The LAMBDA pixel detector with high-Z sensors

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Overview

➢ LAMBDA (Large Area Medipix3-Based Detector Array)

➢ High-Z hybrid pixel detector development
  ▪ Gallium Arsenide
  ▪ Cadmium Telluride
  ▪ Germanium
Large Area Medipix3-Based Detector Array (LAMBDA)

- Aimed at X-ray scattering and imaging at synchrotrons
- Photon-counting system using Medipix3 chip
- Small pixel size – 55 µm
- Large tileable module layout
- High-speed readout
  - 2000 fps with no dead time
- Compatible with high-Z materials
Medipix3 readout chip

➢ Collaboration of ~20 groups led by CERN
  ▪ Talk by Michael Campbell later

➢ Flexible pixel design
  ▪ 2 counters and thresholds per 55µm pixel, plus interpixel communication

➢ Major applications:
  ▪ Fast, deadtime-free frame readout
    • 2000 fps @ 12 bit depth
  ▪ “Colour imaging”
    • Photon hits divided into energy bins
System design

> 12 readout chips bonded to large Si sensor (or smaller high-Z)

256 x 256 chip

1536 x 512 module (750k)

1.5k x 1.5 k multi-module

Common DESY high-speed readout card

- FPGA with PowerPC for control, up to 4 x 10 Gigabit Ethernet links
- See AGIPD and Percival talks in synchrotron session
High-Z pixel detectors

- Aim: Increase quantum efficiency at hard X-ray beamlines
  - Replace silicon sensor in LAMBDA with high-Z semiconductor

- Investigating different materials in collaboration with other institutes and industry
  - Gallium arsenide
  - Cadmium telluride
  - Germanium

![Photoelectric absorption of X-rays](image)

- Silicon (500um)
- Ge / GaAs (500um)
- CdTe (500um)
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Gallium Arsenide

- 6 chip layout (768 x 512 pixel, 55um pixel size)
- Cr-compensated GaAs from RID Ltd, Tomsk - 500 µm thick
  - High-resistivity material with reasonable electron lifetime (~10 ns)
  - Cr compensation and ohmic pixelation done at RID - electron readout
- Bump bonding at University of Freiburg
Gallium Arsenide – imaging performance

- Cellular nonuniformity structure
- 0.16% dark pixels (640), 0.08% hot pixels (300) excluding chip errors

Good time stability – see Elias Hamann (2013), Characterization of High Resistivity GaAs as Sensor Material for Photon Counting Semiconductor Pixel Detectors
Gallium Arsenide – imaging performance

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Flat field (Mo tube @ 40kV, -300V bias)

USB stick, FF corrected

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High-speed imaging with GaAs (1000 fps)

- 1000 fps X-ray imaging, 20 fps playback (x 50 slowdown)
- Mo X-ray tube at 60kV (approx 80 counts in light regions), flat-field corrected and single bad pixels filtered
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Cadmium Telluride

- 6-chip layout (768 x 512 pixel, 55μm pixel size)
- 1 mm-thick CdTe from Acrorad
- *Ohmic* pixel contacts and bump bonding at University of Freiburg – electron readout
  - Higher leakage current than Schottky, but typically less polarisation
Cadmium Telluride – imaging performance

- Some insensitive blobs, network structure
- 0.28% dark pixels (1116), 0.015% hot pixels (60)

Flat field (Mo tube @ 40kV, -300V bias)  USB stick, FF corrected
Cadmium Telluride – time variation

Tested at ESRF ID15C with scattered background for 10 hours

![CdTe normalised count rate graph]

- +4% over first hour
Cadmium Telluride – time variation

> Tested at ESRF ID15C with scattered background for 10 hours

CdTe normalised count rate

Change from start to 1 hour

Change from 1 hour to 10 hours

+4% over first hour
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Germanium pixel detector development

> Advantages and disadvantages

- High-purity, high uniformity wafers of 90 – 110 mm
- Cooling needed to reduce leakage current
  - Operation around -100°C
  - ~1W per chip power

> Sensor development at Canberra France

- Photodiode structure with n-side readout
- 55 µm pixel size, 700 µm sensor thickness
- Single Medipix3 layout – 256 x 256 pixels

> 2 high-purity Ge wafers produced

- 16 sensors on each wafer
Germanium pixel detector development

> Indium bump bonding at Fraunhofer IZM (Berlin)
  - Ductility of In allows safe low-temperature cooling
  - Low temperature processing (<100°C)

> Test setup at DESY
  - LAMBDA uses ceramic circuit board to avoid thermal stresses during cooling
  - Sensor assembly and electronics mounted in vacuum chamber for prototype tests
  - Cryotiger cooling to -100°C
Test results from prototype sensors

- Generally uniform response
  - Edge pixels nonfunctional due to high leakage current. In central region have 0.23% bad pixels (very similar to GaAs)

Flat field from 50kV Ag tube

USB stick (uncorrected)
Effects of temperature

> At warmer temps, current-saturated region at edge grows
> Pixels become noisy with operating point shift (NB – not readjusted)

-100°C  -80°C  -60°C

2.2 mA current!
Further work on Germanium

- 6-chip-layout Ge sensors produced at Canberra
  - Currently being bump-bonded at IZM
- Portable cooling and vacuum system in development
Conclusions

- LAMBDA readout system - high-speed readout of large high-Z sensors
- Gallium Arsenide sensors - good pixel yield and stability, acceptable results after flat-field correction
- Cadmium Telluride - best QE at high energies, acceptable image quality
- Germanium single chips show promising results with higher uniformity
Thanks for listening

There are open positions for PostDocs and Master/PhD students

- http://photon-science.desy.de/research/technical_groups/detectors/index_eng.html
Medipix3 readout chip

- CERN-led collaboration (~20 institutes)
  - Flexible design
  - 256 by 256 array of 55µm pixels

2 photon-counting thresholds available

Interpixel communication

2 x 12-bit counters per pixel
Medipix3 design and high-Z compatibility

- Bipolar input preamp with leakage compensation (followed by shaper)
- Gain selection
- Charge summing (beneficial for thick sensors with fluorescence)

![Diagram of Medipix3 design and high-Z compatibility](image)

Rafael Ballabriga Suñé, CERN Thesis 2010-055
Medipix3 design and high-Z compatibility

> Charge summing (avoids double / lost counts, better discrimination)

Medipix3 RX charge summing

Simulated spectrum - Ge, 100V

Charge summing (avoids double / lost counts, better discrimination)
Medipix3: features and possible operating modes

> Continuous read-write: deadtime-free readout with 12 bit depth
  - 2 x frame rate possible with 6 bit depth

> 24-bit mode (but with deadtime between frames)

> 2 independent counters and thresholds
  - Energy discrimination
  - Pump-probe operation

> With 110µm pixel sensor
  - Up to 8 energy bins
  - Or, 4 with charge sharing compensation and CRW
Detector head

➢ 6 by 2 chips (1536 by 512 pixels)
  ▪ Large Si sensor
    • 300µm Si sensor here
  ▪ 2 x “Hexa” high-Z sensors

➢ Ceramic circuit board (LTCC)
  ▪ Good match to semiconductor CTE
  ▪ Cooling through thermal vias

➢ 500-pin connector on board
  ▪ Full parallel readout (8 LVDS data outputs per chip)
High-speed electronics

- DESY high-speed readout card (also used for AGIPD and PERCIVAL)
  - Virtex-5 FPGA with PowerPC
  - Up to 4 * 10 Gigabit Ethernet links
  - DDR2 RAM (8GB)

- “Signal distribution” board connects to det. head
  - Space for vacuum barrier with germanium detector
Test results with Si module
Comparison of materials

GaAs

CdTe

Ge
Application at synchrotrons

- Powder diffraction patterns measured at PETRA-III P02 (42 keV)
- Standard sample (CeO$_2$) gives usable diffraction pattern in 1 ms
- Possibility of time-resolved and high-speed measurements (e.g. effects of rapid heating or pressure)
Experimental use at PETRA-III

Example – Rheology at PETRA-III P10

- Investigates structure changes and particle dynamics in fluids under shear forces
- Requires high frame rate, high SNR, small pixel size
PRELIMINARY results:

- XPCS measurements demonstrated in rheometer setup
- Sample decorrelates more quickly with increasing shear applied
Ge sensor behaviour

> Relatively high current (measured at -110°C) dominated by guard ring

- Ikrum tests of previous sensor at -70°C showed < 1 nA in working pixels