Fabrication of a TPC X-ray Polarimeter and Preliminary Testing with the Synchrotron Radiation Light Source at Spring-8

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X-ray polarimetry is expected to provide unique information about stars, such as strong gravitational fields around black holes. However, it is far behind in technology in comparison to radio/optical polarimetry, and the observation of Crab nebula by OSO-8 satellite 40 years ago has been the only detection of X-ray polarization among astronomical objects[1]. NASA and RIKEN have been developing the X-ray polarimeter using the time projection chamber (TPC) technique with the sensitivity 10 times greater than the OSO-8 polarimeter, for the Gravity and Extreme Magnetism Small explorer (GEMS), an X-ray polarization telescope mission[a]. Although we have already built the flight model[2], a detailed study is still needed in order to fully understand the characteristics of the TPC polarimeter. We therefore fabricated an in-house TPC polarimeter at RIKEN (RIKEN polarimeter) for tests in various situations. In this report, we present a brief overview and the basic performance of the RIKEN polarimeter.

The TPC polarimeter is a gas-based detector with sensitivity in the energy range of $2-10$ keV. The polarimeter can image a photoelectron and reconstruct its initial direction, where the azimuth angle distribution depends on the linear polarization degree/angle of the incoming X-ray[3].

The design of the RIKEN polarimeter is originally based upon the GEMS polarimeter[4], although handy materials (e.g., bare aluminum instead of copper-tungsten or gold-plated aluminum) are used for easier machining. Another modification is that we adopted the Scalable Readout System (SRS), manufactured by CERN/RD51, instead of a custom-made ASIC as the strip readout. A SRS consists of APV25(s) with a sampling rate of 40 MHz, ADC card(s), and a Front-End Card. Figure 1 shows the photoelectron track taken by the RIKEN polarimeter.

What we actually measure with the polarimeter is a modulation curve, an azimuth angle distribution of the photoelectron. The modulation factor μ is derived from $(f_{max}-f_{min})/(f_{max}+f_{min})$, where f_{max} and f_{min} are the maximum and minimum counts in the curve. The modulation factor of the polarimeter μ_{pol}, which represents the sensitivity of polarimetry, is defined as μ which should be measured with a 100% polarized source. The first step of our study is to determine μ_{pol} of the RIKEN polarimeter.

We performed two experiments: (a) to measure μ with highly (∼85%) polarized source at BL32B2 SPring-8, and (b) to confirm the flat modulation with unpolarized line emission produced by an X-ray generator. We took measurements at 4.5, 5.5, 6.4, 7.0, and 7.5 keV for (a) and 4.5 and 6.4 keV for (b), although we focus on only the result of the 4.5 keV data here.

Figure 2(a) shows the modulation curve taken with the well-collimated (200×200 μm^2) 4.5-keV polarized X-ray at the middle height of the active volume, and (b) shows that with the 4.5-keV unpolarized X-ray under the same condition. The obtained μ_{pol} at 4.5 keV is $0.3\times0.85/p_{beam}$, where p_{beam} is the polarization degree of the X-ray beam, while the observed flat modulation is 0.00 ± 0.02. Meanwhile, the determination accuracy for the polarization angle is about 4° at a certain drift height. A detailed comparison with the GEMS polarimeter and other performance studies (e.g., detector angle dependency for the sensitivity) are in progress.

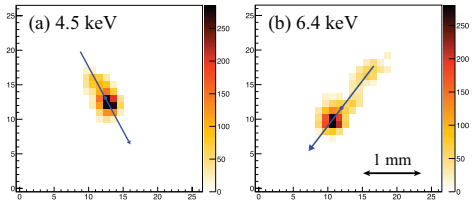

Fig. 1. Charge-weighted photoelectron track image taken by the RIKEN polarimeter with a 6.4-keV X-ray, together with a reconstructed angle with the blue arrow.

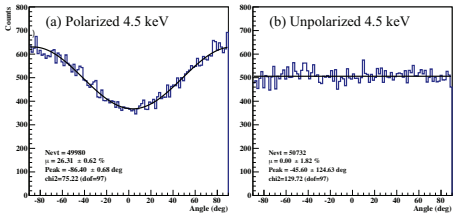

Fig. 2. Modulation curve for 4.5 keV (a) polarized X-ray and (b) unpolarized X-ray taken with the TPC polarimeter.

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a) GEMS was canceled in 2012 regarding the cost.

References

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