The HPAD-AGIPD Detector for XFEL

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Outline

• The European XFEL
• Scientific Case
• Detector Requirements
• HPAD-AGIPD Detector
• HPAD-AGIPD Readout ASIC
• Status & Outlook
The European XFEL

- Superconducting linac driven
- SASE undulators
- $10^{33}$ ph/(s mm$^2$ mrad$^2$ 0.1%BW) peak brilliance
  - $10^9$ wrt. 3rd gen. synchrotrons
  - $10^5$ in av. brilliance
- $E_\gamma=250$eV...12keV
- 100fs pulse width
- 3000 pulses @5MHz

Other FEL sources: LCLS, SCSS
European XFEL Time Structure

- 100 ms
- 0.6 ms
- 99.4 ms
- 200 ns
- <100 fs
- FEL process

FEL process

X-ray photons

av. Rate:
- 30kHz XFEL
- 120Hz LCLS
- 60Hz SCSS

Ulrich Trunk - HPAD-AGIPD - Consortium
Single Molecule Imaging

Just before XFEL pulse

During the pulse

After pulse

X-ray Diffraction Pattern

Henry Chapman, CFEL, Guillaume Potdevin, DESY
Janos Hajdu, Uppsala University and Stanford
### XFEL Detector Requirements

- Energy 0.8..15keV
- No energy resolution
- High efficiency (>0.8)
- High dose 1GGy/3a
- Low dead area <10%
- High dynamic range
- XFEL Timing compliant
- Low noise (<1 ph)
- Low crosstalk
- Vacuum compatible
- Central hole

<table>
<thead>
<tr>
<th></th>
<th>PPnX</th>
<th>PPX</th>
<th>CDI</th>
<th>SPI</th>
<th>XPCS</th>
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<tbody>
<tr>
<td>E (keV)</td>
<td>6–15</td>
<td>12</td>
<td>0.8-12</td>
<td>12.4</td>
<td>6 – 15</td>
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<tr>
<td>ΔE/E</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>QE</td>
<td>&gt;0.8</td>
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<td>Rad Tol</td>
<td>10^16 ph</td>
<td>10^16 ph</td>
<td>2×10^16 ph</td>
<td>2×10^15 ph</td>
<td>2×10^14 ph</td>
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<tr>
<td>Size</td>
<td>200 deg</td>
<td>120 deg</td>
<td>120 deg</td>
<td>120 deg</td>
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<tr>
<td>Pixel</td>
<td>7 mrad</td>
<td>100 μm</td>
<td>0.1 mrad</td>
<td>0.5 mrad</td>
<td>4 μrad</td>
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<td># pixels</td>
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<td>3k × 3k</td>
<td>20k × 20k</td>
<td>4k × 4k</td>
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<tr>
<td>tiling</td>
<td>&lt;20%</td>
<td>&lt;10%</td>
<td>See text</td>
<td>&lt;20%</td>
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<tr>
<td>L Rate</td>
<td>5×10^4</td>
<td>3×10^6</td>
<td>10^5</td>
<td>10^4</td>
<td>10^3</td>
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<td>G Rate</td>
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<td>10^7</td>
<td>10^7</td>
<td>10^6</td>
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<td>Timing</td>
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<td>5MHz</td>
<td>10Hz</td>
<td>5MHz</td>
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<td>Flat F</td>
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<td>Dark C</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
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<tr>
<td>R Noise</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
<td>&lt;1 ph</td>
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<td>Linearity</td>
<td>1%</td>
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<td>1 pixel</td>
<td>100 μm</td>
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<td>Lag</td>
<td>10^{-3}</td>
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<td>7×10^{-5}</td>
<td>10^{-3}</td>
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<td>Vacuum</td>
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<td>Yes</td>
<td>No</td>
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<td>Other</td>
<td>Hole</td>
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<td>Hole</td>
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XFEL Detector Challenges

• Time structure of the photon signals
• High radiation dose at small angles: $10^4$ photons per pixel per shot
  • over 3 years 1 GGy
  • Radiation damage of silicon sensor
  • Radiation damage of underlying electronics
  • Program for radiation damage studies needed
• High radiation dose at specific pixels: $10^5$ photons in $10 \mu m \times 10 \mu m$ (“charge explosion”)
  • $10^5$ photons of 12 keV create: $(10^5 \times 12 \times 10^3)/3.6 = 3 \times 10^8$ electron-hole pairs
  • “plasma effect” gives shielding of drift field
  • diffusion before drift
  • peak broadening (space and time).

Therefore R&D programs on radiation damage & “charge explosion” have been established
HPAD-AGIPD Target Specs

Basic parameters

• 1 Megapixel detector (1k × 1k)
• 200 μm × 200 μm pixels
• Flat detector
• Sensor: Silicon 128 × 256 pixel tiles
• Single shot 2D-imaging
• 5MHz frame rate
• 2 × 10⁴ photons dynamic range
• Adaptive gain switching
• Single photon sensitivity at 12keV
• Noise ≤150e (50 × 10⁻³ photons @ 12keV)
• Storage depth ≥200 images
• Analogue readout between bunch-trains
The AGIPD Detector

- 64×64 pixel/chip
- 2×4 chips/sensor
- 2×4 sensors/quadrant
- 4 quadrants = 1024×1024 = 1048576 pixel

Diagram showing the AGIPD Detector components:
- Bump bond
- Chip
- Sensor
- Wire bond
- HDI
- Base plate

Connector to interface electronics
AGIPD Architecture

- 64 rows
- 64 columns
- 4 outputs
- (16 columns/output)
AGIPD Pixel

- **Wide dynamic input range**
- **Multiple (3) scaled feedback capacitors**
- **Reduced ADC resolution**
  
  (10 bit instead of 12 bit)

- **Analogue + digital (2 bit) pipeline**

**Key Components:**
- Control logic
- Analogue encoding
- Leakage comp.
- Discr.
- Trim DAC
- Analogue pipeline
- 3 levels
- V_{thr} \equiv V_{ADC_{max}}
- Readout amp.

**Additional Features:**
- Analogue pipeline
- Column bus
- Filter/write amp.
AGIPD Dynamic Range

Integrator gain requirements:

- Effective analogue resolution ≥ 8 bit
- Analogue resolution always better than “statistical noise” \( \sqrt{n_{\text{ph}}} \)
- maximum signal ≥ 10^4 photons

<table>
<thead>
<tr>
<th>range</th>
<th>norm. gain</th>
<th>Cf [fF]</th>
<th>max ( n_{\text{ph}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>100</td>
<td>256</td>
</tr>
<tr>
<td>2</td>
<td>1/16</td>
<td>1600</td>
<td>4096</td>
</tr>
<tr>
<td>3</td>
<td>1/64</td>
<td>6400</td>
<td>16384</td>
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</table>

Adaptive gain switching tested on a Si-strip readout chip @ PSI by A.Mozzanica
100msec “loss free” Charge Storage

Thick oxide, (dual) MIM caps in 130nm process are (should be) ok

Switch design is the challenge

Subthreshold characteristics?
Radiation induced leakage currents?
The “hpad 0.1” chip

- 2mm x 2mm
- IBM crmrf8sf DM process
- submitted via MOSIS at 26.03.2008
- Only test structures:
  - Capacitors
  - Switches (FETs)
    - Single & double transistors
    - Linear and enclosed layouts
  - 16-cell analogue storage array
  - OP-Amp & buffer amplifiers
  - Minimum protection pad
Measurement Setup

- HP 4156A high-precision semiconductor parameter tester
  - 4 HRSMUs (1fA res, 20fA accuracy)
  - 4-wire Kelvin connections via Triax cables
- Custom made HPAD 0.1 DUT board
  - Flying leads & pin headers to connect to analyzer
  - CLCC 84 carrier & test socket
  - >5mm wire spacing when possible
  - Special cleaning procedure
**DAQ architecture**

- **Front End Electronics (FEE)**
- **Front End Interface (FEI)**
  - interface to Train Builder
  - integrated in 2D
- **Train builder layer**
  - builds trains
  - simple data processing
- **PC layer**
  - interface to cache
  - additional train building
  - more complex data processing
- **Data cache**
  - hold, analyze, reduce and reject data
  - post processing
  - commit to silo

- **2D pixel FEE**
- **1D FEE**
- **camera**

- **Train builder**
- **Train builder?**

- **PC layer**
- **Data cache**
- **Archive silos**

- Custom
- 10 GE UDP
- 10 GE TCP
- TCP, FC, Infiniband ...
- DESY IT standard
- PCs

C. Youngman, S. Esanov
Summary & Outlook

We are developing a 1Mpix “AGIPD” detector for the European XFEL with

- Adaptive gain switching
  - Functionality tested with Si-strip readout chip at PSI
- Buffer for ≥200 frames @ 5MHz
- Radiation and leakage issues investigation with “HPAD 0.1”
  - Shows encouraging results wrt. leakage
  - Irradiation studies are planned
- Construction of a 16 × 16 pixel chip
  - Well advanced schematics @ PSI and DESY
  - Ongoing simulations
  - Planned fabrication on MOSIS run in March ’09
- 1Mpix system ready in 2012

http://hasylab.desy.de/science/developments/detectors/hpad

Work in Progress!