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Quasiparticle recombination in STJ X-rays detectors

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Abstract

Response of the superconducting tunnel junction X-rays detector Ti/Nb/Al/AlO_x/Al/Nb/NbN with the Ti killed electrode was obtained for different photon energies by the X-rays fluorescence method. A strong nonlinearity of the detector response was analyzed on the basis of a diffusion model taking into account the quasiparticle self-recombination and edge losses.

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Keywords: Superconducting tunnel junction; Detector; Quasiparticles; Recombination

1. Introduction

Superconducting tunnel junction (STJ) detectors have excellent energy resolution. Now these detectors are used in precise X-rays analysis, astrophysics and in some other applications. Unfortunately, the energy resolution of real STJ-detectors usually several times worse than the theoretical limit. The main reason of line broadening is the spatial dependence of the detector signal on the photon absorption site. There are two main mechanisms of this broadening: edge losses of the quasiparticles and the quasiparticle self-recombination. The edge losses are caused by quasiparticles trapping in the regions with a lower energy gap formed at electrode edges during the STJ fabrication process. In this case the amplitude of the signal is reduced as the photon absorption point approaches to the electrode edge [1].

The recombination losses were considered in Refs. [2–4]. It was shown that the quasiparticles self-recombination could cause the signal dependence on the photon absorption site. Unfortunately, the analysis [4] was done in the complex case of the multitunneling mode of the detector.

In this work we propose to study the quasiparticle self-recombination in STJ detectors of special construction, when only one electrode is active and in the other electrode the backtunneling is suppressed by an additional trapping layer placed at the side opposite to the tunneling barrier (killed electrode). Such STJ construction is best to reveal the self-recombination effects.

2. Experiment

STJ detectors with layer structure Ti/Nb(1)/Al(1)/AlO_x/Al(2)/Nb(2)/NbN (30/100/6/2/13/150/30 nm) were fabricated in IRE RAS. The top Al(2)/Nb(2)/NbN electrode with proximity Al-trapping and NbN-reflecting layers was the main absorbing electrode. The bottom Ti/Nb(1)/Al(1) electrode had Ti trapping layer at the surface opposite to the tunnel barrier and worked as killed electrode for excess quasiparticles. Five STJ detectors with areas S 400, 400, 1800, 6400 and 20000 μm^2 were patterned on a chip. The detectors were of rhombus shape with diagonal ratio (1:2). The barrier resistance was $R_N S \approx 3.3\ \mu\Omega\,cm2$. The samples and the experimental setup are described in Ref. [5].

The detectors were irradiated by radioactive sources ^{55}Fe and ^{57}Co. In order to study of the detector response as a function of photon energy in one run, we used the method of X-rays fluorescence for the additional X-ray lines

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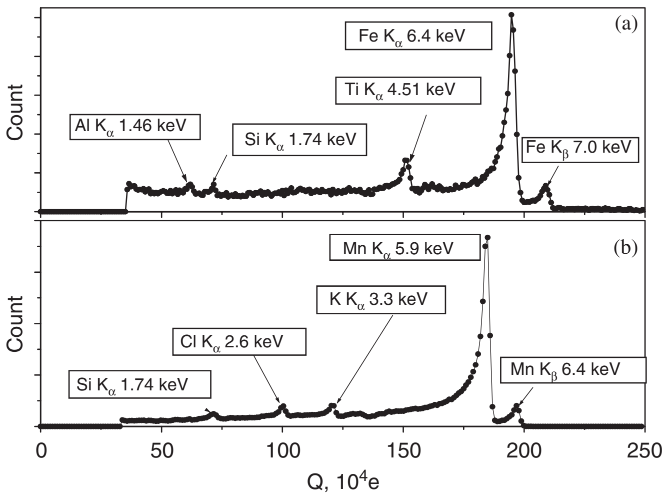

Fig. 1. Pulse height spectra of STJ detectors: (a) ^{57}Co + Ti-screen and (b) ^{55}Fe + KCl filter.

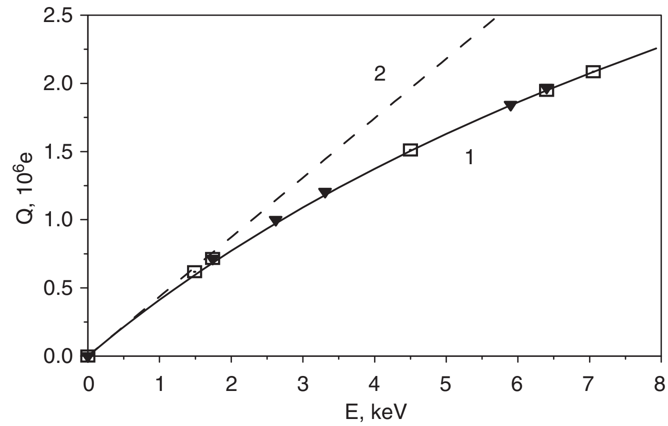

Fig. 2. The dependence of the signal on the photon energy. Squares—^{57}Co + Ti-screen; triangles—^{55}Fe + KCl filter; curve 1—the diffusion model calculations; and line 2—the signal without recombinations.

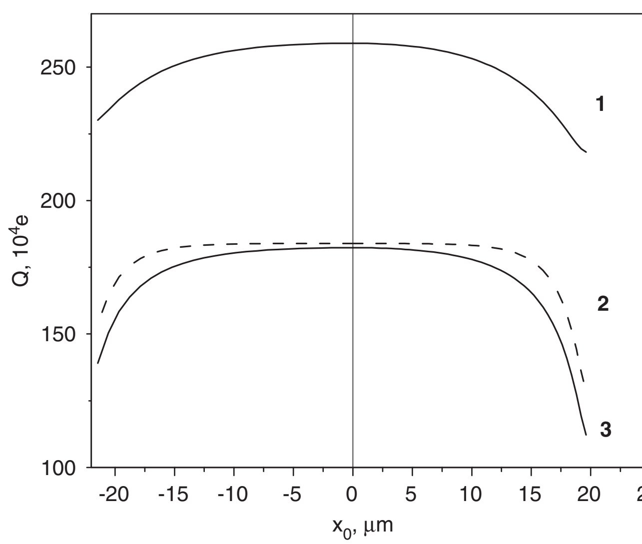

Fig. 3. Dependences of the signal Q on photon-absorption coordinate x_0 for the detector with $S = 1600\,\mu m^2$. Positive X-axis—along the short diagonal of the electrode, negative X-axis—along the line connecting the electrode center and the middle of a side. (1) $R_{ef} = 0$, $\beta = 0.036\,\mu m^{-1}$, (2) $R_{ef} = 2\times10^{-5}\,\mu m^2$, $\beta = 0$, and (3) $R_{ef} = 2\times10^{-5}\,\mu m^2$, $\beta = 0.036\,\mu m^{-1}$.

generation. Two experimental geometries were used: with X-rays screen and with X-rays filter. In the first case the Ti cylindrical screen was placed so that its axis coincided with the line connecting the detector and the source. In geometry with the X-rays filter the thin KCl film was positioned between the source and the detector.

Fig. 1a and b show the pulse height spectra obtained by STJ detectors with the area 6400 μm^2 in the setups with the Ti screen and with the KCl filter. There are five sharp lines in every spectrum. Besides X-ray lines from the sources and the screen or the filter, there are additional weak Si K_α and Al K_α lines which were excited by the source radiation in the Si substrate and Al-layers of the detector.

The width of the lines in the spectra is much larger than the theoretical limit of about 5 eV. In particular, the width of 5.9 keV Mn K_α line is about 120 eV at the noise level of 60 eV. Note that there is no sharp 14.4 keV source line in the case of ^{57}Co. Instead of this line, the continuous spectrum due to the photoelectrons escape from the electrode is observed as a background.

Both spectra were used for obtaining the dependence of the detector signal on the photon energy. The data displays the strong nonlinearity of this dependence (Fig. 2).

3. Diffusion model

The data was considered on the basis of a diffusion model. The model takes into account the quasiparticle diffusion in the top electrode, quasiparticle tunneling and losses, additional losses at electrode edges, and the quasiparticle self-recombination. The signal amplitude (collected charge) was numerically calculated for different photon absorption sites, and then the spectral line shape was calculated under conditions of the homogeneous irradiation.

The main parameters of the model were the tunneling probability $P_1 = \gamma_T/(\gamma_T + \gamma_L)$, where γ_T and γ_L are quasiparticle tunneling and loses rates, the diffusion length Λ_D, the edge losses parameter β [1] and the quasiparticle effective recombination coefficient R_{ef} [3,6]. The model calculations of the detector signal Q versus photon absorption point are shown in Fig. 3. The recombination and edge losses induce the signal reduction for photon absorption points in edge regions and cause line broadening.

Experimental data were analyzed in two steps. In the first step the dependence of the detector response on the photon energy was considered. The result of the fitting is shown in Fig. 2 by the solid line. In the next step the line shape for the most intensive Mn K_α line was fitted. The variable parameters were selected to give the best description of the spectra obtained for detectors of different sizes.

Calculations have shown that both factors, the self-recombination and edge losses, broaden the detector line.

4. Conclusion

The strong nonlinearity of the detector response is due to the quasiparticle self-recombination which is strengthened by 2Δ-phonons absorption in the Ti trapping layer.

An additional amplifying factor of the self-recombination is the slow diffusion of quasiparticles in the polycrystalline electrode [2].

The analysis has shown that the quasiparticle self-recombination reduces the signal amplitude, causes the nonlinearity of the energy dependence of the signal and induces broadening of the detector line.

The diffusion model with a recombination term and edge losses is able to reproduce all main features of the detector line shape and to explain the dependence of the signal on the photon energy.

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References

[1] O.J. Luiten, et al., in: S. Cooper (Ed.), Proceedings of Seventh International Workshop on Low Temperature Detectors (LTD-7), Munich, Germany, 1997, p. 25.
[2] V.A. Andrianov, et al., Phys. Solid State 41 (1999) 1063.
[3] A.G. Kozorezov, et al., Phys. Rev. B 66 (2002) 094510.
[4] R. den Hartog, et al., Phys. Rev. B 66 (2002) 094511.
[5] M.G. Kozin, et al., Nucl. Instr. and Meth. A 520 (2004) 250.
[6] S.B. Kaplan, et al., Phys. Rev. B 14 (1976) 4854.