Applications and imaging techniques of a Si/CdTe Compton gamma-ray camera

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Si/CdTe Compton camera

Gamma-ray detector for ASTRO-H satellite (2014)

Accumulation structure of high resolution (ΔE, ΔX) semiconductor detectors

The direction of incident gamma-ray:

\[ \cos \theta = 1 - m_e c^2 \left( \frac{1}{E_2} - \frac{1}{E_1 + E_2} \right) \]

Characters:

- Si/CdTe (low-Z/high-Z) combination
  - good angular resolution (~1°@ 500 keV)
  - fine energy resolution (~1% @ 500 keV)
- Imaging of low energy gamma-rays around 100 keV (c.f. COMPTEL, 750 keV)
- Compact and portable (c.f. COMPTEL, 2 m, 1.5 ton)

Possible gamma-ray imaging system ... ->
Possible applications

Capability of simultaneous tracking variant radioisotopes.

Near-field (1 ~ 50 cm) applications

Advanced imaging with multiple probes

Small animal imaging for drug discovery
( c.f. Motomura et al. IEEE 2007)

Nuclear medicine

Middle-field (1 ~ 50 m) applications

Hot spot monitoring

None of commercial imaging system that determine the kind of radioisotopes
## Detector requirements

<table>
<thead>
<tr>
<th>Field</th>
<th>Required sensitivity</th>
<th>Detector configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near-field (1-50cm)</td>
<td>&gt;100 cps/MBq @ 10 cm, 300-600 keV (c.f. Commercial gamma camera; ~100 cps/MBq @ 10 cm)</td>
<td>Si; 3.2cm wide, 0.5 mm thick CdTe; 3.2cm wide, 0.75 mm thick Si ; 4 layers CdTe; 4 layers x 4 modules</td>
</tr>
<tr>
<td>Middle-field (1-50 m)</td>
<td>100 MBq of 137-Cs (662 keV) Distance ; 5 m Exposure time ; 300 sec</td>
<td>Si ; 1 or 2 layers CdTe; 4 layers x 1 modules</td>
</tr>
</tbody>
</table>
| Extremely Far-field (Astrophysics) | See Soft Gamma-ray Detector  
(SGD, ASTRO-H)  
H.Tajima et al. IEEE 2005,  
T. Takahashi et al. SPIE 2008 | Adequate sensitivity depends on applications ...                                    |
Flexible detector modules

Selectable in the number of detectors and their combination !!

Example: 5-layer stack system (Si 1, CdTe 4)

Double-sided strip detectors
- Si; 3.2cm wide, 0.5 mm thick
- CdTe; 3.2cm wide, 0.75 mm thick
  250 um strip pitch

ADC implemented VATAs
Floating bias supply
High energy resolution
- Si; 1.5 keV @ 60 keV
- CdTe; 1% @ 511 keV

ASTRO-H HXI model
( 4.0 mm stack pitch )
Typical performance

Si strip detector

-20 °C, 300 V

\(^{241}\text{Am}\)

17 keV

13.9 keV

CdTe strip detector

-20 °C, 300 V

\(^{57}\text{Co}\)

122 keV

14 keV

136 keV
Typical performance

CdTe strip shadow image

Si strip shadow image

Detector

100 V

22 keV
Some experimental results with prototype camera
Near-field

Multi-probe tracker

Imaging test with a living mouse

Si : 1 layer, CdTe: 4 layers

Injected radiopharmaceuticals;

- Iodinated \(^{131}\text{I}\) methylNorcholestenol (18.7 MBq: 5,4 and 3-days before imaging)
  used for adrenal scintigraphy
  marked accumulation to a thyroid

- \(^{85}\text{SrCl}_2\) solution (2 MBq: 1-day before imaging)
  taken up in new bone growth
  scanning for bone lesions
Near-field

Spectrum after 6 hours observation

$^{131}\text{I} (364 \text{ keV})$

$^{85}\text{Sr} (514 \text{ keV})$
Near-field

$^{131}I(364 \text{ keV})$

$^{85}\text{Sr}(514 \text{ keV})$

Feasibility of a multi-probe tracker is demonstrated!!
Middle-field

Advanced hot spot monitor

$^{22}$ Na(511 keV, 0.5 MBq, 1.0 m)

$^{137}$ Cs(662 keV, 2.8 MBq, 1.2 m)

$^{133}$ Ba(356 keV, 2.3 MBq, 1.2 m)

$\approx$ 50 MBq @ 5 m
Results after 10 min

$^{137}$Cs (662 keV, 2.8 MBq)
Results after 10 min

$^{137}$ Cs (662 keV, 2.8 MBq)
Results after 20 min

$^{133}$Ba (356 keV, 2.3 MBq)
Results after 20 min

$^{133}\text{Ba}(356 \text{ keV}, 2.3 \text{ MBq})$
Results after 20 min

$^{22}$Na(511 keV, 0.5 MBq)
Results after 20 min

$^{22}\text{Na}(511 \text{ keV, } 0.5 \text{ MBq})$
Field of view

Experiment (662 keV): $1.7 \times 10^{-2}$ cps/MBq @ 1m, 20 degree
Summary

New compact Compton imaging system based on Si / CdTe semiconductor detector technologies accumulated for past 15 years.

- High energy resolution, low energy threshold (~5keV), 250um pitch double-sided Silicon and CdTe strip detectors.
- ADC implemented VATA ASICs
- Compact detector boards
- Selectable in the number of detector boards

Feasibilities of a multi-probe tracker and advanced hot spot monitor are successfully demonstrated.