Impedance measurement of a gamma-ray TES calorimeter with a bulk Sn absorber

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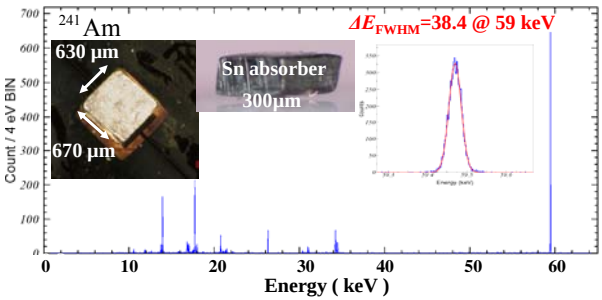
In Oshima et al. (2008) [1], we report the performance of gamma-ray microcalorimeter which showed FWHM energy resolution of ΔE = 38.4 ± 0.9 eV at 60 keV. Its structure is a composite of a bulk Sn absorber (630x670x300 um) to stop incident gamma-rays and a thermometer made of Ti/Au TES(fig. 1). We performed complex impedance measurement of the gamma-ray calorimeter and report on resistance dependency of basic parameters. The calorimeter impedance can be well explained by the two-body thermal model, and we investigated behavior of the parameters of the calorimeter during the superconducting-to-normal transition. We performed the noise analysis and found several excess noise components, as well as the internal fluctuation noise (ITFN) due to the thermal conductance between the Sn absorber and TES. Dominant noise are the excess noise having a similar frequency dependency with the phonon noise and the ITFN noise.

1. Introduction

The response speed of gamma-ray calorimeter tends to slow by the huge absorber. Absorber physically supported by insulator like the epoxy to separate electrically. Because epoxy is an insulator, the thermal conductance is small. Therefore, for fabrication of gamma-ray calorimeter, it is necessary to consider the thermal conductance between TES and the absorber. It is essential to know the response speed of gamma-ray (time constant τ) that shows thermalization speed of sensors. The optimum thermal conductance between TES and the absorber is closely related to not only the time constant of the calorimeter but also the thermal diffusion speed of absorber. From the above reason, the thermal conductance is an important parameter which shows a thermal characteristic of gamma-ray calorimeter.

Figure. 1



2. Impedance measurement

Figure. 2

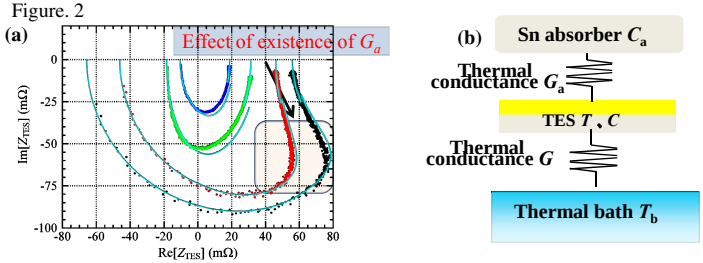


Figure. 2(a) shows Measured impedance of the gamma-ray calorimeter in 20 Hz - 40 kHz. Each color corresponds to different bias point, R/R_N = 0.12, 0.22, 0.50, and 0.78 from inner to outer. They differ from those of a TES microcalorimeter having a simple thermal model without an absorber, which draws a circle on the complex plane. Z_{TES} of the gamma-ray calorimeter exhibits more complex structure (Fig a). This indicates existence of another components in the thermal model. In derivation of the TES parameters from the impedance fit, we assumed the thermal model shown in Fig. 1(b). We calculate complex impedance from above thermal model. The calculated impedance shows below equations.

$$Z_{TES} = Z_\infty + \frac{Z_0 - Z_\infty}{1 - i\omega\tau_d}$$

$$\tau_d = \left(1 - \frac{C_a}{C}\frac{i\omega\tau_a}{1 + i\omega\tau_a}\right)\frac{C + C_a}{G(L-1)} \qquad Z_0 \equiv -R\left(1 + \frac{\beta + 2}{L - 1}\right)$$

$$\tau_a \equiv \frac{C_a}{G + G_a} \qquad Z_\infty \equiv R(1 + \beta)$$

3. Basic parameters ~ α, β, C, C_a, G_a ~

Figure 3a shows the obtained parameters, α, β, C, C_a and G_a. Horizontal axis is relative resistance R/R_N at the bias point normalized by the normal state resistance, R_N = 63 mΩ. Thermal sensitivity α and current sensitivity β have two peaks due to two-step transition in R-T curve. Straight lines at C_a = 6.9 pJ/K, C = 1.5 pJ/K, and G_a = 40 nW/K indicate the estimation by [1].Result of this fit roughly agree with the estimation. Because it is unlikely that heat capacity of the Sn absorber, C_a, changes depending on the bias point, we fixed C_a = 6.9 pJ/K in the fit. Figure 3b shows the obtained parameters. Thermal sensitivity α increased compared with fig3a, while current sensitivity β did not change so much. Thermal conductance C_a became almost constant at about 10 % higher value (～ 45 nW/K) than the estimation.

Figure. 3

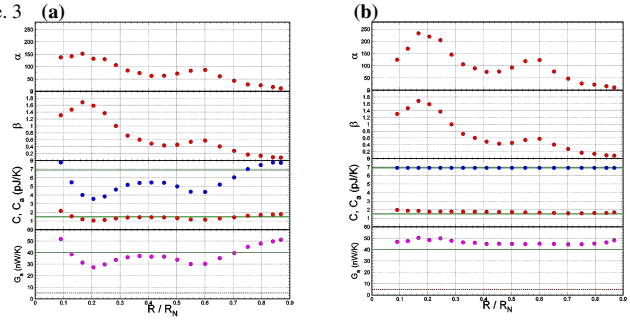
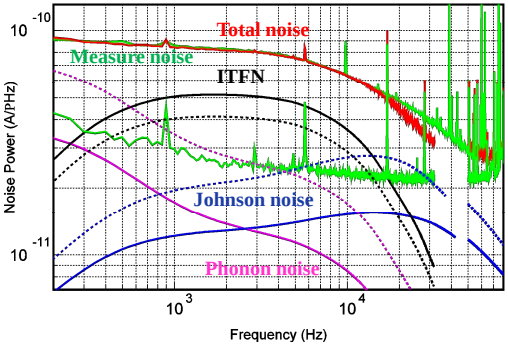


Figure. 4



4. Noise contribution on energy resolution

Using parameters of TES which determined by impedance measurement (tab 1), we calculated the Johnson (Blue), phonon (Magenta), and the ITFN(Black) noise, and they are plotted in Fig. 4. We introduced three kinds of excess noise which have same frequency dependency with the Johnson, phonon, and the ITFN noise. Dotted line shows each excess noise spectrum, and they are 2.0, 2.2, and 0.8 times the Johnson, phonon, and the ITFN noise, respectively. Table 2. shows breakdown of the energy resolution. In this table 1, $\Delta E = (\Delta E_V^2 + \Delta E_b^2)^{1/2}$, where ΔE_b^2 is the baseline energy resolution calculated from the observed overall noise spectrum, and ΔE_V^2 is the contribution of the pulse variation.

Table 1: TES parameters at bias point which achieved ΔE = 38.4 eV @ 60 keV

R/R_N	R	R_P	R_S	T	T_b	G	I	α	β	C	C_a	G_a
(mΩ)	(mΩ)	(mΩ)	(mΩ)	(mK)	(mK)	(nW/K)	(μA)			(pJ/K)	(pJ/K)	(nW/K)
0.41	26	0.5	3.1	154	130	5 6	0.7	75	0.49	1.74	6.9(fix)	45

Table 2: Contribution of each noise component to measured energy resolution

ΔE	ΔE_V	ΔE_b	$\Delta E_{Johnson}$	ΔE_{Phonon}	ΔE_{ITFN}	$\Delta E_{readout}$	$\Delta E_{excess\text{-}J}$	$\Delta E_{excess\text{-}P}$	$\Delta E_{excess\text{-}ITFN}$
38.4	8.1	37.2	4.7	9.2	10.5	**10.4**	7.39	25.32	**13.2**

6. Conclusion

We confirm parameter of the calorimeter obtained by impedance measurement correspond with estimation[1]. Using those parameters, we calculated the Johnson, Phonon and ITFN noise. We found that the phonon-like excess (p-excess; 25.3 eV) and the ITFN noise (14.9 eV) are dominant components of the noise. The p-excess noise is probably originated in fluctuation of T_{bath} due to the irradiation of gamma-ray to the surrounding sillicon substrate [4]. This can be reduced by attaching a collimator. The ITFN can be reduced by increasing the thermal conductance G_a. In the development of the gamma-ray microcaorimeter, an adhesive with good thermal conducitivity is important.

7. Reference

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