Development of Gamma-Ray Transition-Edge-Sensor Microcalorimeters on Thick Membranes

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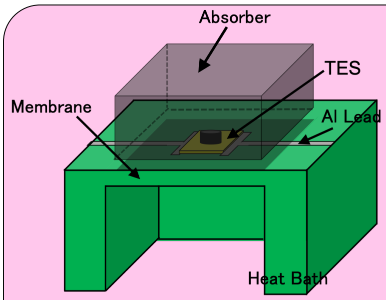
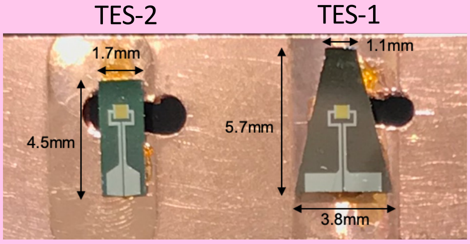
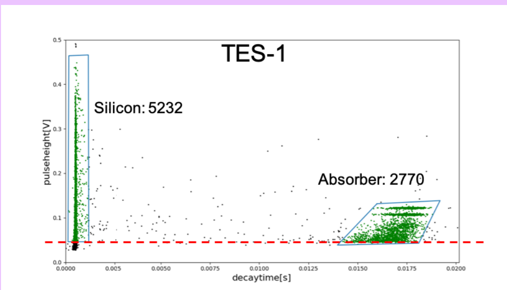
We have been developing a TES microcalorimeter to measure high energy gamma rays up to about 2 MeV. Though large absorbers are necessary for measuring high energy gamma rays, it is necessary to design a thick membrane to support them. However, usually, the thicker the membrane, the higher the thermal conductivity of the thermal link, and the heat of Compton scattering in the silicon substrate flows into the TES, causing noise. Therefore, we investigated how Compton scattering in a silicon substrate affects measurements by fabricating and comparing two devices of different substrate sizes.

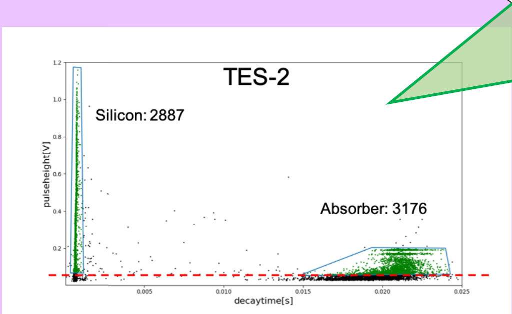


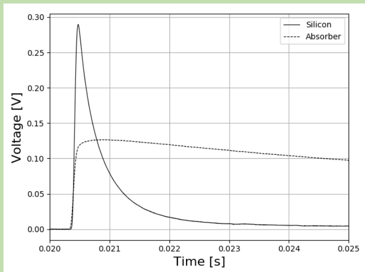


The substrate volume of TES−1 is 5.013 mm^3, and the thickness is 0.359 mm. The new device (TES−2) has a volume of 4.5 mm^3 and thickness of 0.312 mm. TES−2 is 47.6% smaller than TES−1. The thickness of the membrane was not changed. (8 μm)

This photograph shows the Bi absorber bonded to TES. The size of the absorber is 1 mm × 1 mm × 0.8 mm and about 0.012 g.

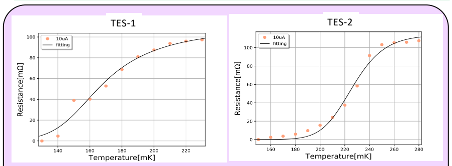




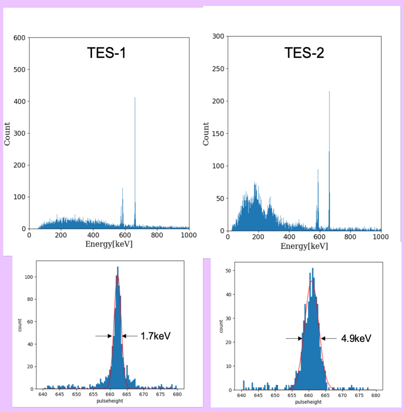


The pulse shape in silicon the substrate shows a fast decay time, and the pulse shape in the absorber has a slow decay time. (The former waveform has various heights.)

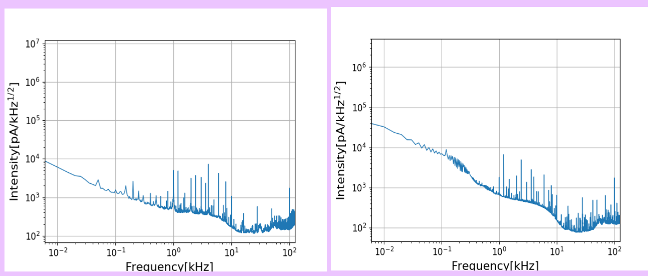
For comparison, the lower limit is set at the same ratio as the peak height (Red Dash).
The silicon signal per 1 absorber signal is 5232/2770 = 1.889 for TES−1 and 2887/3176 = 0.91 for TES−2. We find that the number of gamma rays incident on silicon is reduced by 51.8% with TES−2. Since the volume of the TES−2 device is reduced by 52.4% in comparison to that of TES−1, the silicon signal is also reduced. Therefore, we can confirm that the Compton scattering in the silicon substrate occurred uniformly throughout the substrate.



The transition temperature of TES-1 was 140 mK and that of TES-2 was 210 mK. The transition temperature of TES-2 is higher than expected. The value of α is approximately 15 in both devices, meaning that the device is not ideal.



The energy resolution was 1.7 keV and 4.9 keV for the 662 keV gamma rays of ^{137}Cs and for TES−1 and TES−2, respectively. It was difficult to compare the energy resolution because of the different performance of the two devices, and it was not possible to confirm how much the resolution was improved by reducing the number of gamma rays incident on the silicon substrate. Though the cause is not clear, there seems to be a problem in the fabrication, since the transition temperature is high and (210 mK) α is also small (α=15).



A signal due to Compton scattering in silicon that is too small to be removed appears as noise on the low frequency side. In this experiment, it was not possible to determine the noise at low frequency due to limitations of the equipment. In the next experiment, the low frequency noise will be compared by introducing new equipment currently under preparation.

〈Challenges for the Future〉

・We reconsider the conditions under which TES with appropriate values of transition temperature and α can be fabricated.

・It will be investigated how Compton scattering in the silicon substrate affects the energy resolution by manufacturing the TES device in which the size of the silicon substrate differs from the same silicon wafer.

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