High Performance Hybrid Pixel Detector and its Applications

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Why we need 2D?

Counting and Integrating

Types of Detectors

Specification and Performance
Outline

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Specification and Performance
Why we need 2D?

What is important for “Accuracy”?

All Limited by Detector!

Higher data quality
What is the “Ideal” X-ray Detector

X-ray Photon

Direction (α, β)

Position (x, y)

Energy, Phase

Detector

Never misses photons!

Why we need 2D?
Why we need 2D?

Single Crystal

Powder
  • Texture
  • Orientation

Ideal Powder

2D

1D

6/24
Outline

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Counting and Integrating

X-ray Photon

Photon Integrating
- Integrates all charge generated by photon and noise.

Photon Counting
- Discriminate X-ray pulse from noise by height.
# Detector Materials

<table>
<thead>
<tr>
<th>Photon Integrating</th>
<th>Photon Counting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phosphor</strong></td>
<td><strong>Semiconductor</strong></td>
</tr>
<tr>
<td>• CCD</td>
<td>• HPAD (Hybrid Pixel Array Detector)</td>
</tr>
<tr>
<td>• CMOS</td>
<td></td>
</tr>
<tr>
<td><strong>IP (Image Plate)</strong></td>
<td><strong>Gas</strong></td>
</tr>
<tr>
<td></td>
<td>• MWPC (Multi-Wire Proportional Counter)</td>
</tr>
<tr>
<td></td>
<td>• MPGD (Micro-Pattern Gas Detector)</td>
</tr>
<tr>
<td><strong>X-ray Film</strong></td>
<td></td>
</tr>
</tbody>
</table>
Outline

Why we need 2D?

Counting and Integrating

Types of Detectors

Specification and Performance
**Charge Coupled Device (CCD)**

**Single Pixel**
Electrons are integrated in a potential well

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**X-ray Photon**

**Phosphor**

**Gate electrodes**

**Similar to shift register**
Complimentary Metal-Oxide Semiconductor (CMOS)

Similar to random access memory
Types of Detectors

Micro-Pattern Gas Detector (MPGD)

Direct Detection by Gas

- Delay line readout: Global count rate limitation

Window

Gas ionization

Micromesh

X-ray Photon

Conversion

Amplification

HV_{drift}

HV_{amp}

Readout strips
Hybrid Pixel Array Detector (HPAD) : Closest one to the Ideal Detector

Direct detection

X-ray Photon

Sensor

ROIC

CSA
Shaper
Comparator
Counter
## Compare HPAD to CCD, CMOS and MPGD

<table>
<thead>
<tr>
<th>Types of Detectors</th>
<th>Photon Integrating</th>
<th>Photon Counting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCD</td>
<td>CMOS</td>
</tr>
<tr>
<td>Sensitivity at Cu K (electron/photon)</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Read noise (electron, rms)</td>
<td>~ 20</td>
<td>~ 200</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>$10^4$</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Dark Current (photons/sec/µm²)</td>
<td>~ $10^{-7}$</td>
<td>~ $10^{-5}$</td>
</tr>
<tr>
<td>Readout time</td>
<td>~ 1000 ms</td>
<td>~ 500 ms</td>
</tr>
</tbody>
</table>
Outline

Why we need 2D?

Counting and Integrating

Types of Detectors

Specification and Performance
## Comparison of photon integrating and counting

<table>
<thead>
<tr>
<th></th>
<th>Photon Integrating</th>
<th>Photon counting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detector Material</strong></td>
<td>Phosphor (CCD, CMOS), IP, Film</td>
<td>Semiconductor, Gas</td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Dark Current</strong></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Read noise</strong></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td><strong>Dead time</strong></td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Application Fields</strong></td>
<td>Lab, SR, XFEL</td>
<td>Lab, SR</td>
</tr>
</tbody>
</table>
Detective quantum efficiency
HPAD (Si 300 μm) 99 % @ 8.04 keV
MWPC, MPGD (3 atm, 1 mm) 80 % @ 8.04 keV

Spatial resolution
HPAD = 1 pixel (∼ 100 μm)
MPGD ∼ 250 μm FWHM Gaussian

Count rate
HPAD local 100 kcps / pixel
MPGD local 100 kcps / pixel
global 2 Mcps
## HPAD Chip Specifications

<table>
<thead>
<tr>
<th>Detector</th>
<th>Medipix 2</th>
<th>PXD-18k*</th>
<th>XPAD3</th>
<th>PILATUS II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pixel Size</strong></td>
<td><img src="55_55um.png" alt="Image" /></td>
<td><img src="100_100um.png" alt="Image" /></td>
<td><img src="130_130um.png" alt="Image" /></td>
<td><img src="172_172um.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Count rate</strong></td>
<td><img src="7e7.png" alt="Image" /></td>
<td><img src="2e8.png" alt="Image" /></td>
<td><img src="4e7.png" alt="Image" /></td>
<td><img src="3e7.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td><img src="23.png" alt="Image" /></td>
<td><img src="20.png" alt="Image" /></td>
<td><img src="12.png" alt="Image" /></td>
<td><img src="6.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Read time</strong></td>
<td><img src="256us.png" alt="Image" /></td>
<td><img src="7ns_3.7ms.png" alt="Image" /></td>
<td><img src="1ms.png" alt="Image" /></td>
<td><img src="2.3ms.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Specification and Performance

Zero dead time Measurement

Read time: 7 ns (571 fps)

Read time: 3.7 ms (183 fps)

Exposure time 1.75 ms / frame

Switch between 2 Counters
Time Delay Integration (TDI)

Integrated Image

Increases sensitivity & area
Decreases “wall time”
Time Delay Integration (TDI)

Sample: LaB$_6$
Scan Speed: 10°/min
Cu Target: 40 kV, 30 mA

TDI Image

Single Image

60 deg  40 deg  20 deg
Summary

2D detector
  • More information and shorter measurement time

Photon counting
  • Very high signal to background ratio

Hybrid pixel array detector
  • High quantum efficiency and spatial resolution

Fast readout (Zero dead time mode)
  • In-situ measurement

HPAD promises us a higher quality of data.
Thank You
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