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Search for a Radiation Detector using a Superconducting Tunnel Junction

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Electric signals induced by $Ga_xAl_{1-x}As$ pulse-laser light in an Sn-SnO_x-Sn superconducting tunnel junction (STJ) have been observed in the temperature region of 1.4~4.2 K. Comparison of the present results with our previous works with α rays as well as with laser light suggests that an STJ would be a useful radiation detector.

KEY WORDS: Superconductivity/ Tunnel junction/ Laser light/ Radiation detector/

One of the most interesting features of superconductor is the existence of a very small energy gap (~1 meV) at the Fermi surface, and this promoted various attempts[1~7] to apply it as a radiation detector with much better energy resolution than a semiconductor detector. These works revealed many fundamental aspects of superconductor, but so far the practical use of a superconductor as a radiation detector has not yet been established.

Recently, we have studied the electric signals induced by α-particles in a crossed-film STJ of Sn and found that the impulsive change in I-V characteristics of the STJ cannot be explained simply by the localized superconducting-normal transition due to temperature increment, but excess quasiparticles are essential to the characteristic change in the STJ.[8]

Based on this experimental evidence, we searched the possibility of a high-resolution nuclear radiation detector consisting of a superconductor-insulator-superconductor tunnel junction. First, estimation of the mean energy loss ε by radiations per excess quasiparticle in a superconductor was made by taking into consideration the energy shared by the lattice. It has been found that the upper limit of ε is 4Δ, where Δ is the half of the gap energy.[9] Note that more refined estimation gave that $\varepsilon=1.68\Delta$ and the Fano factor $F=0.2$ for Sn.[10] Second, we studied the potential application of STJ as a detector in view of the signal to noise (S-N) ratio.[11] By taking into account the recombination effect of quasiparticles, the radiation-induced signal is analytically obtained in connection with the time constants of the junction and the amplifier. The estimation revealed that the S-N ratio for ~5-MeV α-particle detector is about 36000 for conventional empirical conditions, which is much better than that for a semiconductor detector.

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In the previous experiment with α rays,[8] the energy spectrum measured for a constant current did not form a peak, but spreaded to a rather wide region (see Fig. 2 of Ref. 8). Analytical explanation for this broadness could not be made, but as pointed out in the work, there are three possible reasons. (i) Since the sample thickness ($\sim$6000 Å) is much smaller than the mean range of $\sim$5-MeV α particles, statistical fluctuation of energy losses by ionization is relatively large even for an equal path length. (ii) The pulse height sensitively reflects the span of particle path length. In other words, different incident angle (0 $\sim$45°) of α particles directly affects the energy deposition in the sample. (iii) Since the sample is a crossed-film type, the number of excess quasiparticles which contribute to the change in the I-V characteristics may depend on the incident position of α particles on the junction, *i.e.,* the diffusion effect of excess quasiparticles from the junction to the electrodes plays some role to prevent the production of a sharp peak.

To overcome these ambiguities, the whole-surface irradiation of laser light, instead of α rays, is preferred. As the first step, we attempted to measure the time spectrum of laser-induced signals from an STJ.[12] Using an STJ of Sn (0.3×0.4 mm^2, total thickness is $\sim$4000 Å), electric signals induced by $Ga_xAl_{1-x}As$ pulse-laser light were observed. The characteristics of the laser diode are; wave length 8300 Å, threshold current 200 mA, rise time 1 nsec, and the maximum power 5 mW. The repetition rate was 30 kHz and the pulse width was 300 nsec. Since the signals from the STJ were so small ($\sim$7 μV) and completely masked in the noise level (100 $\sim$ 150 μV) of the measuring system, we have developed a convenient method for observation of electric signals obscured by background noise.[13] By this method, we successfully observed the time spectra of laser-induced signals.[12]

In the above experiment, however, due to the dc Josephson current flowing through the junction, we had to use relatively high bias current ($\sim$3 mA), and this eventually resulted in observations of the change in energy gap. In order to get larger electric signals, it is preferred to apply much smaller bias current. For this purpose, the sample room was mounted in a superconducting magnet and the dc Josephson current was suppressed by applying a weak magnetic field ($\sim$5 Gauss) to the STJ. Besides, in the present measurement, the power irradiated to the STJ was much lowered than that in previous measurements, less than 1/10. Consequently, at the bias current of 3 mA, no electric signals could be observed. This was naturally expected, because at this bias current, the electric signals reflect only the change in energy gap.

In Fig. 1 are shown the typical I-V characteristic curve of the STJ in the magnetic field at 1.4 K, as well as the experimental point where the time-spectrum and pulse-height measurements were carried out. It is noted that at this experimental point, the electric signals induced by laser light can be expected to be much larger than those at 3 mA bias current. In fact, as shown in Fig. 2, we observed a clear time spectrum even for a small power of laser light. And it is evident that the peak height of the present time spectrum is much improved when compared with Fig. 6 of Ref. 12.

In Fig. 3 are shown the pulse-height distributions of the signals from the STJ: (a) is the distribution of the signals induced by laser light, and (b) is the distribution

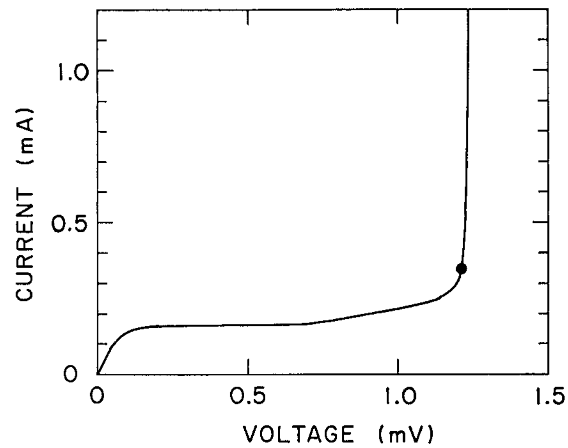

Fig. 1. The *I-V* characteristic curve of the junction exposed to a weak magnetic field. The closed circle indicates the measuring point.

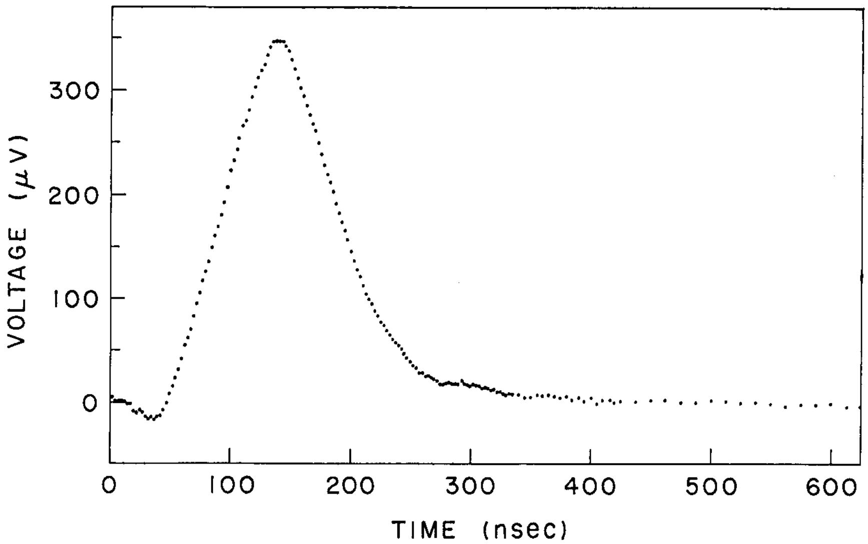

Fig. 2. Time spectrum of signal induced by laser light before subtraction of systematic noise.

obtained by supplying pulser outputs to the test-input terminal of the preamplifier connected to the STJ (without irradiation of laser light).

The spectrum (a) appears to show single peak. In a series of present measurements, however, the spectrum induced by laser light showed multipeak in many cases (not shown in the figure). The reason of this is not clear yet, and hence even for (a) we cannot say definitely that the absorbed laser energy per beam was really unique. Nevertheless, it is apparent that the spectrum (a) supports our view mentioned above concerning the broadness of α-particle induced spectra, *i.e.,* the use of laser light eliminates three ambiguities involved in α-particle irradiation.

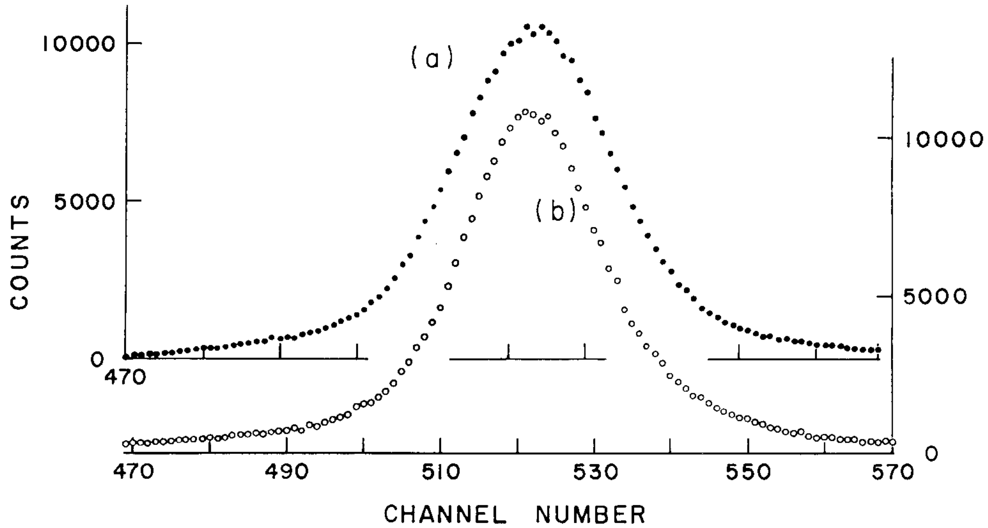

Fig. 3. Pulse-height distributions of the signals from the STJ: (a) is the distribution of the signals induced by laser light, and (b) is the distribution obtained by supplying pulser outputs to the test-input terminal of the preamplifier.

It is interesting to point out that the spectrum (b) has a similar peak width to (a). This indicates that the width of (a) is mostly shared by the electric noise of measuring system, and therefore if the noise can be effectively suppressed, an STJ would be a powerful radiation detector with an excellent energy resolution, we believe. More refined experiment with X rays is in progress.

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