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X-ray polarimetry with the microstrip gas chamber

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A two-dimensional microstrip gas chamber (MSGC) with a 5 cm × 5 cm detection area has been developed. It has 254 anodes and 255 back strips, both with 200 μm pitches. Using this MSGC, linear polarization of X-rays was successfully measured in the energy range 6–14 keV. In addition, the performance of the MSGC as an X-ray imaging polarimeter has been simulated using the *EGS*4 program (*Electron Gamma Shower*, Version 4) modified for this purpose. In this article, the results of both the polarization measurement and the simulation are reported.

Keywords: microstrip gas chambers; X-ray polarization.

1. Introduction

We have developed a two-dimensional microstrip gas chamber (MSGC) with a 5 cm × 5 cm detection area based on multi-chip module (MCM) technology (Tanimori *et al.*, 1996). It has a very thin substrate of 20 μm thickness, 254 anodes and 255 back strips, both with 200 μm pitches. The MSGC provides an excellent position resolution and many other capabilities. In particular, the fine position resolution of the MSGC allows us to measure the track of photoelectrons emitted from gas, which provides us with information about the electric field vector **E** of incident X-rays.

Our research mainly incorporates the MSGC as a real-time X-ray imaging detector at the SPring-8 synchrotron radiation facility in Japan (*SPring-8 Annual Report*, 1994). Using this MSGC, we succeeded in measuring the X-ray polarization in the range 6–14 keV (Ochi *et al.*, 1997). In addition, we have simulated the performance of the MSGC for polarization measurements to optimize the parameters of the MSGC, such as the pitches of the anodes and back strips, as an imaging polarimeter.

2. Detection of X-ray polarization by the two-dimensional MSGC

The MSGC has a detection area of 5 cm × 5 cm. As shown in Fig. 1, 10 μm-wide anodes and 100 μm-wide cathodes are formed on the thin polyimide substrate with 200 μm pitches. Between the ceramic base and polyimide substrate, there are back strips with a 200 μm pitch orthogonal to the anodes. All electrodes are made of gold with a thickness of 1 μm. To define the drift field, the drift plane was placed at 3 mm above the substrate. Each anode and back strip is connected to the readout electronics individually. Then there are more than 500 outputs. The readout system (Tanimori *et al.*, 1996) consists of pre-amplifier cards, discriminator boards and multi-hit CAMAC TDCs (time to digital converters, LeCroy 2277). A UNIX workstation acquires TDC data of each anode and back strip and ADC data of cathodes from the CAMAC system. By using the timing of pulses, accidental or electrical noise was perfectly removed.

Incident X-rays are absorbed by the photoelectric effect in the gas of the MSGC (Ar 80%, C_2H_6 20%). The differential cross section of the photoelectrons as a function of scattering angle is as follows (Heitler, 1954),

$$d\sigma = r_0^2 \frac{Z^5}{137^4}\left(\frac{\mu}{k}\right)^{7/2} \frac{4(2)^{1/2}\sin^2\theta\cos^2\varphi}{(1-\beta\cos\theta)^4}\, d\Omega, \tag{1}$$

where θ is a polar angle and φ is an azimuth angle which is measured from the direction of the electric field vector **E**.

This formula shows that photoelectrons prefer to emanate along the electric field vector **E**, and also that electron clouds will expand along **E**. The range of the photoelectron in Ar gas (1 atm) is approximately 1 mm for 8 keV X-rays. This is sufficient for a photoelectron to run beyond several strips of the MSGC. Therefore, when electron clouds drift to the anode strips and induce charge to the anode and back strips, an asymmetry appears between the numbers of hit anodes and back strips. As mentioned above, our MSGC is being developed as a real-time X-ray imaging detector, and fast data acquisition is very important. Therefore, each strip's pulse heights are not recorded; only digital information, hit or not, is recorded by the data-collecting system. Then, in the present system, information about polarization is derived from only the difference between the 'hit number' of the anodes and that of the back strips.

For the measurement of the polarization, the modulation factor, M, is defined as

$$M = (A-B)/(A+B), \tag{2}$$

where A (or B) is the total event number such that the hit number of the anodes (or back strips) is larger thanthat of the back strips (or anodes).

In this measurement, the polarized X-rays were generated using perpendicular Thomson-scattering X-rays from the plastic plate which was irradiated by the Cu-target X-ray generator. The MSGC was rotated against the electric field vector **E** of incident X-rays. Two-dimensional histograms of anode and back-strip hit

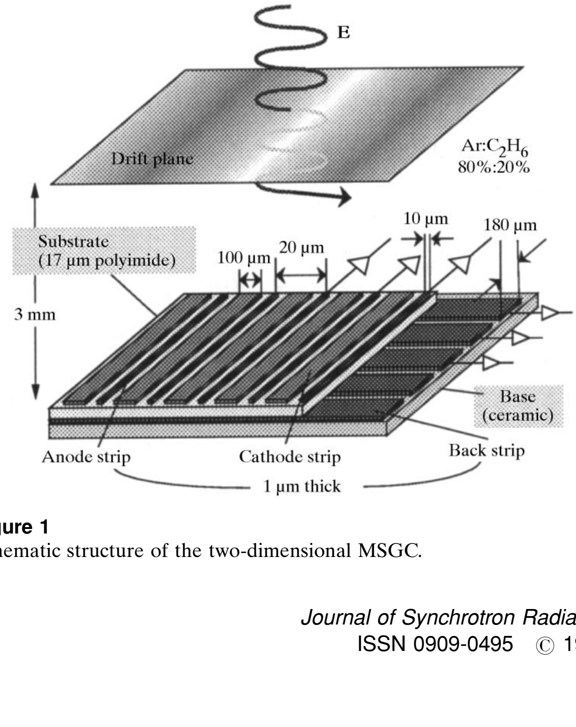

Figure 1
Schematic structure of the two-dimensional MSGC.

number are shown in Figs. 2(*a*) and 2(*b*). Here, θ is the angle between the anodes and **E**. There is a clear difference of hit number pattern between these two figures. *A* (or *B*) is the total event number of the lower (or upper) part of the centre line in Fig. 2.

The measured modulation factors are shown in Fig. 4 as a function of incident X-ray energy, which was measured from the pulse height of the cathode signal (Fig. 3), where θ is the angle between the direction of the anode strips and the electric field **E** of incident X-rays.

Thus we successfully measured the X-ray polarization in the energy range 6–14 keV. Recently, CCDs with smaller pixel size (6.8 μm × 6.8 μm) have also been able to measure X-ray linear polarization at energies above 15 keV (Schmidt *et al.*, 1995). Considering the flexibility of the MSGC (gas pressure, strip pitch *etc.*), we believe that the MSGC is superior to the CCD as an imaging X-ray polarimeter below 15 keV.

3. The simulation

We developed the simulation of polarimetry in the MSGC based on *EGS*4. In order to simulate low-energy X-ray and photoelectron transport in *EGS*4, we added some expansion codes of *EGS*4 – *PRESTA*, *LSCAT*, and the code which calculates the angle of photoelectrons according to equation (1) (Namito *et al.*, 1996). Since, in *EGS*4, an Auger electron is regarded as an energy deposit at the point where the photoelectric effect occurs, we emitted an electron having the same energy as an Auger electron isotropically from the hit point. The output data of *EGS*4 were used as the input data of another code which was developed for the simulation of the response of the MSGC. In this code, the energy deposits were converted into electron–ion pairs using the *W* value for argon (26 eV), and secondary electrons were diffused according to a Gaussian distribution. Since we were unable to find an accurate value of the diffusion constant of the gas used (Ar 80%, C_2H_6 20%), we examined the effects of the diffusion constant by changing its value between the typical values, 50, 150 and 300 μm.

The geometry used in the simulation is shown in Fig. 5. The pixel size is 200 μm × 200 μm, which is the same as the strip pitch of the MSGC. Samples of simulated tracks of photoelectrons and Auger electrons by 8 keV X-rays are also shown in this figure. Incident X-rays were assumed to be completely linearly polarized, and were put in the central pixel uniformly. The number of secondary electrons was summed up along the direction of each

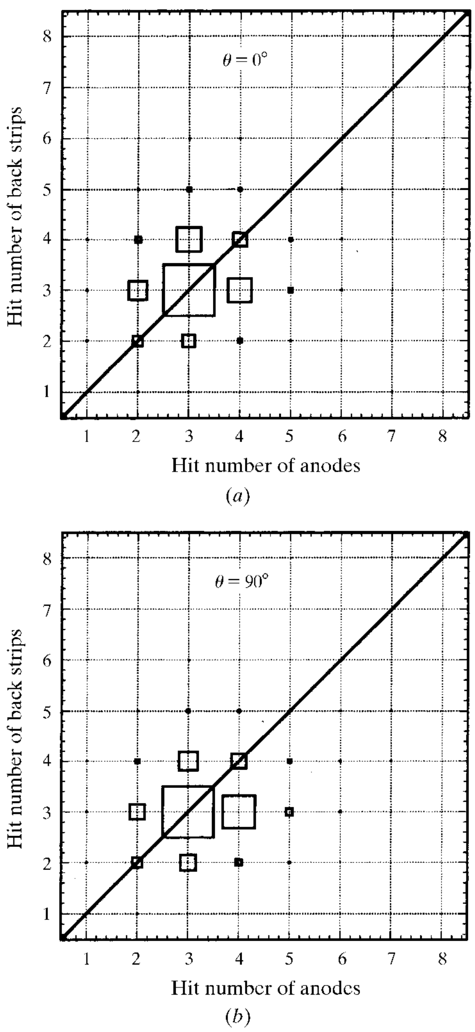

Figure 2
Hit number distribution for (*a*) θ = 0° and (*b*) θ = 90°.

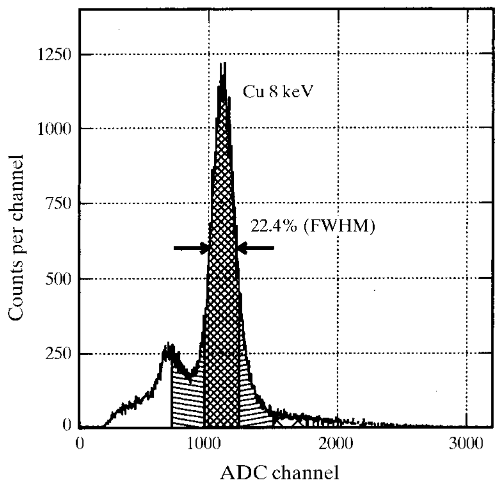

Figure 3
X-ray energy spectrum.

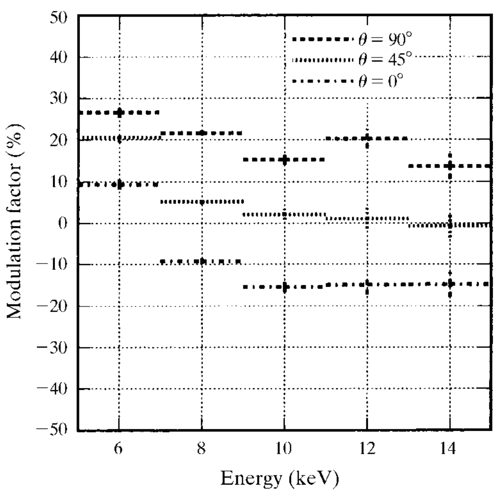

Figure 4
Experimental result of modulation as a function of energy.

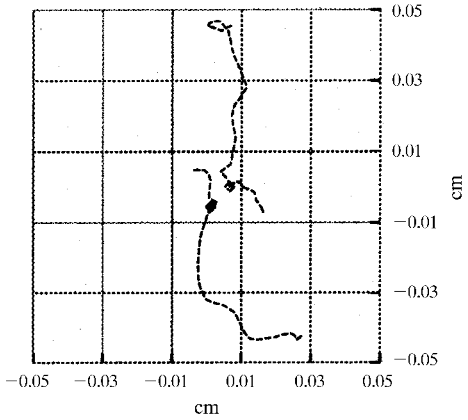

Figure 5
Samples of tracks.

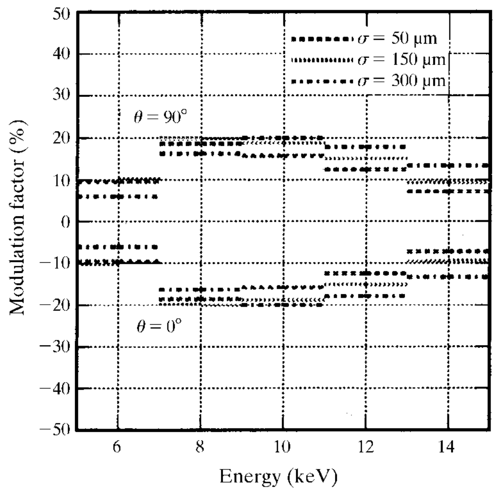

Figure 6
Simulation result of modulation as a function of incident X-ray energy.

strip, which was defined as a column of pixels. When more than 36 electrons were collected in one strip, the strip was considered to be hit (36 electrons correspond to the experimental threshold for each strip's pulse height). Fig. 6 shows the simulated modulation factor as a function of incident X-ray energy.

As shown in Figs. 4 and 6, our simulation results are approximately consistent with the measurement. Fig. 6 shows the simulated results by changing the diffusion constant; the uncertainty of the diffusion constant is found to have little effect for the simulated result. The abscissas in Figs. 4 and 6 are not the same; in Fig. 4 it denotes the energy band, while in Fig. 6 it denotes the monochromatic energy of incident X-rays.

4. Conclusions and the future

We succeeded in detecting X-ray linear polarization with an MSGC in the energy range 6–14 keV. Theses days, CCDs and MSGCs seem to be able to detect X-ray imaging and polarization simultaneously. But MSGCs can measure lower-energy X-ray polarization than CCDs.

In addition, we have simulated the performance of the MSGC as a polarimeter with reasonable accuracy using the modified *EGS*4 program. This simulation well reproduced the measurement. We will optimize some parameters of the MSGC, for example, gas mixture, strip pitch *etc.*, in order to improve the analysing power of the MSGC as an imaging polarimeter.

As a next step, we will use analog memory for the readout system, and record the pulse heights of all strips. We expect that a new readout method will provide the MSGC with more sensitivity for low-energy X-ray polarization measurement and analysing power.

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