Imaging and spectral performance of a 60μm-pitch CdTe double-sided strip detector

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CdTe Semiconductor

CdTe Semiconductor

- High density & Large Atomic number
  \( \rho = 5.85 \text{ g/cm}^3, \ Z_{\text{Cd}} = 48 \ Z_{\text{Te}} = 52 \)
  → High detection efficiency

- Large Bandgap Energy \( E_{\text{Gap}} = 1.44 \text{ eV} \)
  → A portable experimental system

- Lower charge transport properties
  \( (\mu \tau)_e = 2 \times 10^{-3} \ (\mu \tau)_h = 1 \times 10^{-4} \ [\text{cm}^2 / \text{V}] \)
  - Uniform & Thin device
  - Schottky diode (Takahashi+ 1998)
  - Guard ring (Nakazawa+ 2004)

Extremely low leakage current, High bias voltage
→ Full charge collection & High energy resolution
CdTe-DSD and its Applications

CdTe Double-Sided Strip Detector (CdTe-DSD)

Strip electrodes orthogonally placed on both side → Energy and 2-D position information

Applications

✓ Non-destructive analysis (Katsuragawa+ 2018)
✓ Medical Application: in-vivo imaging
  SPECT system for small animal (Takeda+ 2018)
  etc...

60 μm fine-pitch CdTe-DSD (128×128 strips)
for the FOXSI-3 Sounding Rocket experiment
(Steven+ 2016, Sophie+ 2019, Furukawa+ 2019)

- Depth of Photon Interaction
- Charge sharing event
Energy Spectrum $^{241}$Am

Gamma-ray spectra of $^{241}$Am

Condition: Bias Voltage = 200 V
Operating Temperature = -20 °C

At high energy peak ~ 60 keV,
Pt (Cathode) side forms a tail structure

Caused by low charge transport of holes
$(\mu \tau)_e = 2 \times 10^{-3}$  $(\mu \tau)_h = 1 \times 10^{-4}$  [cm$^2$/V]

- Low Energy photon $\lesssim$ 30 keV near the surface of Pt (Cathode)
- High Energy photon near the surface of Al (Anode)
→ more holes can be trapped

Depth of Interaction correction is important!
Depth of Interaction Effect

Al Side Energy vs Pt Side Energy
(Anode) (Cathode)

Energy Average vs Energy Difference

\[ \frac{E_{Al} + E_{Pt}}{2} \text{ vs } E_{Pt} - E_{Al} \]

Structure caused by charge loss of holes

This caused a tail of spectrum at high energy peak
**Definition of “Angle $\theta$”**

1) Pick up one pixel, and draw “Energy Average” and “Energy Difference”

2) Distribute counts randomly in each bin (bin which counts less than 3 are ignored)

3) Define “Angle $\theta$” using Principal Component Analysis (PCA)

repeat 1) - 3) using every pixel (128ch × 128ch)

$\theta_{MAX} = 60.94 \text{ deg.}$

define $\theta$
every pixel


Energy Reconstruction Method

1) $|E_{Pt} - E_{Al}| < 0.5$ keV
Simply using Energy Average $\frac{E_{Al} + E_{Pt}}{2}$ as a reconstructed energy

2) $|E_{Pt} - E_{Al}| > 0.5$ keV
Correct tail structure using straight line of angle $\theta_{MAX}$ and calculate a reconstructed energy
Reconstructed Energy Spectrum

Pt & Al side Energy

- Pt side Energy $E_{Pt}$ (Cathode)
- Al side Energy $E_{Al}$ (Anode)

1.3 keV (FWHM) @60 keV, Al side
1.1 keV (FWHM) @14 keV, Al side

Reconstructed Energy

1.2 keV (FWHM) @60 keV
0.78 keV (FWHM) @14 keV

Energy resolution is improved by using both side of energy information.
Tail structure at high energy peak is properly corrected.
Radioisotope for Evaluating Imaging Performance

Purpose: Obtain a sub-strip position resolution (< 60 μm)

1 mm is too big!

Microchannel phantom (\(^{57}\text{Co} 800\text{kBq}\))

(in collaboration with the Japan Radioisotope Association)

A new type of **sealed radioisotope** (RI) with from **0.167 mm to 1 mm pattern** structure

It is suitable for testing how accurately we can reconstruct the fine structure of target sources in a laboratory easily
100 μm Pinhole

100 μm knife-edge Pinhole

5 mm thick Tungsten
Opening angle : 40 degree

For high energy photon, effective pinhole diameter is a little bigger
14 keV : 105 μm  
30 keV : 120 μm
(90% Absorption)
100 µm strip Setup

To make 100 µm size RI source,

- \(^{133}\text{Ba}\) point radioactive source (diameter = 1 mm)
- 100 µm slit made by 0.5 mm thickness tungsten

To suppress background Pb-Sn-Cu graded-Z shield was installed under the pinhole
Reconstruct image using 28-32 keV Energy events

60 μm strip resolution is insufficient to image 100 μm slit

To realize sub-strip resolution, charge sharing information between the adjacent channel should be considered
Interaction Depth vs Charge Sharing

\[ E_{Al} \gg E_{Pt} \quad \leftarrow \text{holes are trapped} \]
\[ = \text{interact near the surface of Al (Anode)} \]

As Photon interacts deeper, Pt charge sharing events increase
\[ \rightarrow \text{Charge cloud is spreading} \]
## Position Reconstruction Method

<table>
<thead>
<tr>
<th>Previous Methods (Furukawa+ 2019)</th>
<th>Improved Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 strip = 60 μm</td>
<td>$E_1 = 20 \text{ keV}$</td>
</tr>
<tr>
<td></td>
<td>$E_2 = 10 \text{ keV}$</td>
</tr>
<tr>
<td>Randomly assigned according to</td>
<td>$X = \frac{E_1X_2 + E_2X_1}{X_1 + X_2}$</td>
</tr>
<tr>
<td>Uniform probability distribution</td>
<td></td>
</tr>
<tr>
<td>The width of two region</td>
<td></td>
</tr>
<tr>
<td>= Ratio of Single/Double-strip event number</td>
<td></td>
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</tbody>
</table>

**Single-strip event**  **Double-strip event**

Randomly assigned according to **Uniform probability distribution**

Double-strip event = Energy-weighted center of each strip position of $X_1$ and $X_2$
Sub-strip Resolution Image

100 μm slit image was properly reconstructed!

By using charge sharing information, sub-strip resolution was confirmed.

Previous Methods

Improved Methods
Summary

60 μm fine-pitch CdTe-DSD for the FOXSI-3 Sounding Rocket experiment

Spectral Performance

Tail structure of Pt side (Cathode) at high energy peaks

Depth of Interaction correction

- Correct tail structure properly
- 1.2 keV (FWHM)@60 keV, 0.78 keV (FWHM)@14 keV

Imaging Performance

Using an information of charge sharing between the adjacent channel

100 μm slit image was properly reconstructed → sub-strip resolution was confirmed