Research of superconducting tunnel junction X-ray detectors with direct signal observation method using a fast current readout system

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Abstract

We have developed a fast current readout system for STJ detectors with a fast current preamplifier by direct signal observation. The preamplifier has frequency bandwidth of 110 MHz with stable voltage bias operation. By the various experiments using a Ta STJ and Nb STJ, it is confirmed that the readout system is effective for the evaluation of STJs, research of the mechanism for signal production process and the X-ray detection with high counting rate.

1. Introduction

We have studied superconducting tunnel junction (STJ) X-ray detectors by direct signal observation method using a fast current readout system (Refs. [1,2]). The purposes of use of the current readout system are; (1) to evaluate performances of the STJ for fabrication of excellent STJs, (2) to research the detection mechanism of STJs and (3) to realize a high counting rate and high-energy resolution X-ray detector using the STJ in practical. For this purpose, it is necessary to observe directly fast current pulses produced in STJs. Although SQUID readout systems have been applied on the current amplification of STJs recently, the frequency bandwidth for the SQUID is about 5 MHz (Ref. [3]). Therefore, a fast low-noise current preamplifier with bandwidth of 110 MHz was developed and a fast current readout system was constructed.

2. Current readout system

Fig. 1 shows the current readout system constructed for research of superconducting tunnel junction X-ray detectors. The readout system consists of a fast current preamplifier with a bias circuit, a current pulse dividing circuit, fast integral amplifiers, spectroscopy amplifiers, rise time to pulse height converters and a three-dimensional MCA system.
The current preamplifier developed is shown in Fig. 2. The STJ is operated with a stable voltage bias by using the circuit with a pulse transformer. The bias voltage is directly measured using a low-noise DC amplifier set up near the STJ in a cryostat. Current signals produced in the STJ are amplified by the fast low-noise current amplifier (SA-230F5) with a frequency bandwidth of 110 MHz. Rise time of the current readout system is less than 10 ns. Moreover, the stable voltage bias can be applied by using a pulse transformer.

The direct current pulse signals are divided into two current signals of rise (fore) and decay (rear) parts by a current pulse dividing circuit with linear gate circuits. The charges of two parts are integrated, respectively, by the integral circuits. The current signal is integrated by the integral amplifier in order to obtain total charge, which is normally measured by a conventional charge sensitive amplifier. Current duration time is obtained by measuring rise time of the total charge signal. Moreover, rise time of the direct current signals is analyzed by the rise time to pulse height converter. Various correlations between these parameters are analyzed by the three-dimensional MCA system.

3. Experimental and results

The evaluation experiments of this readout system were carried out with a Ta/Nb/Al/AlO$_x$/Al/Ta/Nb STJ fabricated by Nippon Steel Co (Ref. [4]). Thickness of the films are 150, 10, 15, 2, 30, 150 and 50 nm, respectively. Applied bias voltage is 0.4 mV. Fig. 3 shows typical current pulses of the STJ measured by the fast current preamplifier. One can see that the current rise part of the pulses consists of three components. The fastest rise time observed in the pulses of the Ta STJ is 20 ns due to the limit by the current preamplifier. At the end of this part, the signal reaches the half of the current peak. The rise time and the decay time for the pulses are 0.12 and 1 $\mu$s, respectively.
Fig. 3. Typical current pulses measured by a fast current pre-amplifier with frequency bandwidth of 110 MHz.

Fig. 4 shows the correlation along the charge rise time (i.e., pulse duration time), the current rise time and total charge of the Ta STJ measured by using a $^{55}$Fe X-ray source. These results show that the signals produced in each electrode of the STJ can be separated. Also, the correlation between the current rise time and the pulse duration time for the counter electrode is different from that for the base electrode.

Usually, the pulses produced in the counter electrode and the base electrode of the STJ can be distinguished by the difference of the current rise time (Ref. [5]). In case of the Ta STJ, the rise time of current pulse produced from both electrodes is almost same, as shown in Fig. 5. However, the pulses for both electrodes can be distinguished by using ratio of the integrated charges in the rise part and the decay part as shown in the same figure because the slope of the ratio versus the total charge is different.

On the other hand, another important advantage of the current amplification is that detection of X-rays with high counting rates is possible. A Nb/Al/AlO$_x$/Al/Nb STJ was fabricated in a condition of a Josephson current of 500 A/cm$^2$ for this purpose. Applied bias voltage is 0.1 mV and magnetic field is 100 G. Typical current pulse of this Nb STJ by using the developed fast current amplification.
preamplifier is shown in Fig. 6. The rise time and the duration time are 0.1 and 0.26 $\mu$s, respectively. Fig. 7 shows X-ray spectra for total charge obtained by using the integral circuit and current peak obtained by using a peak hold circuit. One can see that the X-ray spectrum for the current peak is improved compared to that for the total charge. These results show that X-ray measurements with high counting rate more than 100 kcps might be carried out with combination use of STJs having short duration time, the fast preamplifier and the fast peak hold circuit.

4. Conclusion

We have developed the fast current readout system with the fast low-noise preamplifier. By the various experiments, it is confirmed that the readout system is effective for the evaluation of STJs, research of the mechanism of signal production.
process and the X-ray detection with high counting rate.

References


