Detectors for Photon Science.

Challenges
Projects
Perspectives

Heinz Graafsma; DESY and European XFEL
DESY Instrumentation Seminar
05 Feb. 2010
The Challenge #1: a moving target

- PETRA-3
- ESRF (2000)
- ESRF (1994)
- Second generation
- First generation
- X-ray tubes
- FEL Sources
- Synchrotron Sources
The Challenge #2: many targets

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<th>Number</th>
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<td>Dynamics beamline, IXS, NRS</td>
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<td>P02</td>
<td>Powder and extreme conditions</td>
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<td>P04</td>
<td>Variable Polarization XUV</td>
<td>5 m UE65 (APPLE)</td>
<td>0.2 - 3.0 keV</td>
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<td>Macro molecular crystallography I</td>
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<td>M. Cianci, EMBL</td>
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<td>P14</td>
<td>Macro molecular crystallography II</td>
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<td>G. Bourenkov, EMBL</td>
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The Challenge #3: different target

Single shot science
Electron bunch trains; up to 2 700 bunches in 600 μsec, repeated 10 times per second. Producing <100 fsec X-ray pulses (up to 27 000 bunches per second).

FEL process
Single shot experiments

One pulse, one measurement
Particle injection

10 fs pulse

Noisy diffraction pattern

Solve the well known Phase Problem

Combine $10^5$ - $10^7$ measurements

Classification

Averaging

Orientation

Reconstruction
The projects launched

Radiation damage study
Charge cloud/explosion study

Large Pixel Detector (LPD)

DEPFET Sensor with Signal Compression (DSSC)

Adaptive Gain Integrating Pixel Detector (AGIPD)
Hybrid Pixel Technology

Sensor Substrate

- Sensor Substrate
- p-type silicon layer
- high resistivity n-type silicon
- aluminium layer
- electronics chip
- single pixel read-out cell
- flip chip bonding with solder bumps
- CMOS ROIC
The **DEPFET Sensor with Signal Compression (DSSC)** project
DEPMOS Sensor with Signal Compression

- DEPFET per pixel
- Very low noise (good for soft X-rays)
- non linear gain (good for DR)

- In pixel ADC
- *Digital* storage pipeline

Hexagonal pixels at 200μm pitch combines DEPFET with small area drift detector

> MPI-HLL, Munich
> University Bonn
> University Heidelberg
> University Siegen
> Politecnico di Milano
> University Bergamo
DEPMOS Sensor with Signal Compression

DEPFET: Electrons are collected in a storage well

⇒ Trigger current from source to drain

Fully depleted silicon

![Diagram of DEPFET sensor]

Signal charge collection in Internal Gate

- channel region
- inner source region
- outer source region

Output voltage as function of charge

![Graph showing output voltage vs. injected charge]
The Adaptive Gain Integrating Pixel Detector (AGIPD) project
The Adaptive Gain Integrating Pixel Detector

**High dynamic range:**

**Dynamically gain switching system**

**Extremely fast readout (200ns):**

**Analogue pipeline storage**

![Diagram showing the Adaptive Gain Integrating Pixel Detector circuit](image-url)
Some Thoughts and Perspectives:

> For every photon measure:
  - Time of arrival (which bunch): ~ nsec time resolution (APD’s)
  - Position: ~ micro-meter resolution (center of mass)
  - Energy: ~ few 100 eV resolution (fano-limit)
  - Polarization: few degrees resolution

At SR: “never” more than 1 photon per pixel per bunch
At FEL: often more than 1 photon per pixel per bunch ➔ sum of deposited energy

Note: a photon is either fully absorbed, or not detected at all (no tracks)!
Hybrid Pixel Technology

Other Sensor materials:
- Better at high E: Ge; GaAs; Cd(Zn)Te; …
- Better at low E: DEPFET; APD’s

More functionality per pixel:
- Moore’s law:
  250 nm CMOS in use
  130 nm CMOS development
  90, 65, 45, ….nm
- Good for digital; bad for analogue

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The technology is out there:

**Technology enablers:**
TSV processing during CMOS process

- **Technology:**
  - fabrication at device level, i.e. as a part of (CMOS) flow
  - after FEOL, before BEOL
  - will become established in advanced CMOS foundries (core partners, e.g. TSMC, Matsushita, Intel, Micron, ...) participate in 3D IC work at IMEC

- **Specifications:**
  - Si thickness: 10 – 20 um
  - via diameter: 3 – 5 um
  - via pitch: 10 um

- **Applications:**
  - Pixel level interconnect
  - imager/processor/logic/memory stacking
The technology is out there:

**Detector systems:**

**RelaxD: tilable X-ray imagers**

- **Application:** large area X-ray detection by tiling of imager modules
- **Using Si X-ray detectors (Canberra) hybridized on Medipix ROICS (CERN)**
- **Issue:** 'dead area' and hence loss of information at imager boundary due to:
  - wiring at > 1 side
- **Solution:**
  - Vertical electrical interconnections using 3D integration by using TSVs

![Diagram of X-ray detector and Medipix ROIC integration](image)
Summary and Comments

> Full identification of each photon is (probably) possible in the future (like in HEP experiments).

> This needs money (deep sub-micron and 3D chip technology are not cheap), and people (still in developmental phase)

> Photon science needs medium-Z sensors

> Develop detectors for well defined science applications (but choose them carefully)

> Data rates will grow exponentially (need HEP like approaches)

> Storage Ring - FEL - HEP combination extremely powerful!