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EVALUATION OF ABSORPTION EFFICIENCY FOR NIS TUNNEL JUNCTION DETECTOR WITH SEGMENTED ABSORBERS

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Abstract

We estimated the X-ray absorption efficiency of an NIS tunnel junction detector as functions of X-ray energy and the number of segmented absorbers employing the EGS4 code. With dividing an absorber into several segments and increasing the thickness of each segmented absorber, the detector can be sensitive to X-rays with higher energy, with keeping the high energy resolution. In addition, the "edge effect" induced by the increase of the number of segments was found negligible.

1 Introduction

Radiation detectors with high energy resolution are required in various fields: X-ray astronomy, neutrino spectrometry, and material analysis. Semiconductor detectors and crystal spectrometers have been very popular as detectors with high energy resolutions: 130 eV and a few eV for 6 keV X-ray, respectively. Semiconductor detectors, however, have to be operated at liquid nitrogen temperature. On the other hand, crystal spectrometer is a wavelength-dispersive one and requires longer measurement time compared to energy-dispersive ones such as semiconductor detectors.

Nowadays, radiation detectors with superconducting material are studied extensively, for this type of detectors have excellent energy resolutions [1,2]. Superconductor radiation detectors, however, have two shortcomings: very low operating temperature and small sensitive area. Most of superconductor radiation detectors are operated at below 100 mK to have better energy resolutions. The typical sensitive areas of superconductor radiation detectors are in the order of $100 \times 100\ \mu\text{m}^2$, i.e., 1/10000 of those of semiconductor detectors.

An NIS (Normal metal - Insulator - Superconductor) tunnel junction detector and a TES (Transition Edge Sensor) are superconductor radiation detectors being classified as calorimeters, which energy resolutions are proportional to the square root of the heat capacities of their absorbers. In case the thickness of an absorber is reduced to have a larger sensitive area, the X-ray absorption efficiency becomes smaller. It is difficult to enlarge a sensitive area without deteriorating the energy resolution and the efficiency of the detector. Radiation detectors with larger sensitive area and high efficiency, however, are desirable, in practical use.

For the enlargement of the sensitive area of an NIS-type detector without deteriorating its energy resolution, we proposed a method to divide the absorber into several parts [3,4]. The heat capacity of each segmented absorber remains small, and in addition, the summed area of them becomes large. Moreover, the detector can be sensitive to high energy X-rays by increasing the number of segments, with keeping the heat capacity of each segmented absorber constant.

In this paper, we estimate the X-ray absorption efficiency as functions of X-ray energy and the number of segments employing the Electron Gamma Shower version 4 (EGS4) code [5].

2 Estimation Method of X-ray Absorption Efficiency

2.1 Method of dividing absorber

Energy resolution of an NIS tunnel junction detector is described as, $\Delta E = A(k_B T^2 C)^{1/2}$ [6]. Here, A is an energy deterioration factor (A>1) and determined by phonon escape and amplifier noise. The constant k_B is a Boltzmann factor. T and C are the temperature and the heat capacity of the absorber, respectively. Therefore, making the volume of an absorber larger to obtain the better absorption efficiency deteriorates energy resolution. With dividing an absorber into several segments and increasing the thickness of each segmented absorber, we can have good absorption efficiency for X-rays with higher energy, with keeping the high energy resolution.

The absorber shown in Fig. 1 (a) with the dimensions of 300μm $\times$ 300μm $\times$ 1μm is taken here as a typical one for NIS-type detectors. Next, we divide the absorber into four parts and make each absorber four times thicker as shown in Fig. 1 (b). The gaps between absorbers are 10μm each. The sensitive area of (b) is the same as that of (a). I n addition, the heat capacity of each segmented absorber is equal to that of (a). Therefore, all the detectors shown in Fig. 1 have the same energy resolution. By increasing the number of segments in this way, as shown in Fig. 1 (c), 64-segmented absorbers have 64-fold thickness of the absorber (a). By absorbers with the increased thickness, good absorption efficiency for X-rays of higher energy is expected.

In the present calculation, energy absorption efficiency is evaluated for the case that an absorber is divided in the way described above. Thickness and width of each segmented absorber is listed in Table 1.

2.2 Monte Carlo simulation code

The EGS4 code is a Monte Carlo simulation code for the coupled transport of photons, electrons, and positrons. We employed Low-Energy Photon-Scattering Expansion for the EGS4 Code (LSCAT) [7] in order to treat low energy photon transport more correctly.

The geometry for the present problem is illustrated in Fig. 1. Photons with energies of 5 to 100 keV are incident normally on the upper surface of Au absorbers from a mono-directional plane source.

3 Results and Discussion

3.1 Absorbed energy spectrum

Figure 2 shows absorbed energy spectrum calculated for the case of 64-segmented absorbers with the X-rays of 100 keV in energy. In the spectrum, there are characteristic peaks around 20, 32, 88 keV. These peaks are attributed to K_β, K_α, L fluorescent X-rays of Au which escaped from absorbers. For the estimation of the geometrical effect of the gaps between the segmented absorbers, absorbed energy spectrum was calculated for the absorber with the same thickness but no gaps. We could observe no significant difference between two energy spectra.

3.2 Absorption efficiency

Figure 3 shows the peak absorption efficiency as a function of the number of segmented absorbers. Here, peak absorption efficiency is defined as the ratio of the number of histories which deposited all the incident energy into the absorbers to the number of total histories. As shown in Fig. 3, 16-segmented absorbers have the absorption efficiency of approximately 95 % for 10 keV X-ray, 25-segmented ones have that of 60 % for 30 keV, and 36-segmented ones have that of 10 % for 100 keV. Therefore, it can be said that, with dividing an absorber into several segments and increasing the thickness of each segmented absorber, an NIS tunnel junction detector can be sensitive for X-rays with higher energy, with keeping the high energy resolution.

Figure 4 illustrates the absorption efficiency for the X-rays with energy of 30 keV when the gap between each segmented absorber varies from 0 to 100μm. The absorption efficiency of 64-segmented absorbers with gaps of 100 μm is approximately 3 % less than that of the absorber with the same thickness but no gaps. Thus, the deterioration of absorption efficiency by dividing an absorber into several parts can be considered negligible.

4 Conclusions

In this paper, X-ray absorption efficiency for NIS tunnel junction detector with segmented absorbers was estimated employing the EGS4 code. From a result of the Monte Carlo simulation, it was shown that, with dividing an absorber into several segments and increasing the thickness of each segmented absorber, an NIS tunnel junction detector with segmented absorbers could be sensitive for X-rays with higher energy, with keeping the high energy resolution. In addition, absorbed energy spectra of 64-segmented absorbers and mono-absorber with thickness of 64 μm were calculated for the estimation of the geometrical effect of the gaps between the segmented absorbers. There was no significant difference between two energy spectra. Additionally, the leakage of X-rays from the edge of absorbers induced by the increase of the number of segments found negligible.

Acknowledgements

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Table 1 Geometrical parameters for the calculation.

Number of absorbers	Thickness [μm]	Width [μm]
1	1	300
4	4	150
9	9	100
16	16	75
25	25	60
36	36	50
49	49	42.9
64	64	37.5

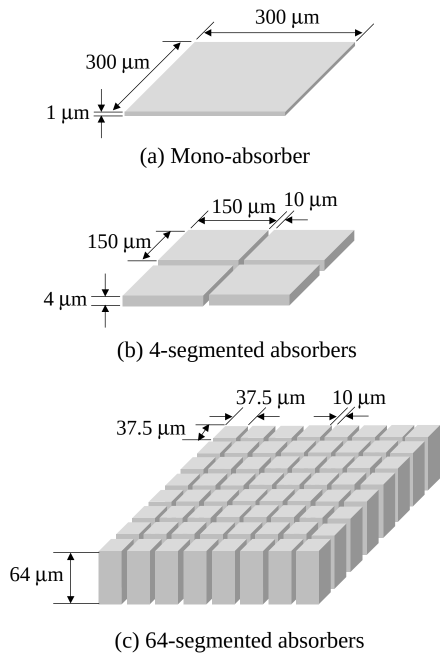

Figure 1: The schematic diagram of a method to divide an absorber into segments.

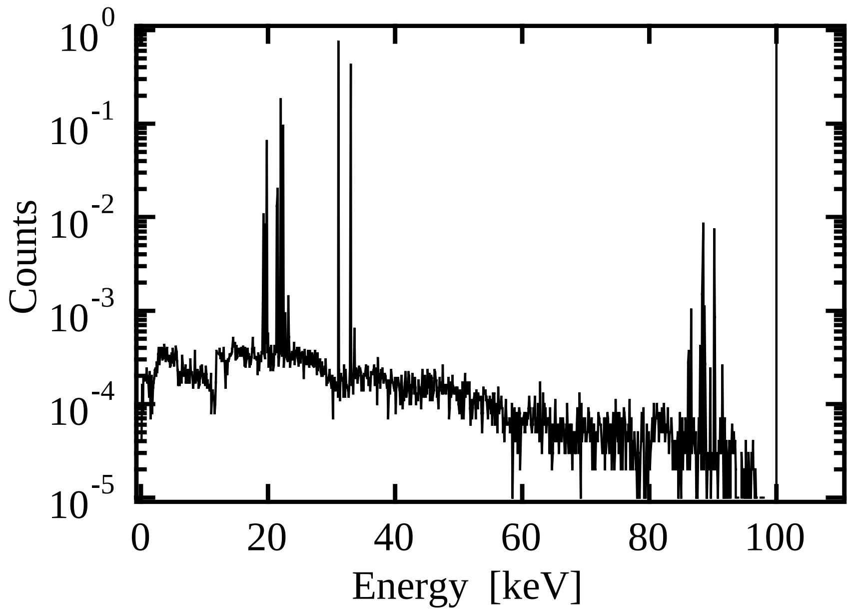

Figure 2: The absorbed energy spectrum for 64-segmented absorbers for X-rays of 100 keV.

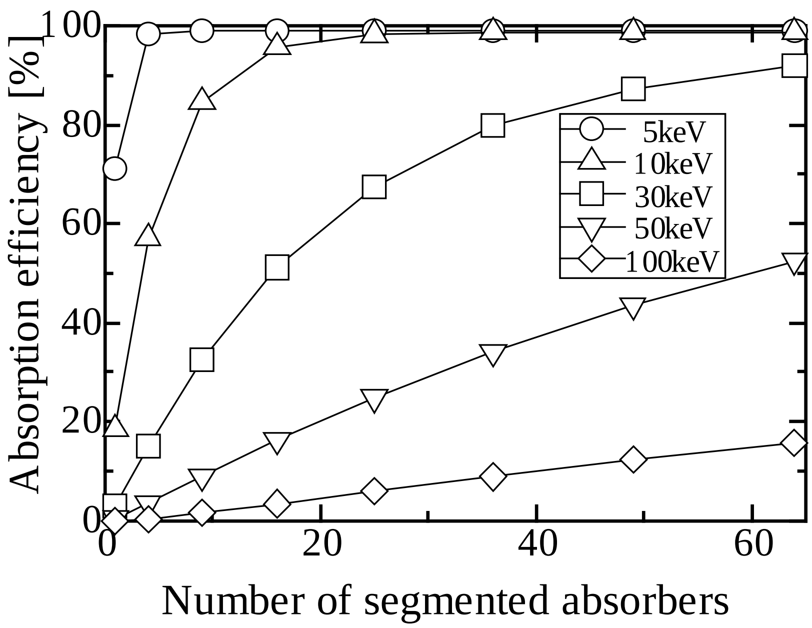

Figure 3: The X-ray absorption efficiency as a function of the number of segmented absorbers. The values of the number of segmented absorbers are equal to the thicknesses of each segmented absorber in μm.

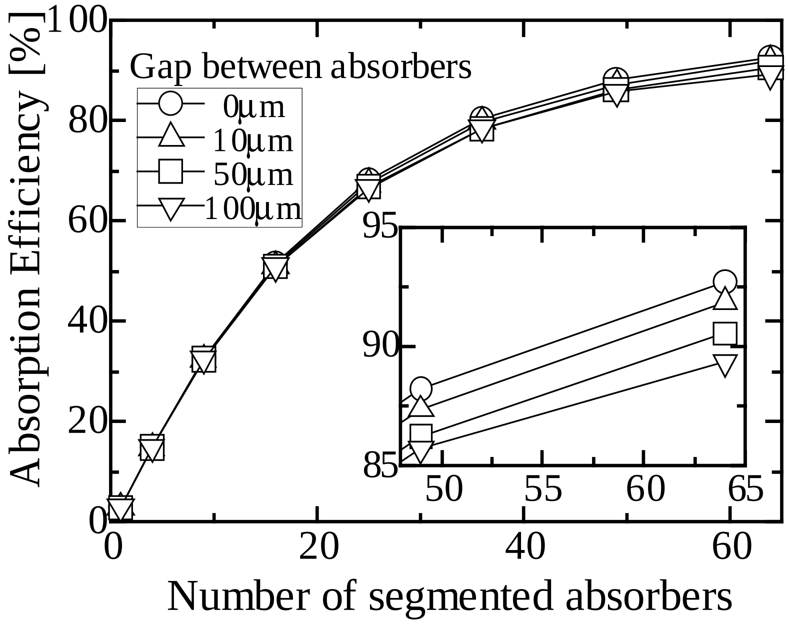

Figure 4: The X-ray absorption efficiency as a function of the gap between segmented absorbers. The incident energy is 30 keV.