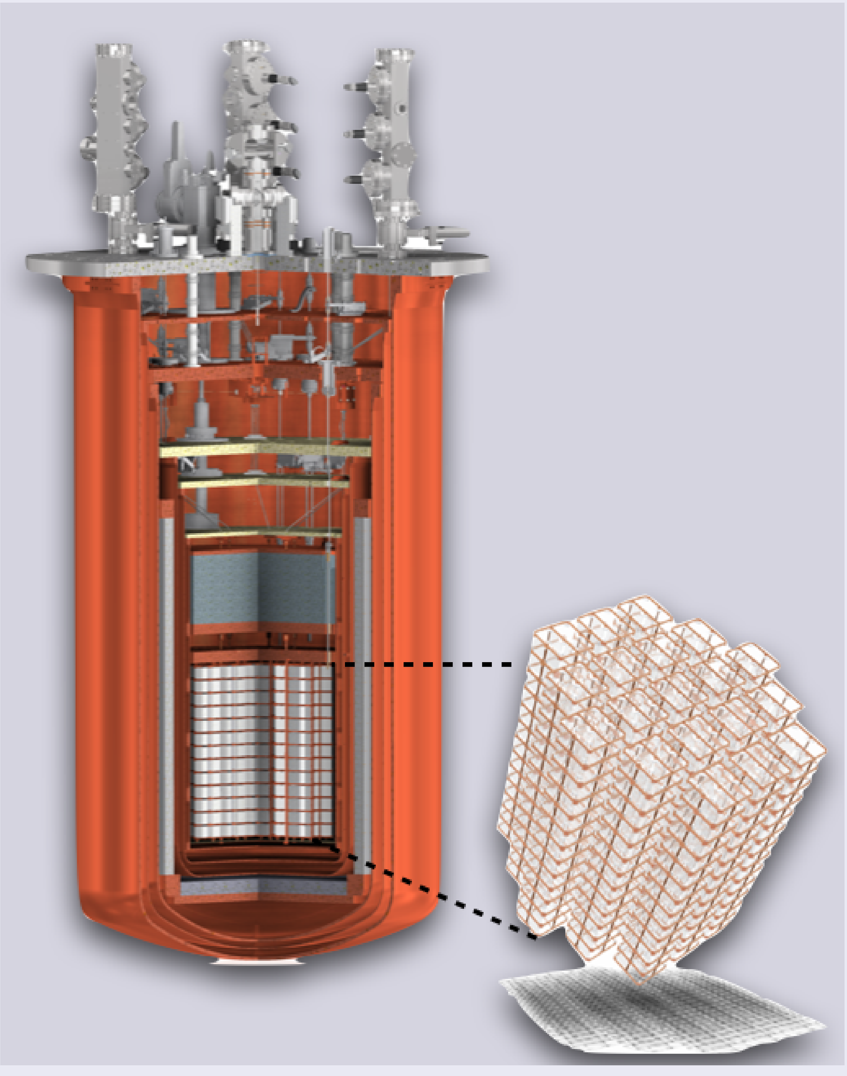


Figure: Rendering of the CUORE cryostat and the 19 detector towers

T he Cryogenic Underground Observatory for Rare Events (CUORE[1])

- One-ton scale low-temperature calorimetric experiment.
- Largest mass operated at 10 mK.
- Searches for neutrinoless double beta decay of ^{130}Te in the LNGS underground lab in Italy.

Current Status:

⇒ **Resolution:** 7.7 ± 0.5 keV at 2.5 MeV (FWHM).

⇒ **Background:** 0.014 ± 0.002 cnts/kev/kg/yr.

⇒ **Background limitation:** We measure only the thermal channel. β and α events of equal energy exhibit the same thermal response in our sensors.

CUPID[2]: Proposed next-gen Experiment

⇒ Increased isotopic mass through enrichment.

⇒ Active background rejection of α events from β.

⇒ detect phonon and photon signals, simultaneously.

⇒ optical photon detection using a thin Si or Ge based low temperature calorimeter.

Cherenkov light in TeO_2:[3]

⇒ TeO_2 does not scintillate. However, β events will emit Cherenkov light while α won't.

⇒ Low light yield $\mathcal{O}(100$ eV). Requires low threshold $\mathcal{O}($ 20 eV).

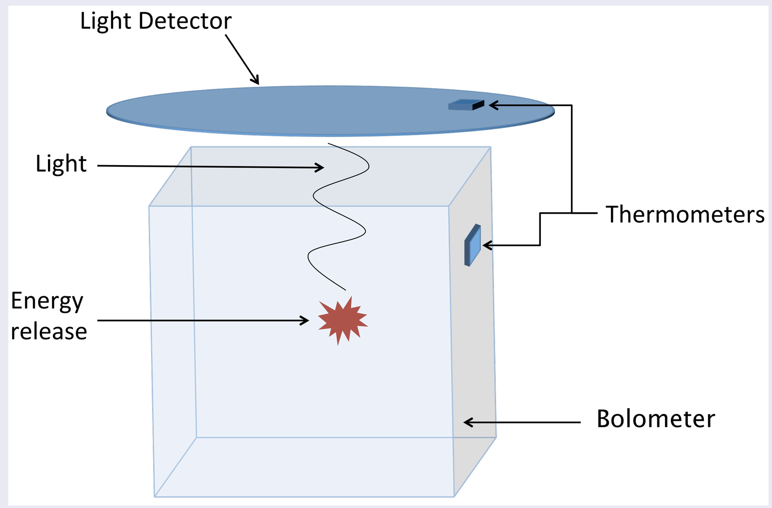


Figure: Schematic for simultaneous detection of heat and light signal.

Scintillation in $Li_2{}^{100}MoO_4$:[4]

⇒ Scintillating crystals have better light yield $\mathcal{O}(1$ keV) but crystal growth $\mathcal{O}(1500)$ needs to be investigated.

Transition Edge Sensor based device

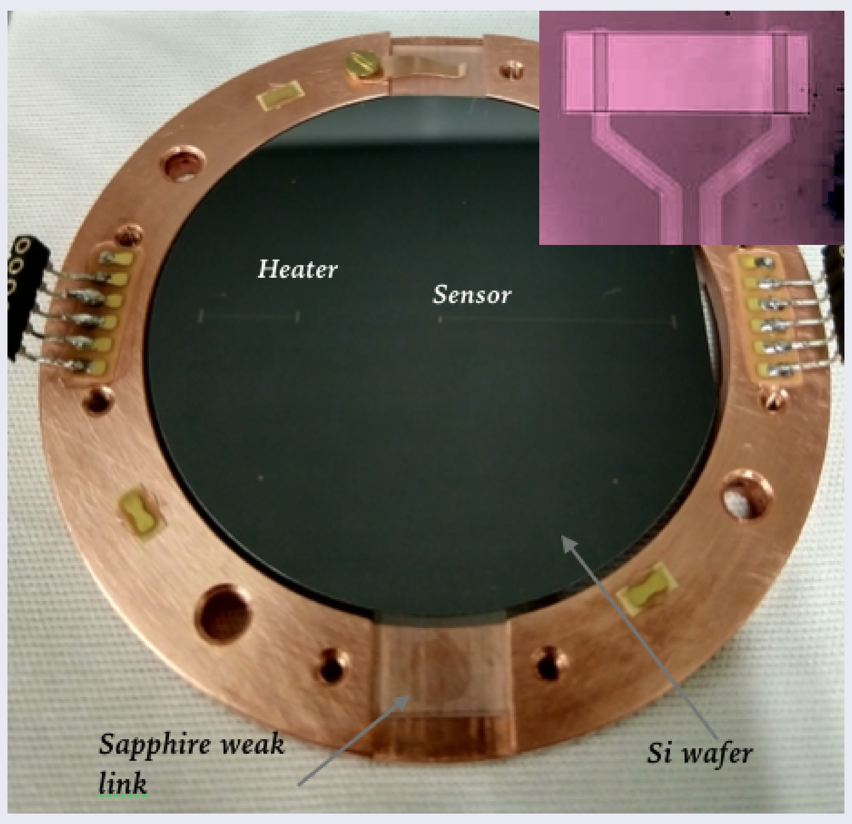


Figure: Silicon wafer with the deposited sensor and heater. The inset figure shows a micrograph of the sensor.

Device fabrication is done at Argonne National Lab.

Device specifications:

- Ir/Pt (100 nm/60nm) bilayer with Nb traces as electrical leads.
- Sensor dimension 500 μm x 500 μm
- Transition temperature of $\sim$ 33 mK.
- 2" silicon wafer as optical photon absorber
- Sapphire weak heat link.

IV characteristics:

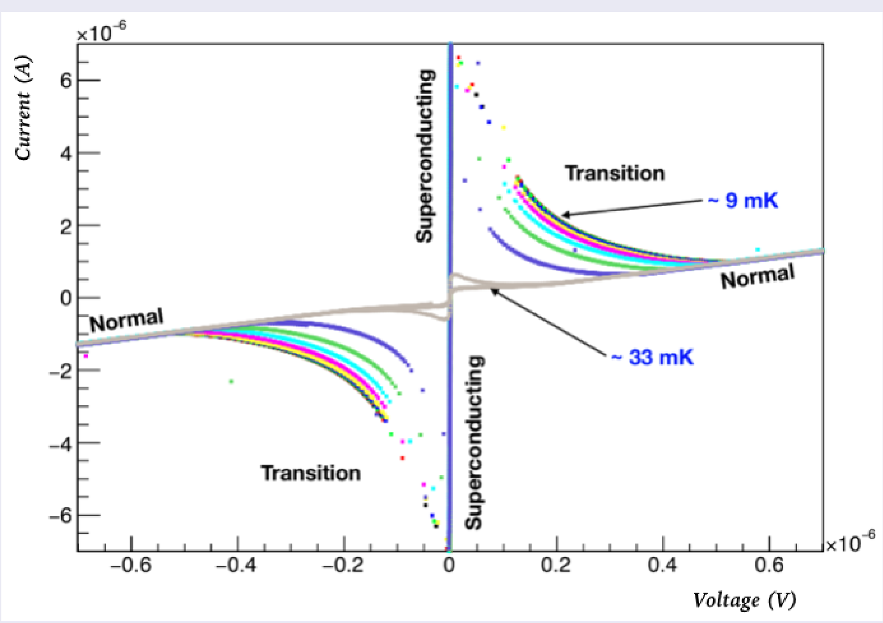


Figure: Typical IV curves for Ir/Pt (100nm/60nm) on the wafer at different temperature.

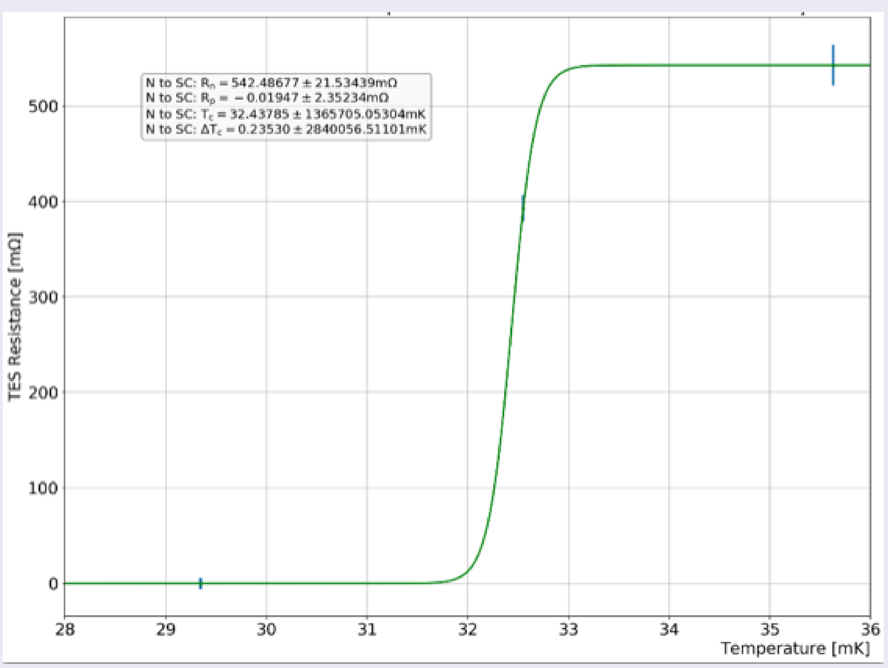


Figure: Resistance of the TES as a function of temperature, for a current of 400 nA flowing through the sensor.

Future Work

- Our immediate goal is to improve the thermal coupling between the sensor and the wafer.
- We will optimize the thermal coupling between the thermal bath and the wafer.
- We are planning to show the feasibility of using frequency domain multiplexing to read out multiple channels. This is crucial for CUPID where we envisage reading out $\mathcal{O}(3000)$ detectors.

Energy Response

Energy response to heater pulses:

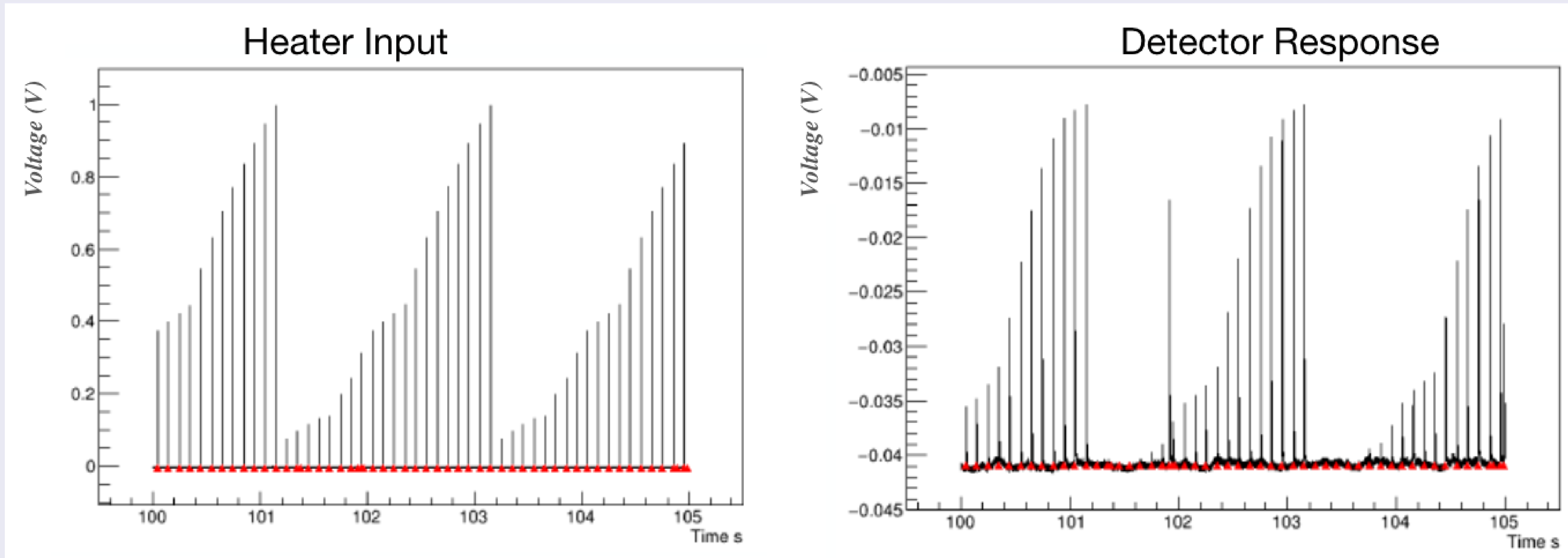


Figure: (Left) We send in a heater pulse with a known precise energy. The heater resistance was measured separately at low temperature using ac resistance bridge. (Right) Response of the detector for each heater excitation.

Pulse Shape:

- Typical risetime of 200 μs makes it suitable for rejecting pile-up events in rare event studies.
- The non-linearity of the device is under study.

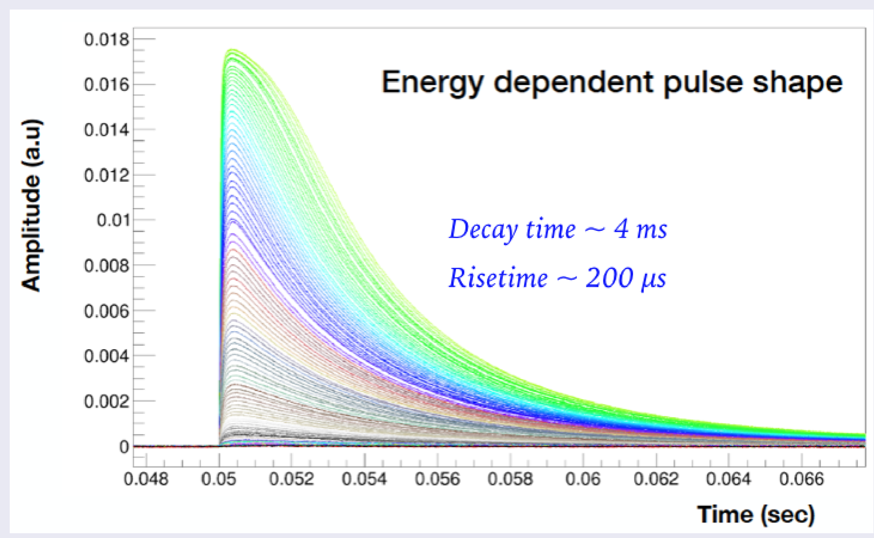
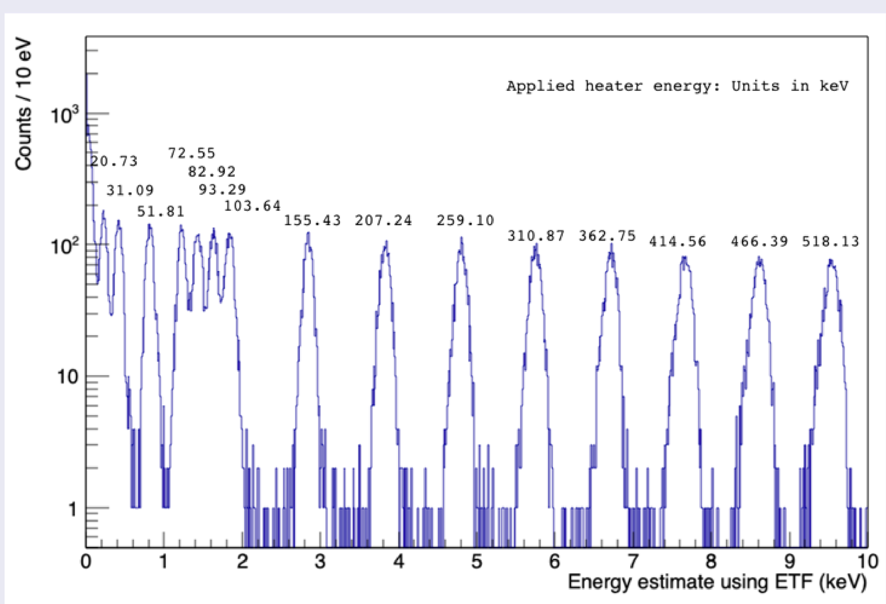


Figure: Average pulses for different heater energies.



The discrepancy between the applied heater energy and the energy seen by the TES suggests that not all the absorbed power on the wafer is measured by the TES.

References

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3. N. Casali et al., Eur. Phys. J. C 75 , 12, 1 (2015).
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