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Nuclear Instruments and Methods in Physics Research A 520 (2004) 617–620

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Multispectral/fluorescence CT using superconducting tunnel junction detector for 3-D material analysis

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Abstract

We have developed superconducting tunnel junctions (STJs) for applications to astrophysics, particle physics, material physics, etc. The spectrum capability of STJs is the wide wavelength/energy range from visible light to X-ray. STJs are applicable to photon detectors with good energy resolution and a high photon-counting rate. STJs also have good efficiency because of their high absorption efficiency below 1 keV photon energy. This is advantageous in low photon emission observation like fluorescence from objects. STJs have potentials to open new windows of the Multispectral/fluorescence computed tomography (CT) below 1 keV photon energy. As first step, we are starting STJ-CT experiments from the high-energy X-ray region (6–20 keV). We report and discuss the CT using STJs.

PACS: 85.25; 07.57.K; 07.85.F

Keywords: Superconducting tunnel junction; Series array; Radiation detector; Computed tomography

1. Introduction

Computed tomography (CT) is well established in medical X-ray imaging. The reconstructed images give us a dramatic impact and huge information. CT is applied also in the optical, UV, sound wave, etc., and is a very useful tool in various fields, for example, in biological science, materials science, plasma science, semiconductor industry, etc. This method is extended to 3-D CT, where the 3-D image are constructed from a series of 2-D CT image [1]. Although CT in high energy X-ray is able to determine distribution of heavy elements, it is difficult to determine distributions of light elements. Soft X-ray is suitable for light elements. This energy region, including the water window, is very important for biological science. However, CT below the 1 keV photon energy region, from EUV to soft X-ray, is underdeveloped. The reason is that there is no high sensitive detector in the region. Superconducting tunnel junctions (STJs) are one of the detector candidates for low energy photon. STJs have the potential to be used as photon detectors with a good energy resolution and a high photon-counting rate. STJs are also good detector for the photon detection in soft X-ray and EUV bands, because the materials

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2003.11.330

of STJs have high absorption below 1 keV. Theoretically, the reflectivity for the normal incidence of soft X-rays and EUV photons is below 0.04 and the detection efficiency is almost 100% in this energy region [2].

The combination STJs and CT, is expected to become an important tool for various fields. As a first step, we are starting STJ-CT experiments from the high energy X-ray region (6–20 keV).This paper reports the concept of CT using STJs and preliminary results of the high energy X-ray CT.

2. Superconducting tunnel junction detector

STJs have a potential to realize better energy resolutions because of their small break-up energy for Cooper pairs. So far, detectors using single STJ have been developed by many groups including us. We have developed Nb STJs with Al trapping layers on both sides of the tunnel barrier (AlO_x). We have fabricated and tested them by measuring X-ray spectra. We have achieved an energy resolution of 41 eV for X-rays with an energy of 5.9 keV [3]. Note that this value is three times better than the theoretical limit for semiconductor detectors. However, because of the superconducting layer of the STJ is very thin (several hundred nano meter), STJ is transparent for photons whose energy is above several 10 keV. In addition, the size of the single STJ is typically $100 \times 100\ \mu m^2$. Therefore, a multi-pixel STJ chip should be needed to realize large detection area and there are many difficulties with signal readout. To overcome these problems, we have started to develop substrate-absorption-type cryogenic detectors using series array STJs [4]. The chip is shown in Fig. 1. High-energy X-rays could be detected by selecting a suitable substrate material, and large effective area could be realized easily.

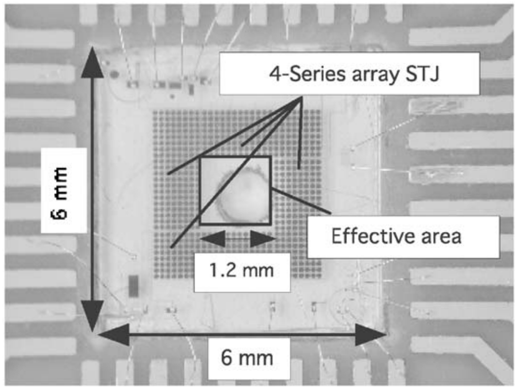

Fig. 1. Substrate-absorption-type cryogenic detectors using series array STJs.

3. Computed tomography using STJ

The measurements for tomographic reconstructions are sets of line integrals of the absorption along rays crossing the sample. A 2-D image is reconstructed from a series of 1-D projections by using an important theorem, central-slice or projection-slice theorem, and the convolution backprojection. STJs have potentials to open new windows of the Multispectral/fluorescence CT below 1 keV photon energy. Multispectral measurements of samples enables material analysis.

4. CT experiments and results

4.1. Set up

The experiment was done by measuring high energy X-rays at the Photon Factory beam line BL-14A of the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan. The beam spot size was 0.5 mm vertically and is 0.2 mm horizontally. We selected the photon energy from the synchrotron radiation beam by using a monochromator. We used a multi-pixel STJ chip as detector, and selected a well-known object "Twisty tie" as sample. The basic layout of the experimental set up is shown in Fig. 2.

4.2. Results

The pulse height spectrum is shown in Fig. 3. 6 keV beam energy was selected by using the monochromator. The series array STJs detected 6 keV photons and higher-order diffracted

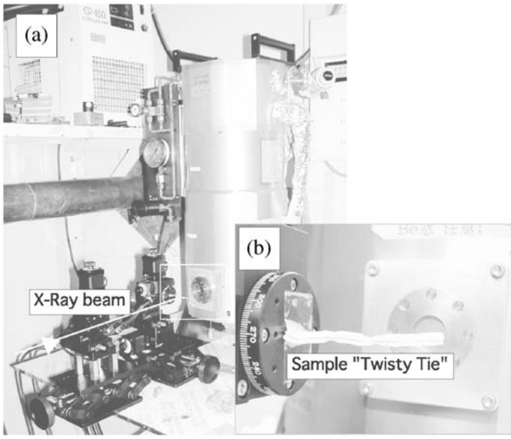

Fig. 2. (a) CT experimental set up; (b) close up "Twisty tie" sample.

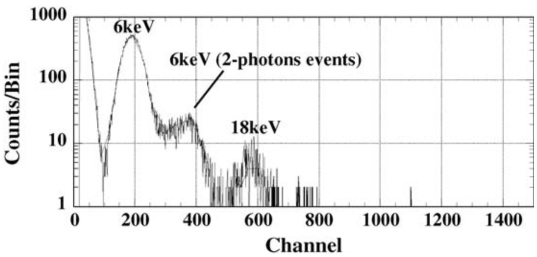

Fig. 3. Pulse height spectra for X-ray measured at 0.35 K. We selected 6 keV photon energy using the monochromator . The spectrum includes photons of higher order diffracted photons and 2-photons (6 keV) events.

photons (18 keV). Average total counting rate was 90 000 cps (live time). Measurement of the advantageous of STJ which is measurable at such a huge high counting rate. Cross section images of twisty tie at 6 and 18 keV are shown in Fig. 4. The iron wire of twisty tie becomes an opaque object at 6 keV, so, the measurement data are incomplete 1-D projections. The reconstructed image has a hollow structure. Medoff et al., reported a reconstruction algorithm from limited data [5]. However, we could determine the width of a twisty tie plastic part, as 4.2 mm. On the other hand, at 18 keV, we could determine the diameter of the iron wire, as 0.9×0.6 mm. Because of contrast from the plastic part was not obtained, due to its complete translucence in this energy region, we could not determine the width of a twisty tie plastic part. Thus, it has proved that multispectral measurements are a useful method for materials analysis.

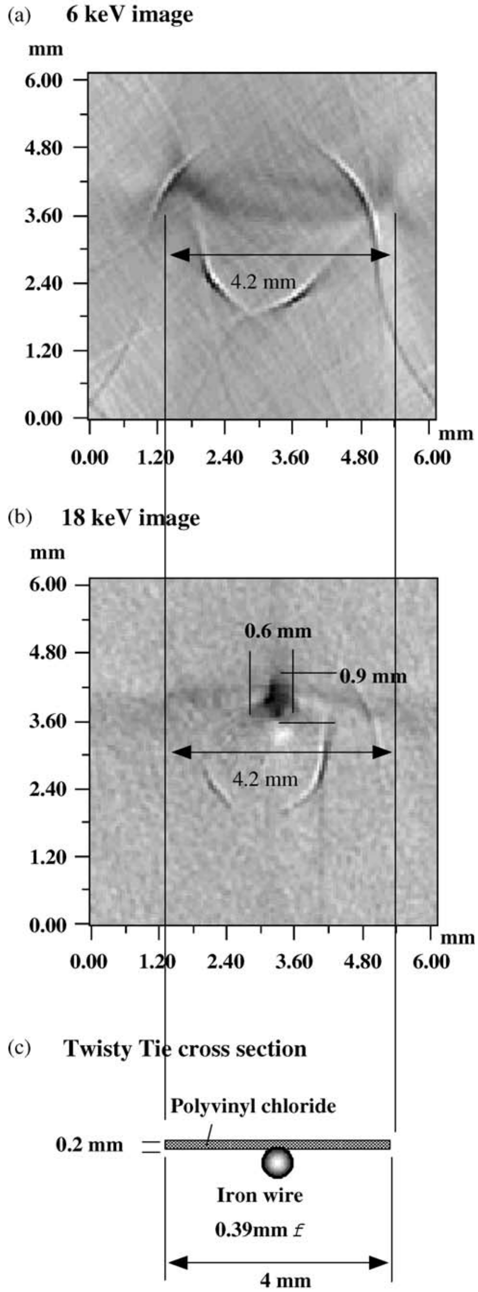

Fig. 4. Cross section images of twisty tie. (a) 6 keV image; (b) 18 keV image; (c) size of twisty tie.

5. Conclusion and next step

We successfully demonstrated multispectral CT using STJs in the high-energy X-ray region. The result indicates the possibility of the observation of 3-D density distribution of individual materials in a sample. We are planning the following as a next step:

(1) 3-D reconstructed image.
(2) Fluorescence CT experiment.
(3) Energy range shifts from high-energy X-ray to Soft X-ray.

References

[1] O. Nakamura, et al., Appl. Opt. 29 (11) (1990) 1671.
[2] Y. Takizawa, et al., IEEE Trans. Appl. Supercond. 11 (2001) 721.
[3] H. Sato, et al., Japan J. Appl. Phys. 39 (2000) 5090.
[4] M. Kurakado, et al., Nucl. Instr. and Meth. A 506 (2003) 134.
[5] B.P. Medoff, et al., J. Opt. Soc. Am. 73 (11) (1983) 1493.