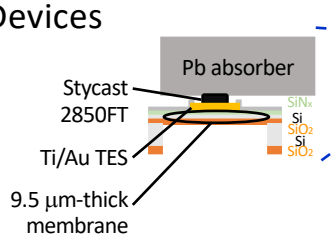
Development of Gamma-ray Position-Sensitive Transition-Edge Sensor Microcalorimeters

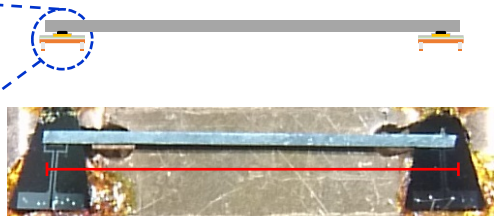
Naoko Iyomoto, Y. Kurume, T. Kuroiwa, S. Asagawa, T. Tsuruta, Y. Nishida, Y. Hamamura, K. Maehata (Kyushu University, Japan)
T. Hayashi, H. Muramatsu, K. Mitsuda (ISAS, Japan)

Concept

We propose position-sensitive transition-edge-sensor (TES) microcalorimeters (PoSTs) for gamma rays up to a few MeV. A gamma-ray PoST consists of a long gamma-ray absorber with a TES on each end. The comparison of signals between the two TESs determines the location of the gamma-ray interaction.

Devices

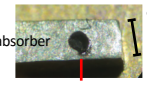




TES 1 — 18.8 mm Pb absorber — TES 2 (SQUID didn't work)

After a thermal cycle (300 K – 0.1 K – 300 K)

- TES 2 of PoST 1 had fallen off from the absorber
  → To investigate adhesion, we dismounted the other end of the absorber from TES 1

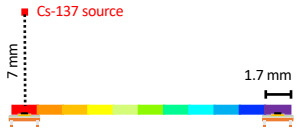


TES on 9.5-μm thick membrane

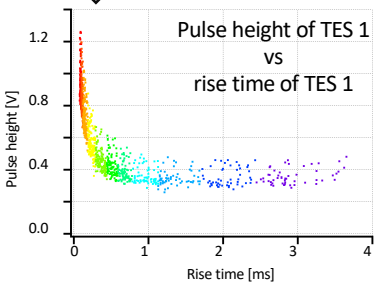
Thick membranes were robust but, adhesion between epoxy and TES was poor

- PoST-2 has survived the thermal cycle

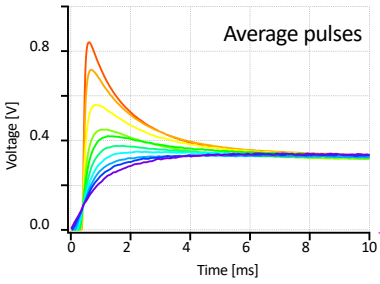
Measurements



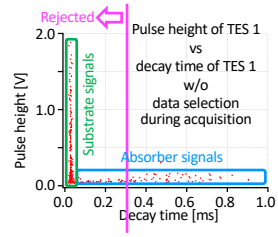
- 171 mK transition temperature
- 165 mK bath temperature (not low enough)
- Low frequency noise from mechanical cooler



We divided the 662 keV signals into 11 regions, assuming that the Cs-137 source is point-like



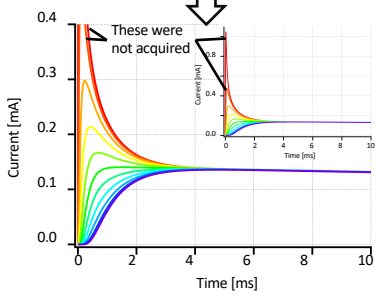
Actual pulses



Too strict data acquisition criteria

if the fastest pulses has not been acquired because of the too strict data acquisition criteria

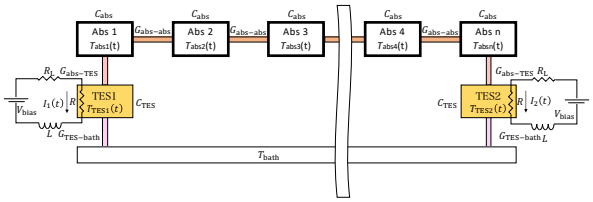
In good agreement



Simulated pulses with $G_{TES\text{-}abs}$ of 3 nW/K (Poor adhesion between Stycast and TES)

The poor adhesion made $G_{TES\text{-}abs}$ so small that decay time is restricted by $G_{TES\text{-}abs}$.

Simulations



2 electrical and 13 thermal differential equations→solved numerically

$$\frac{dI_1(t)}{dt} = -\frac{1}{\tau_{el}} I_1(t) - \frac{L_I G_{TES-bath}}{I_0 L} T_{TES1}(t) + x_1(t)$$

$$\frac{dT_{TES1}(t)}{dt} = \frac{I_0 R(2+\beta_I)}{C_{TES}} I_1(t) + \left(-\frac{1}{\tau_I} - \frac{G_{abs-TES}}{C_{TES}}\right) T_{TES1}(t) + \frac{G_{abs-TES}}{C_{TES}} T_{abs1}(t) + x_2(t)$$

$$\frac{dT_{abs1}(t)}{dt} = \frac{G_{abs-TES}}{C_{abs}} T_{TES1}(t) + \left(-\frac{G_{abs-TES}}{C_{abs}} - \frac{G_{abs-abs}}{C_{abs}}\right) T_{abs1}(t) + \frac{G_{abs-abs}}{C_{abs}} T_{abs2}(t) + x_3(t)$$

$$\frac{dT_{abs2}(t)}{dt} = \frac{G_{abs-abs}}{C_{abs}} T_{abs1}(t) - 2\frac{G_{abs-abs}}{C_{abs}} T_{abs2}(t) + \frac{G_{abs-abs}}{C_{abs}} T_{abs3}(t) + x_4(t)$$

$$\vdots$$

$$\frac{dT_{absn}(t)}{dt} = \frac{G_{abs-abs}}{C_{abs}} T_{TESn-1}(t) + \left(-\frac{G_{abs-TES}}{C_{abs}} - \frac{G_{abs-abs}}{C_{abs}}\right) T_{absn}(t) + \frac{G_{abs-TES}}{C_{abs}} T_{TES2}(t) + x_{n+2}(t)$$

$$\frac{dT_{TES2}(t)}{dt} = \frac{G_{abs-TES}}{C_{TES}} T_{absn}(t) + \left(-\frac{1}{\tau_I} - \frac{G_{abs-TES}}{C_{TES}}\right) T_{TES2}(t) + \frac{I_0 R(2+\beta_I)}{C_{TES}} I_2(t) + x_{n+3}(t)$$

$$\frac{dI_2(t)}{dt} = -\frac{L_I G_{TES-bath}}{I_0 L} T_{TES2}(t) - \frac{1}{\tau_{el}} I_2(t) + x_{n+4}(t)$$

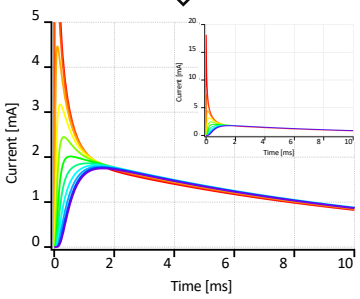
Assumed parameters

TES (Ti/Au)	Thickness	[nm]	40/120
	Area	[mm²]	0.5×0.5
Absorber (Pb)	Length	[mm]	18.8
	Width	[mm]	0.5
	Height	[mm]	0.5
Membrane (Si)	Thickness	[μm]	9.5
	Area	[mm²]	0.8×0.8
Transition temperature		[mK]	170
Bath temperature		[mK]	165
Bias point		[% Rn]	20

Alpha	[-]	100 *
Beta	[-]	1.0 *
$C_{absorber}$	[nJ/K]	0.8 **
C_{TES}	[pJ/K]	0.9 **
$G_{absorber}$	[nW/K]	100
$G_{TES\text{-}absorber}$ (poor adhesion)	[nW/K]	3
$G_{absorber}$	[nW/K]	200 **
$G_{TES\text{-}absorber}$ (design value)	[nW/K]	200 **
$G_{membrane}$	[nW/K]	30 *

* Estimated from results of single-pixel devices
** Based on literatures

If the adhesion is improved



Simulated pulses with $G_{TES\text{-}abs}$ of 200 nW (Design value)

Because the poor $G_{TES\text{-}abs}$ causes a huge internal thermal fluctuation noise, we need to improve the adhesion.

Conclusion

We have demonstrated that PoSTs can serve as one-dimensional imaging spectrometers for 662 keV gamma rays, although we still need to
- detect all signals from PoST absorbers by distinguishing them from the substrate signals
- improve the adhesion between the TES and the epoxy for better energy and position resolutions
- operate both of the two TESs at the same time for good position and energy resolutions in all of the effective pixels