X-ray polarimetry and spectroscopy with the CMOS detector IU233N5-Z

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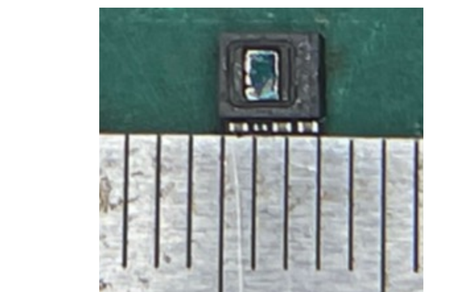
1. Introduction

Polarization of X-/γ-rays are important clue to understand the high-energy radiation mechanism, however, γ-ray polarization is difficult to observe, and there are not enough observations

	CMOS	Scintillator
γ-ray Sensitivity	Not Good	Very Good
Spatial resolution	Good	Bad

Scintillator with microstructure [1]



➡ Recently, scintillators with ~μm microstructure have been developed

CMOS with good spatial resolution
＋
Scintillator sensitive to gamma rays
(Scintillator with microstructure)

Polarization detection is expected

Purpose:
Detect the X-/γ-ray polarization with the CMOS detector and scintillator

Goal 1: Detect the polarized X-ray with CMOS
→ Evaluate the X-ray performance

Goal 2: Detect the polarized γ-ray with CMOS + scintillator
→ Detect the scintillation light with CMOS detector

2. Detector

CMOS (IU233N5-Z)

SONY

- pixel size: 1.12 μm × 1.12 μm
- number of pixels: 1296 × 816
- weight: ~0.02g
- optical sensor
- monochrome [2]

IU233N5-Z without lens

Scintillator (CsI(Tl))

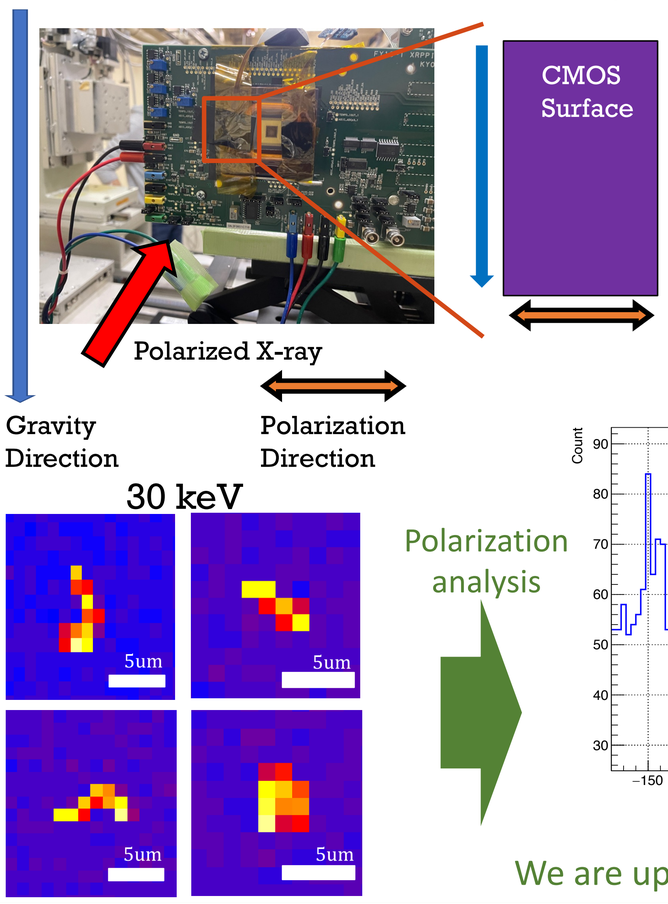
Leading Edge Algorithms

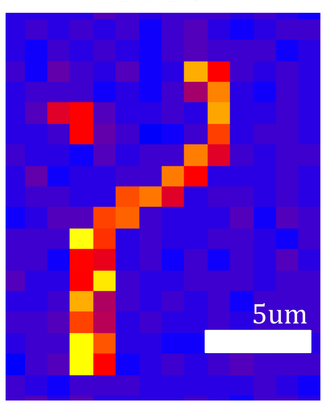
- density: 4.53 g/cm^3
- light yield: 56 photons/keV
- size: 1cm × 1cm × 3cm
- decay time: 1050 ns
- without microstructure [3]

CsI(Tl) with ESR

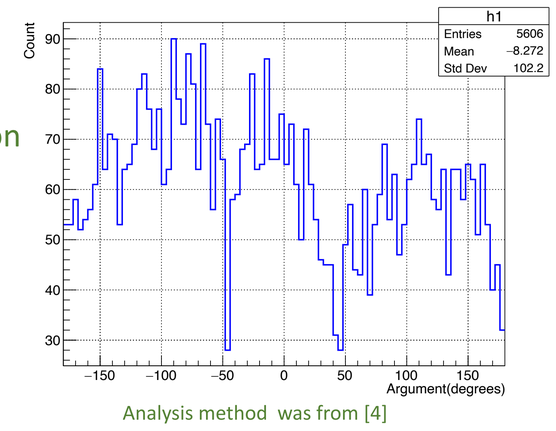
3. X-ray Polarization　Only CMOS

We irritated the polarized X-ray at SPring-8
We used the astro software ([5]) to take images





Polarization analysis



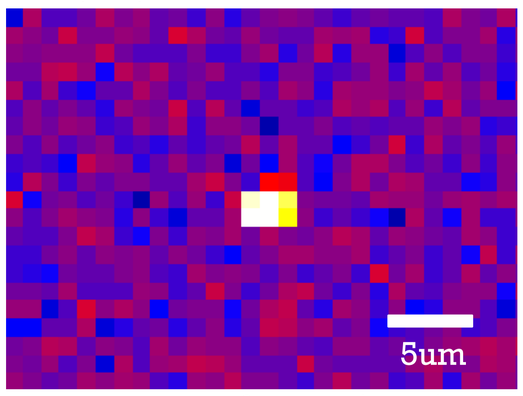
Analysis method was from [4]

We are updating the analysis method

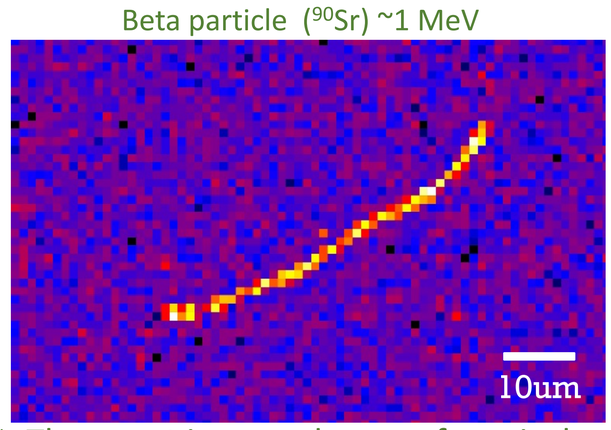
4. Imaging (α-/β- ray)　Only CMOS

We did imaging with very small pixels (1.12 μm)

Alpha particle (^{241}Am) 5 MeV



Beta particle (^{90}Sr) ~1 MeV

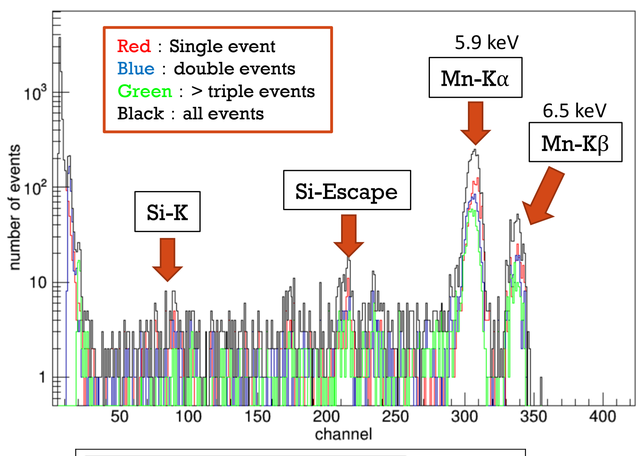


- α-ray: mean free path is short → The event is spread over a few pixels
- β-ray: mean free path is long → The event is spread over tens pixels

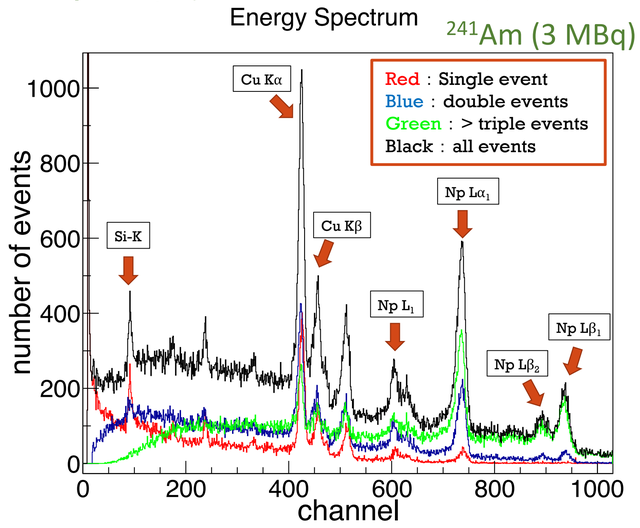
5. X-ray evaluation (Spectrum)　Only CMOS

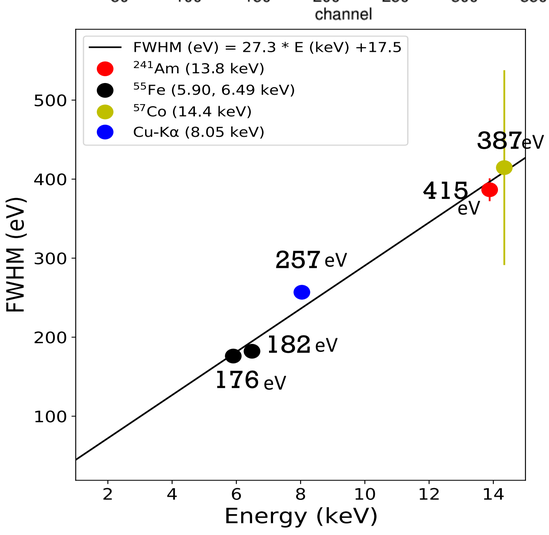
We evaluated the energy resolution of the X-rays　(Exposure time = 1200ms, 1000 times)

Energy Spectrum ^{55}Fe (896 kBq)



Energy Spectrum ^{241}Am (3 MBq)





Gain linearity: Channel = 53.08 × E (keV) – 2.66

Event Number (^{241}Am)

	Entries	Cu-K	Entries Rate (/all event)
single	50695	5418	0.24
double	74079	6991	0.35
> triple	87507	4820	0.41

From the result of ^{55}Fe, in CMOS, the reaction probability P is

$$P = \frac{^{55}\text{Fe Detected rate}}{^{55}\text{Fe emission source rate}} = \frac{0.235\ (\text{count/sec})}{11{,}867.9\ (\text{count/sec})} = 1.98\times10^{-5}$$

➡ Depletion layer thickness: **d = 6 μm**

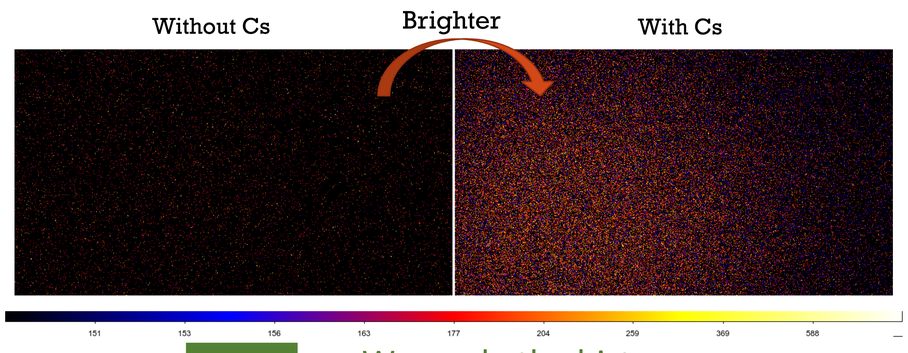
6. Readout of scintillation light

We irradiated ^{137}Cs to the scintillator and read out the scintillation light by CMOS

We set the ^{137}Cs (18.5 MBq) at 1 cm from the scintillator　(Exposure time = 1200ms)

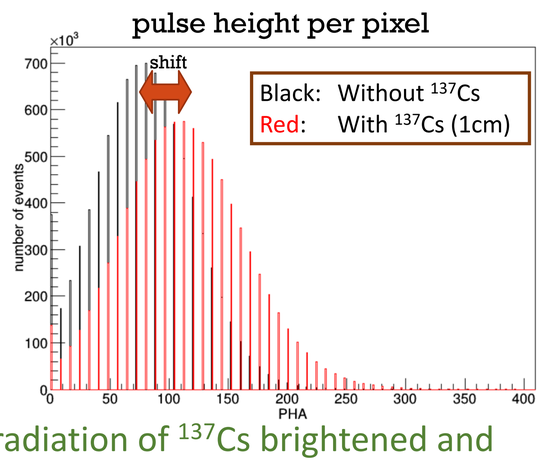
Reaction probability ~0.17

(Scintillation light is optical, thus, one photon produces one electron-hole (pair))

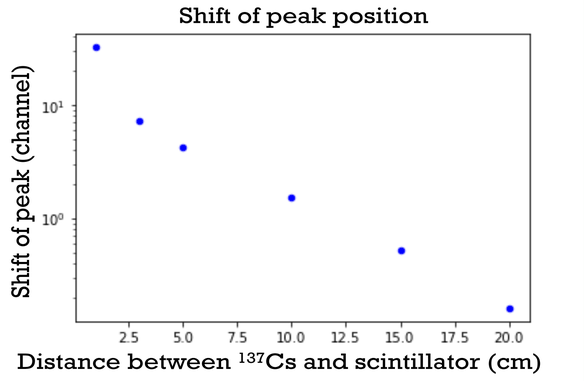


Irradiated with ^{137}Cs, the full surface of the CMOS became brighter!

We made the histogram



Irradiation of ^{137}Cs brightened and shifted the peak (32.4 channel/pixel)



The shift became smaller as the source was moved away from the source due to the steric angle

Reference

1, Yamamoto, S., Kamada, K. & Yoshikawa, A. Sci Rep 8, 3194 (2018)
2, IU233N2-Z/IU233N5-Z product brief
3, CsI(Tl) data sheet, Leading Edge Algorithms
4, Hashizume, M., Suda, Y., Fukazawa, Y., et al. PoS, ICRC2023, 873 (2023)
5, Astro https://soho-enterprise.com/page-915/astro