Comparison of three types of XPAD3.2 / CdTe single chip hybrids for hard X-ray applications

Clément BUTON on behalf of the CHipSPeCT collaboration
Goal: find the best suited hybrid configuration for a 56 chips detector

Preliminary tests on first batch of hybrids

Used both XPAD3.2-S and XPAD3.2-C chips wrt the sensor polarity

Two test campaigns (July & September 2013) on synchrotron beamlines (ESRF & SOLEIL)

Radioactive source at CPPM (marseille) for stability and bias optimization measurements
Chips sample

<table>
<thead>
<tr>
<th>circuit</th>
<th>name</th>
<th>board</th>
<th>dead pixels [#]</th>
<th>used at</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohmic e⁻</td>
<td>1-1</td>
<td>DE2</td>
<td>801</td>
<td>×</td>
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<tr>
<td>Ohmic e⁻</td>
<td>1-3</td>
<td>C4</td>
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<td>Schottky h⁺</td>
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<tr>
<td>Schottky h⁺</td>
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<td>C4</td>
<td>6</td>
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<tr>
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<td>×</td>
<td>×</td>
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- 9 hybrids (Ajat + Acrorad) in 3 configurations (Ohmic e⁻, Schottky h⁺ & Schottky e⁻)
- 2 evaluation boards: «DE2» with a spy pixel and «C4» for synchrotron measurements
- Hybrids quality very heterogeneous
## Chips sample

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<td>CPPM</td>
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- **2 evaluation boards** : «DE2» with a spy pixel and «C4» for synchrotron measurements
- **Hybrids quality very heterogeneous**
First batch of sensors was broken:
- Overheating during the transfer of the chips on the printed circuit board
- Delay in the sample preparation (bias optimization)

Received the second batch just in time for our first test campaign at SOLEIL

CdTe chips are much more fragile than Si
Calibration

- Pulses amplitude proportional to $E_\gamma \pm \varepsilon$
- Per pixel adjustable threshold
- Per chip global threshold scan
- Per pixel local threshold scan
- 64 DAC level (6 bits)
- Calibration « S-curve »
- Electronic noise peak
Calibration

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Calibration

- Calibration at $E_\gamma/2$
- Diminution of the charge sharing effect
- Optimization of the detector efficiency
- Several calibration methods available
- Article submission next June (JSR)
Calibration

- *Ad hoc* calibration at half the energy
- Method «robust, fast and focused on the data»: publication on calibration soon
- Same method applied for all hybrids
- Over-the-noise calibration for tests on radioactive source
- Article in preparation, to be submitted in June 2014
Measurements - SOLEIL

### Beam energies [keV]

<table>
<thead>
<tr>
<th></th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>32</th>
<th>40</th>
<th>24</th>
<th>27</th>
<th>13.5</th>
</tr>
</thead>
</table>

### Biases [V]

<table>
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<tr>
<th></th>
<th>Ohmic e(^-) [1-3]</th>
<th>Schottky e(^-) [3-2]</th>
<th>Schottky h(^+) [2-5]</th>
</tr>
</thead>
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<tr>
<td>Voltages</td>
<td>-100</td>
<td>-400</td>
<td>+400</td>
</tr>
</tbody>
</table>

- 8 different energies: from 8 to 40 keV
- Non-optimized biases due to scheduling delay...
- Scatterer: air, Teflon or glass wrt the incident energy
- Tests on:
  - the image quality
  - the threshold / energy relation
Image quality - SOLEIL

- 12 keV *ad hoc* calibration maps
- 100 s images at 24 keV
- 3 detector configurations
  - Schottky $e^-$: many defective pixels
  - Schottky $h^+$: good detection surface despite the unoptimized bias
  - Ohmic $e^-$: cross patterns due to unconnected pixels
- Edge pixels behave differently: bump in the distribution
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Ohmic e⁻ [1-3]
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- Edge pixels behave differently: bump in the distribution
• Pixel threshold as a function of the energy
• Median ± nMAD of the chip DACL matrix (ad hoc) for each energy
• $\chi^2$ Fit to test the significance of the linear relation
• Similar slopes were expected:
  - higher value for the Schottky $h^+$ due to unoptimized bias
Bias optimization - CPPM

• In-situ measurements at CPPM with $^{241}$Am source
• MCA connected to the spy-pixel of the «DE2» evaluation board
• 200 s exposures for different high voltage values
• Bias optimization: maximizing the signal amplitude while keeping the peak resolution (FWHM) as small as possible
• Schottky $h^+$ [2-1] broken (Bias set to +900 V)
• Ohmic $e^-$ cooled (23°C) due to high leakage current
Stability measurements

- Follow the evolution over time of the integrated counts
- Due to polarization effects, the Schottky configurations need bias resets
- Test on 3 configurations at CPPM ($^{241}$Am) with over-the-noise calibration
- Test on 2 configurations at ESRF (24 keV) with ad hoc calibration

<table>
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<tr>
<th>Detector Type</th>
<th>Exposure Time [s]</th>
<th>Reset Cycle [min]</th>
<th>Exposure Number [#]</th>
<th>Bias [V]</th>
</tr>
</thead>
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<tr>
<td>Ohmic e$^-$ [1-3]</td>
<td>150</td>
<td>×</td>
<td>240</td>
<td>−200</td>
</tr>
<tr>
<td>Schottky e$^-$ [3-5]</td>
<td>40</td>
<td>20</td>
<td>460</td>
<td>−400</td>
</tr>
<tr>
<td>Schottky h$^+$ [2-4]</td>
<td>40</td>
<td>20</td>
<td>400</td>
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<tr>
<td>Schottky e$^-$ [3-4]</td>
<td>60</td>
<td>7</td>
<td>60</td>
<td>−400</td>
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<tr>
<td>Schottky e$^-$ [3-4]</td>
<td>60</td>
<td>10</td>
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Stability - CPPM

- **Ohmic e⁻ [1-3]:**
  - No polarization expected
  - Stabilisation after 5 hours
  - 5% counting decrease

- **Schottky e⁻ [3-5]:**
  - Resets every 20 min
  - 0.13% RMS

- **Schottky h⁺ [2-4]:**
  - Resets every 20 min
  - 0.06% RMS
  - most stable
Stability - ESRF

- **Schottky e⁻ [3-4]:**
  - Inconsistent results
  - Chaotic behavior
  - Unusual leakage current…

- **Schottky h⁺ [2-5]:**
  - Resets 7, 10 and 15 min
  - RMS much higher than at CPPM
  - Chips [2-4] & [2-5] are intrinsically different
Inhomogeneities - CPPM

• Individual pixels can have different counting behaviors: decreasing, stable or increasing
• ~1/3 of the pixels behave differently than the counts integral behavior
• Is there any pattern or structures?
Inhomogeneities - CPPM

- Difference between the average count rate of the 5 firsts and 5 lasts exposures in between resets
- Pixels neighboring an unconnected zone seem to have a strong decreasing pattern
- Edge pixels are also affected
- Ohmic e⁻ [2-3] more affected than other chips
- Structures intensity depends on bias
- Overall fluctuations < 1%
Comparison of three types of XPAD3.2 / CdTe single chip hybrids for hard X-ray applications in material science and biomedical imaging


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Abstract
The CHIPSrtCT consortium aims at building a large multi-modules CdTe based photon counting detector for hard X-ray applications. For this purpose, we tested nine XPAD3.2 single chip hybrids in various configurations (i.e. Ohmic vs. Schottky contacts or electrons vs. holes collection mode) in order to select the most performing and best suited configuration for our experimental requirements. Measurements have been done using both X-ray synchrotron beams and 241Am source. Preliminary results on the image quality, calibration, stability, homogeneity and linearity of the different types of detectors are presented.

Keywords: X-ray detectors, Hybrid pixel detectors

1. Introduction
Modern X-ray imaging systems allow to obtain images immediately after exposure. The systems based on amorphous silicon photo-diodes and CCD detectors are very commonly used. Two decades ago, a new type of X-ray imagers based on photon counting instead of charge integration during exposure has been introduced for particle tracking in high energy physics experiments [1]. This approach called quantum X-ray imaging is capable of discriminating and processing each single X-ray photon in addition to counting them. It also offers improved image quality and noise subtraction compared to the former devices [2] while operating at room temperature. In this so-called hybrid approach where analytic electronic chain is physically bound to each pixel, the sensor material can be chosen according to the energy of the X-ray photons to be detected and the electronics custom-designed for specific applications [3, 4]. Sensor and electronics are assembled using bump-bonding and flip-chip technologies resulting in a hybrid-pixels photon counting detector.

Silicon based hybrids are now regularly used X-ray detectors for material science, medical imaging and for the development of photon counting and spectral micro-computed tomography (CT) [5, 6, 7, 8, 9, 10, 11]. However, the detective quantum efficiency of thin (500 microns) silicon based hybrids is decreasing steadily from 99% at 12 keV to less than 40% at 20 keV [8, 9]. Therefore, a grown interest in studying new high-density high-Z sensor materials for experiments at energies above 25 keV appeared (i.e. for third generation synchrotron sources or new generation medical X-ray detectors). Thanks to its high resistivity at room temperature and its large linear attenuation coefficient, the cadmium-telluride (CdTe) appeared to be a good prospective material for room temperature semiconductor detectors.

This paper reports tests that have been performed both with radioactive sources and on synchrotron beamlines. We will determine the best suited configuration for the production of hybrids with CdTe sensors using either Schottky or Ohmic contacts in hole or electron collection modes, bump bonded to the different flavors of the XPAD3.2 chip. Several single chip hybrids were assembled and evaluated, allowing for the selection of the detector type. Their linearity, stability robustness were evaluated in order to chose the most relevant technology to build a large detector composed of 56 single chip modules dedicated to material science and preclinical imaging.

2. Hybrid pixels detectors
2.1. The cadmium telluride sensors
The CdTe semiconductor sensor material has a higher Z than Si and a higher density, and thus a better X-ray absorption efficiency. Nevertheless, despite the recent progress in growing and processing this material, good quality and homogenous sensors are not yet available in sizes comparable to silicon. Furthermore, they are fragile and the bump bonding process needs to be optimized.

Cadmium telluride is a II-VI semiconductor. A couple of methods are currently available to grow CdTe crystals: the traveling heater method (THM) used by Acrorad® in Japan, for the

References
1. Important discrepancies in between hybrids of a same type
2. More statistics for each type are needed to achieve a proper selection
3. More hybrids have been ordered
4. Schottky h+ appears to be the most reliable choice at this time

Paper published in NIM A last week.

Conclusion

March 24, 2014