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X-ray spectroscopy in atomic collision experiment using superconducting tunnel junctions

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Abstract

A superconducting tunnel junction (STJ) is a newly developed X-ray detector which has advantages of not only high energy-resolution but also timing information and high counting-rates. The STJ fabricated in RIKEN has a layered structure of Nb (200 nm-thick, lower electrode)/Al (50 nm)/AlOx/Al (50 nm)/Nb (150 nm, upper electrode). Its sensitive region has an area of 100×100 μm^2. The output signals were amplified by either a charge-sensitive amplifier or a SQUID amplifier. We used the STJ to measure X-rays emitted in collisions of highly charged ions with various solid targets. The ions used were Ne, O and Ar of 10 kV/q extracted from an ECR ion source at RIKEN. The X-ray spectra from 500 to 900 eV were obtained with an energy-resolution of 20–30 eV at a counting-rate higher than 500 counts/s.

Keywords: Superconducting tunnel junction; X-ray; Atomic physics; Highly charged ion; SQUID amp

1. Introduction

In atomic physics, a precise measurement of X-rays from atoms or ions is very important. Superconducting tunnel junction (STJ) X-ray detector provides not only high energy-resolution, but also timing information with high counting-rates, i.e., various coincidence measurements among X-rays, charge states of projectiles and recoil ions, recoil momentum, etc. get feasible with high energy-resolution of X-rays. When a slow highly charged ion approaches a solid surface, the ion is accelerated toward the surface with its image potential and then the ion resonantly captures valence electrons from the surface into its highly excited states keeping inner shell vacancies, which

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is called a hollow atom (ion) [1]. Since the hollow atom so formed exists until it arrives at the surface, its existence time is $\sim 10^{-13}$–10^{-14} s, which would be shorter than its intrinsic lifetime. To avoid the hollow atoms hitting against the surface and to observe their intrinsic nature, a microcapillary target is employed [2,3].

Before using the microcapillary target, a collision experiment which used a flat surface target was carried out with STJ detector, because the yield of X-rays by the stainless target is higher than that by the microcapillary target. The STJ fabricated in RIKEN was characterized with 5.9 keV RI source and an energy-resolution of 41 eV was achieved. However, depending on the X-ray energy and the thickness of absorption electrodes of the STJ, two peaks appear in pulse height distribution made by a charge-sensitive amplifier even for monochromatic X-ray, which correspond to the absorption at the upper and lower electrode. In order to select the upper absorption events, we made a waveform analysis with a superconducting quantum interference device (SQUID) amplifier, which is a kind of current-sensitive amplifiers. The method of the analysis is described in Ref. [4]. The experimental setup and measurements are respectively reported, in Sections 2 and 3, and the summary is presented in Section 4.

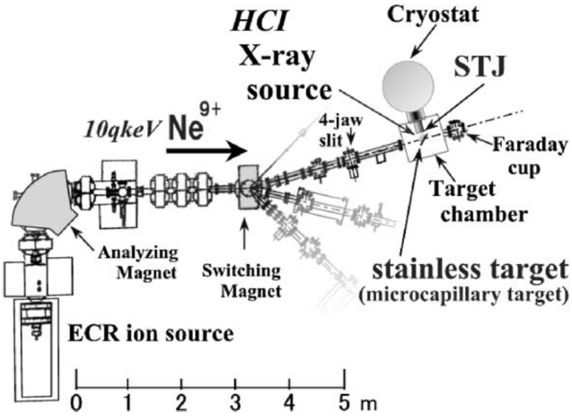

Fig. 1. Schematic view of the beam line.

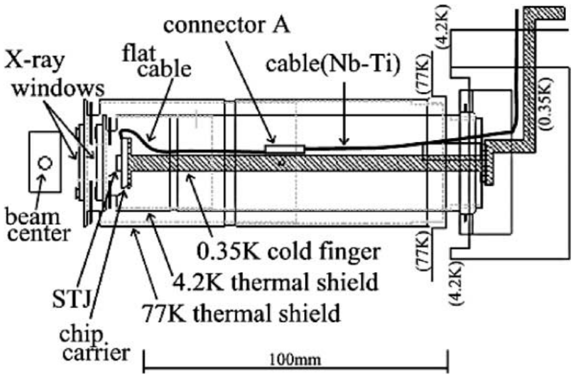

Fig. 2. Drawing around the STJ.

2. Setup

A schematic view of the beam line is shown in Fig. 1. Ions extracted from a 14.5 GHz Caprice type electron cyclotron resonance (ECR) ion source were transported through a momentum-analyzing magnet and a switching magnet, and then collimated by a four-jaw slit to a size of 6×6 mm^2. The target chamber, whose dimension was $120 \times 120 \times 120$ mm^3, was sandwiched by a Helmholtz coil to apply a magnetic field of 5–30 mT for STJ operation. The ion current was monitored by a Faraday cup installed downstream of the target chamber. The surface target was made of stainless steal with a size of about 10×10 mm^2. The angle between the target surface and the beam was 45°. The STJ was mounted on a cold stage of a cryostat. A drawing around the STJ is given in Fig. 2. The cryostat was a depressurized ^{3}He refrigerator directly connected to the target chamber. After about 7 h preparation for cooling, the STJ was kept at 0.35 K for more than 10 h without any additional cryogenic fluids. The X-ray windows in front of the STJ must eliminate a thermal radiation from higher temperature stages. And they must have a large transmission for X-rays. The windows used here were 100-nm-thick Al films supported by a nickel mesh whose aperture was about 80% so that the total transmission of soft X-rays around 900 eV was kept more than 50%.

The STJ had a layer structure of Nb (200 nm thick, lower electrode)/Al (50 nm)/AlOx/Al (50 nm)/Nb(150 nm, upper electrode). Its sensitive region has an area of 100×100 μm^2. It corresponds to the solid angle of $1.4 \times 10^{-6} \times 4\pi$ sr for the distance of 24 mm along radial direction, which was the distance between the beam center and the STJ surface. The STJ chip of $5 \times 5\ mm^2$ was glued on a chip carrier with a flat cable. The flat cable and a Nb–Ti cable were connected by the connector A so that the replacement of the STJ can be done easily. The SQUID amplifier was mounted at 4.2 K stage. The output signals from the SQUID were amplified again at the room temperature amplifier whose gain was 100.

3. Measurements

Ions were Ne^{9+}, O^{7+} and Ar^{14+} accelerated by 10 kV. The pressure in the target chamber was about 10^{-7} Torr. The beam intensity at the target was 50–100 nA. The counting-rate of the STJ was higher than 500 counts/s. Fig. 3 is an energy spectrum of Ne^{9+} K X-rays obtained by the STJ. The Ne^{9+} K X-rays have the energies of the satellite X-rays ranged from 840 to 890 eV. The solid line showed the spectrum obtained with a charge-sensitive amplifier (ORTEC 142). On the other hand, the hatched peaks were obtained with the SQUID amplifier. Fig. 4 is a spectrum of O^{7+} K X-rays with the charge-sensitive amplifier. Both spectra were obtained at the same gain of the charge-sensitive amplifier. The peak around 500 ch in Fig. 3 and the peak around 310 ch in Fig. 4

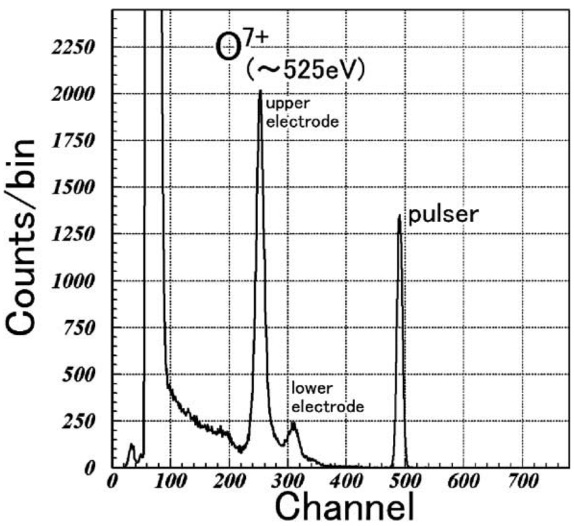

Fig. 3. Energy spectrum of Ne^{9+} K X-rays obtained by STJ.

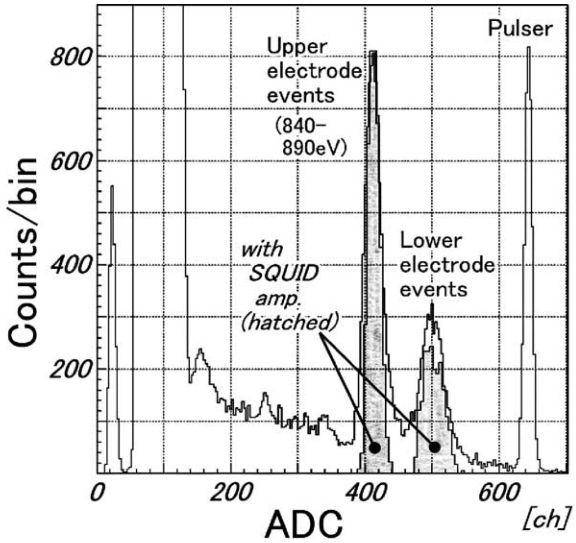

Fig. 4. Energy spectrum of O^{7+} K X-rays.

came from the events which the K X-rays were absorbed at the lower electrode of the STJ. Using the SQUID amplifier, these two electrode events were separated clearly in off line analysis. The decay time of the signal from a lower electrode event is longer than that of upper one. In off line analysis, this difference in the decay time was considered. Fig. 5 is a scatter plot of a ratio of

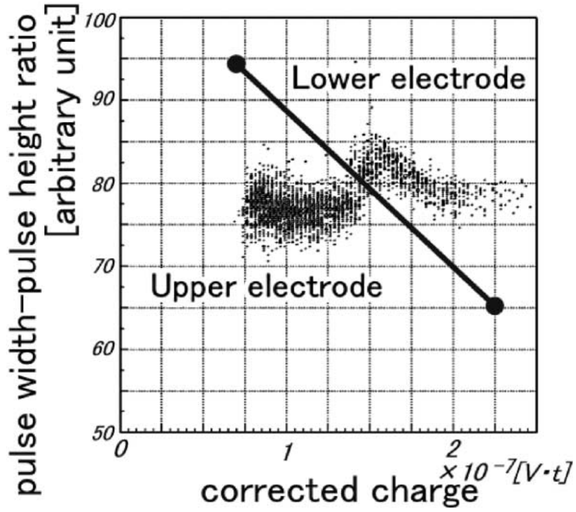

Fig. 5. Scatter plot of a ratio of pulse width to pulse height as a function of corrected charge which is proportional to the energy for Ne^{7+} ions.

pulse width to pulse height as a function of corrected charge which is proportional to the energy for Ne^{7+} ions. Both upper and lower event distribution in the scatter plot have tails at high-energy sides. The reason is expected to be the pile-up events or the phonon events from the peripheral region, because the counting-rate was more than 1000 counts/s only for the SQUID amplifier operation. Pulser peaks for the evaluation of electronics noise were included in the spectra. They were generated by the simulated signals from a pulser module. The electronic noise levels of the charge-sensitive amplifier and the SQUID amplifier were 20–30 eV and 15 eV, respectively.

4. Summary

The STJ was used in an atomic physics experiment. The X-ray spectra were obtained from Ne, O and Ar ions with an energy-resolution of 20–30 eV and a counting-rate of higher than 500 counts/s. A SQUID amplifier was successfully used for separating the upper electrode events from the lower electrode events.

Acknowledgements

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