X-ray Polarimeter using Optical Imaging Capillary Gas Proportional Counter

Department of Physics, Yamagata University
H. Sakurai, S. Gunji, and F. Tokanai
Objective X-ray energies: 2 keV-----20 keV
(thermal and/or non-thermal)
Sources: point like to extended (B.H., Pulsar, Synchrotron Nebula etc.)

X-ray polarimetry: statistical treatment for detection

Significant collection power of X-rays with low background

X-ray mirror

Focal plane detectors

Photoelectron track imaging detector
X-ray polarization and Imaging of an X-ray photoelectron track

Incoming X-ray

X-ray Polarization

Ejected K-shell Photo-electron

Angular distribution on the detector plane (X-Y)

\[
\frac{d\sigma}{d\Omega} = \frac{Z^5}{137^4} \left( \frac{mc^2}{\hbar \nu} \right)^2 \frac{4\sqrt{2} \sin^2(\theta) \cos^2(\varphi)}{(1 - \beta \cos(\theta))^4}
\]

Material for photo-absorption

Gas: He, Ne, Ar

The energy loss is described by Bethe’s law.

\[
\frac{dE}{dx} \propto \frac{1}{E}
\]
Capillary Gas Proportional Counter

X-rays

Beryllium Window

Absorption and Drift Region

Drift Voltage

HV

CGPC

Equipotential contour

Inlet

Outlet

X-ray polarization

electron cloud

electron

800µm

100µm capillary

20mm capillary plate
Optical Imaging Capillary Gas proportional Counter

Penning gas mixture: 
Ar+CH4(8%)+TMA(2%)
X-ray Polarization in two synchrotron facilities:

SPring-8, KEK-PF

Thomson/Compton scattering polarimeter for beam calibration

To test the performance of X-ray polarimeter:
It is necessary to have highly polarized beam
With monochromatic X-rays for any energy.
Degree of X-ray polarizations at the beam lines

SPRING-8 | BL38B1 (99%) | KEK-PF | BL14A (82%)

Polarization for energy at BL38B1
Imaging of photoelectron tracks for polarized X-rays
With the Optical Imaging CGPC

Accumulated Images

SPring-8  KEK-PF

Single p.e. track
Images of Photoelectron tracks

15keV X-rays

20keV X-rays
Relationship between the charge signal and the optical image

Charge

Light yield (CCD)

ER=13.7%

ER=33%

15 keV X-rays

3 keV/15 keV
Barycenters for 15 keV polarized X-rays

Start - Barycenter

Count

Distance (mm)

Start-Barycenter: \( \theta_1 \)

Counts

Angle (degree)

M.F. = 25.1 \( \pm \) 2.0%
The optical imaging CGPC with a quenching gas of CF$_4$

N.A.: 1
Q.E. : 90%

Design of Integral molding  Optical Imaging CGPC

TMA(290 nm) $\rightarrow$ CF$_4$(620 nm)

Simulated result of diffusion (x 100 µm/3cm)
For 10% quenching.
Images of photoelectron tracks with Ar + CF$_4$(10%)  
For 15 keV X-rays

At KEK-PF
Relationship between the charge signal and the optical image with Ar + CF$_4$ for 15 keV X-rays
15 keV polarized X-rays With Ar + CF$_4$

Start - Barycenter

Count

Distance (mm)

M.F. = 24.4 ± 2.2%

M.F. = 25.8 ± 2.2%

M.F. = 34.9 ± 2.2%

Second-Moment I: $M_1$

Second-Moment II: $M_2$
Calculation of the direction of photoelectron track

- Start-Barycenter: $\theta_1$
- Second-Moment I: $M_1$
- Second-Moment II: $M_2$
Preliminary results of Ne + CH₄(8%) + TMA(2%)

Fe 5.9 keV X-rays

X-ray@Ta : 8.14keV

Charge signal

Light signal (PMT)

VADC

QADC

E.R.: 20.3%

E.R.: 22.8%

Counts

Counts

Counts

VADC Channel

QADC Channel

Light Yield

Y-projection (1bin=241m)
Summary

• The optical imaging capillary gas proportional counter (CGPC) has been developed as an X-ray Polarimeter.
• Degree of X-ray polarizations of beam lines at synchrotron facilities are checked to test the performance of X-ray polarimeter.
• Fine images of photoelectron tracks were obtained for polarized X-rays in the energies 15 keV and 20 keV with the gas mixture of Ar + CH4(8%) + TMA(2%).
• With the gas mixture of Ar + CF4(10%), fine images of photoelectron tracks were obtained for polarized X-rays in the energies 15 keV.
• From the photoelectron track images, the modulation factors were 25±2 %, 24±2% at the beam lines of synchrotron facilities.
• A photoelectron track image was obtained with Ne + CH4+ TMA gas mixture for 8 keV X-ray.