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Inhomogeneous spatial response of superconducting x-ray detectors

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Introduction

Superconducting x-ray detectors, which use a superconducting energy gap (2Δ) as a scale for measuring the energy of an incident photon and a superconducting tunnel junction (STJ) as a read-out device, have a theoretical energy resolution better than 0.1%, a moderate x-ray detection efficiency of ~10%, and high count rate capabilities of more than 100k counts/s.

One of the current problems of the superconducting detectors with dimensions larger than 100x100μm^2 is that the energy resolution degrades because of spatial inhomogeneity depending on the photon absorption point. Therefore, imaging diagnosis, which is enabled by Low Temperature Scanning Synchrotron Microscope [1], plays an important role in the detector development. The direct comparison, which has been impossible before, between the inhomogeneous spatial response to x-rays and model calculations has been performed in this study.

Results and discussion

The charge output variation along the diagonal direction shown by the arrow in Fig. 1 for the junction with a size of 146x146μm^2 is shown in Fig. 2. The x-ray beam with a diameter of 5μm and an energy of 5keV was scanned at an interval of 5μm along the diagonal direction, and the charge output values for the absorption events in the bottom electrode was recorded at bias currents of 15nA and 30nA. A standard model (QD model) for the inhomogeneity takes account of the diffusion of quasiparticles, which are produced by the photon absorption, back-tunneling, reflection at the junction edges, and quasiparticle loss at the edges[2]. In the QD model, there are three fitting parameters such as $\beta=L(1-R)/2l$, $\Lambda=[D/(\gamma+\gamma_{loss})]$, $\gamma'=\gamma/(\gamma+\gamma_{loss})$, where L is the length of junction edges, R is the quasiparticle reflection probability at the junction edges, l is the mean free path, D is the diffusion constant of quasiparticles, and γ and γ_{loss} are the tunnel and loss rates of the quasiparticles. The solid lines denote the calculation curves for β=0.353, Λ=8.65μm, γ'=0.703 at 15nA, and for β=0.616, Λ=11.26μm, γ'=0.803 at 30nA. When we take a l value of 10nm for polycrystalline niobium films and a γ_{loss} value of 1/1.4μs is assumed, the quasiparticle reflection probabilities at the edges and the diffusion constants are calculated to be R=0.99995, D=1.8cm^2/s at 15nA, and R=0.99992 and D=4.5cm^2/s at 30nA. The calculation curves perfectly fit the experimental data. There is, however, no chance for the R and D values to depend on bias current. Therefore, it is concluded that the QD model is inadequate for the present junction. We have also revealed that the spatial inhomogeneity of the charge output changes with junction size, the strength of magnetic field applied to suppress Josephson effects. These results imply that there are new signal creation mechanisms other than the conventional quasiparticle tunneling.

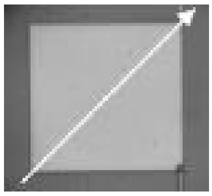

Fig. 1. Photograph of a superconducting detector and scanning direction.

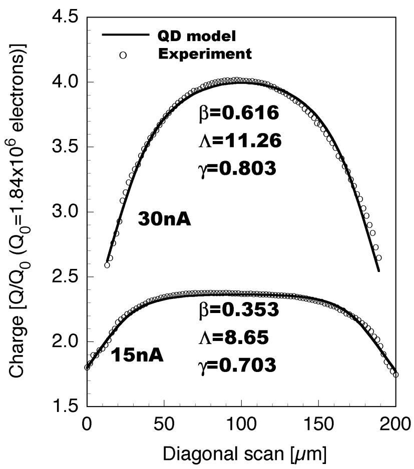

Fig. 2. Charge output vs. x-ray beam position along the diagonal direction for a superconducting tunnel junction x-ray detector with a size of 146x146μm^2 at different bias currents.

References

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