Edge effects in detector-grade cadmium telluride

Marten Bosma¹, Alex Fauler², Michael Fiederle² en Jan Visser¹

1. Nikhef, Amsterdam, The Netherlands
2. FMF, Freiburg, Germany
Digital radiography advantages:
- Larger dynamic range
- Immediate image preview; real-time imaging
- Image enhancement processing
- Overall cost reduction

But:
- Gray-scale images
- Only one storage capacitor and TFT per pixel
Medipix

- Hybrid pixel detector
- High granularity: $(55\,\text{um})^2$ pixel pitch
- Excellent contrast transfer:
  - Large dynamic range
  - Noise suppression

Medipix3 features 1080 transistors / pixel:
- Charge summing circuitry
- Simultaneous counting and read-out; no dead time
- Colour mode: seven energy bands can be resolved
Large-area coverage

- 3 inch
- ~7.5 cm
- ~0.5 cm

M.J. Bosma at Physics @ FOM, Veldhoven
Why cadmium telluride?

- Direct conversion
- Wide band gap (1.45 eV)
- Short attenuation length ($Z_{\text{avg}} = 50$)

![Diagram showing X-ray interaction with CdTe, a-Selenium, and Silicon]

January 18, 2011
Spatial non-uniformity

- Tellurium inclusions and sub-grain boundaries
Polarisation

Schubweg: \( \lambda_{e/h} = \mu_{e/h} \times \tau_{e/h} \times E \)

<table>
<thead>
<tr>
<th></th>
<th>Mobility ( \mu ) (cm(^2)/Vs)</th>
<th>Lifetime ( \tau ) (s)</th>
<th>( \mu \tau )-product (cm(^2)/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons</td>
<td>1100</td>
<td>( \sim 3 \times 10^{-6} )</td>
<td>3.3 \times 10^{-3}</td>
</tr>
<tr>
<td>Holes</td>
<td>100</td>
<td>( \sim 2 \times 10^{-6} )</td>
<td>2 \times 10^{-4}</td>
</tr>
</tbody>
</table>

Silicon: \( \mu \tau_{e/h} \geq 1 \)

\[
\lambda_{e/h} = \frac{\mu_e}{h} \times \tau_e \times E
\]

Non-polarising detector

Polarising detector

\( \Phi_{\text{critical}} \approx 10^9 \text{ ph/mm}^2\text{s} \)
Edge termination

Edge issues:
- Charge injection
- Depletion zone confinement
- High-field regions

Reduction of inactive periphery by:
- Less-deleterious dicing:
  - Etching
  - Laser dicing
- Design:
  - Active edges
Conventional versus edgeless

Conventional structure

Edgeless structure

500 µm

50 µm

M.J. Bosma at Physics @ FOM, Veldhoven

January 18, 2011
Silicon: surface-current dominance

<table>
<thead>
<tr>
<th>Sample</th>
<th>Inactive edge (µm)</th>
<th>$I_{\text{volume}}$ (nA)</th>
<th>$I_{\text{surface}}$ (nA)</th>
<th>$I_{\text{surface}}/I_{\text{volume}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edgeless</td>
<td>30</td>
<td>0.72</td>
<td>2.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Conv.</td>
<td>680</td>
<td>1.5</td>
<td>0.72</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Silicon: energy deposition

Spectral response to pion test beam
Silicon: count-rate loss

Active edge distance of 50 μm

Active edge distance of 20 μm

Cu-target X-ray tube:
- -40 V bias;
- 3s. acq. time;
- 50 kV; 15 mA;
- 0.2 mm Cu filter.

M.J. Bosma at Physics @ FOM, Veldhoven
Weighting potential

center  edge  corner

Z (mm)  Z (mm)  Z (mm)

E\(_{\text{backplane}}\)

1400  1400  1400

0  0  0

Counts

center  edge  corner

E\(_{\text{pixel}}\)

122 keV  122 keV  122 keV

FWHM = 3.7%  FWHM = 4.7%  FWHM = 6.4%

20 ns - 1 ns
Tiling

Pad spectral response

Stand-alone

Closely surrounded by other detectors

Counts

Counts

M.J. Bosma at Physics @ FOM, Veldhoven
Summary

• Cadmium telluride hybridised to Medipix is a promising candidate as a digital radiography detector.

• Moderate homogeneity and resulting polarisation remain a problem.

• Medipix size and small single-crystal areas ➔ seamless tessellation of edgeless detectors.

• We have proven to be able to reduce the inactive periphery by more than a factor 10 while maintaining an acceptable leakage current.

• Edge effects can be reduced by proper cutting, effective passivation as well as active-edge technology. Inherent physical edge effects can be reduced by close tiling.
References

- Rossi et al., “Pixel Detectors: From Fundamentals to Applications (Particle Acceleration and Detection)", Springer, March 2006
Excellent image contrast at low dose:

- High spatial resolution
- **✓ 55 um square pixel pitch**
- Large dynamic range and good noise performance
- **✓ 13 bit deep counter and noise suppression per pixel**
- High quantum efficiency and high sensitivity
- **✓ CdTe: Z ≈ 50; w = 4.4 eV, i.e. ~13.500 e-h pairs / 60 keV photon**
- Room-temperature operation
- **✓ CdTe: Wide band gap, i.e. high resistivity**
- Uniformity of spatial and temporal response
- □ Defects and polarisation at high photon fluxes
- Full field coverage with minimum amount of dead regions
- × 8 cm² Medipix module versus ~(40 x 40) cm² flat-panel AMA
Towards an edgeless module

Maximally, 3 inch diameter single-crystal wafers