Micron Scale Pixel Hybrid Detector for Hard X-rays

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Digital Radiography

CR
Computed Radiography

Indirect conversion

Storage phosphors

DR
Direct Radiography

Indirect conversion

Indirect conversion

Direct conversion

Scintillator-TFT

Scintillator-CCD

Image Intensifier

Photoconductor FDP

Selenium-drum

70-200 μm Pixels
Solid-State X-ray Detection

Indirect conversion

Direct conversion
Amorphous Selenium (a-Se) Photoconductor

- Easily processed as a uniform thick layer over large area
- Atomic number (34) sufficient for hard x-ray imaging
- Low dark current & High charge collection efficiency

High Inherent Spatial Resolution, High Absorption for Diagnostic X-rays

→ Low noise, Small Pixel Pitch CMOS

Interaction volume X-ray photon

Mean size = 2-6 µm @ 20-40 keV
X-ray Attenuation Coefficients for a-Se

K-edge = 12.66 keV
X-ray Interaction Energy Deposition in a-Se

Weighting Factors:

- $p_{pe} = 0.866$
- $p_{K_\alpha} = 0.111$
- $p_{K_\beta} = 0.018$
- $p_C = 0.005$

35 keV
Cascaded Systems Theory

X-ray Spectrum Model

K-Fluorescence Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>K-edge energy (keV)</td>
<td>12.66</td>
</tr>
<tr>
<td>K-shell contribution to photoelectric effect</td>
<td>0.864</td>
</tr>
<tr>
<td>K-fluorescent yield</td>
<td>0.596</td>
</tr>
<tr>
<td>Escape probability</td>
<td>0.30-0.38</td>
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</tbody>
</table>

Detective Quantum Efficiency (DQE)

\[
DQE(u) = \frac{SNR^2_{\text{out}}(u)}{SNR^2_{\text{in}}(u)}
\]
X-ray Interaction MTF for a-Se
Objective

Develop hybrid a-Se/CMOS detectors to achieve a unique combination of high spatial resolution (≤10 µm pixel) and high quantum efficiency for hard x-rays for X-ray diffraction imaging.

a-Se Films on ITO-glass by Physical Vapor Deposition + CMOS Readout Integrated Circuit (ROIC)
Deposition of a-Se Films by Thermal Evaporation

Thermal Evaporator for a-Se at G2N Centre, University of Waterloo

CMOS Readout IC

Shadow Mask
A micrograph of etched CMOS passivation

A diagram of the a-Se/CMOS detector cross-section
Polyimide Layer Conduction

- Charge build-up at the a-Se/PI -> E-field reduction -> sensitivity loss
- Reversing the detector bias resets the device.

35 kVp, 250 mAs
1 min. between exposures
5 min. between HV changes)

HV = 140V

HV = 280V

Signal stabilizing and experiencing ghosting
LIBRA Readout IC

- 3T active pixel sensor
- $7.8 \times 7.8 \, \mu \text{m}^2$ pixel pitch
- $1000 \times 1000$ pixel array
- $7.8 \times 7.8 \, \text{mm}^2$ imaging area

**Images**

- a-Se Deposition
- Au Deposition
- Packaging

Ceramic package (before wirebonding)
Microfocus Spectrum Characterization

Tube potential (kV) | 60
---|---
Filter (mm Al) | 3.0
Half-value-layer (mm Al) | 1.69
Mean Energy (keV) | 34.3
Fluence per Exposure (mm$^{-2}$ R$^{-1}$) | $1.26 \times 10^8$

9 µm spot size
Slanted-Edge Technique
FWHM = 9.7 µm

50% contrast for 11 µm object

High Resolution Scintillator Comparison:
15 µm GADOX 9 µm pixel FWHM = 27 µm

Larsson et al., Scientific Reports 6, 2016
Best reported to date:
15 μm GADOX
9 μm pixel
QE = 0.13

Larsson et al., Scientific Reports 6, 2016

Vs
LIBRA @ ANL APS Beamline 1-BM

LIBRA camera

Aperture

Power Supply
LIBRA Responsivity @ 21 keV and 63 keV
LIBRA Spatial Resolution @ 63 keV
JIMA RT RC-05 Transmission Bar Target @ 21 keV
50 µm Pinhole Lag @ 63 keV

Scanning Pin Hole _ 63 KeV_ Scan Rate = 25.6 pix/sec

1.2% lag @ 1 sec
0.5% lag @ 13 sec

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Conclusions

• The a-Se/CMOS prototypes demonstrate a remarkable combination of high spatial resolution and high quantum efficiency for hard x-rays

*Factor of 3x DQE improvement despite being relatively unoptimized*
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