Future trends of radiation detector technologies

Outline

Introduction

Helsinki Detector Laboratory

Types of radiation detectors

Applications of radiation detectors

Trends in radiation detecting

Science

Health

Safety, Security & Safeguards

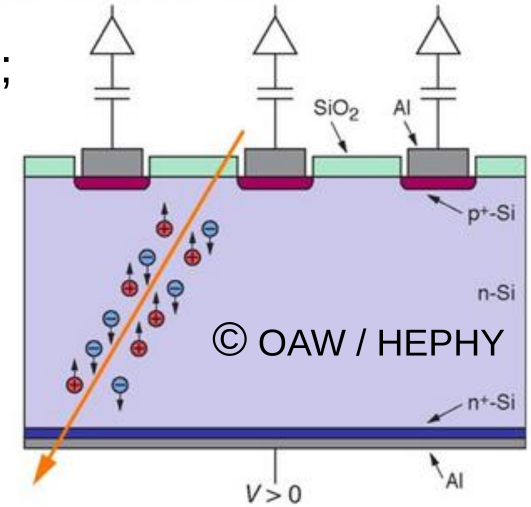
Helsinki Detector Laboratory

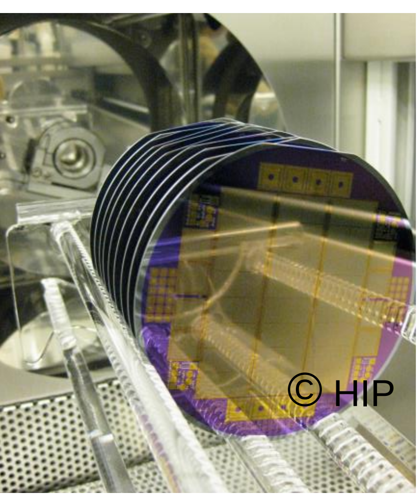
- Permanent infrastructure with premises, equipment and personnel for detector development, prototyping, assembly and quality assurance;
- Common Infrastructure of Helsinki Institute of Physics (HIP) and University of Helsinki / Department of Physics;
- Center for instrumentation of Finnish CERN and FAIR activities;
- Cooperation with universities, research institutes and companies (e.g. Micronova, JYFL, LUT, CERN);
- Education and outreach.

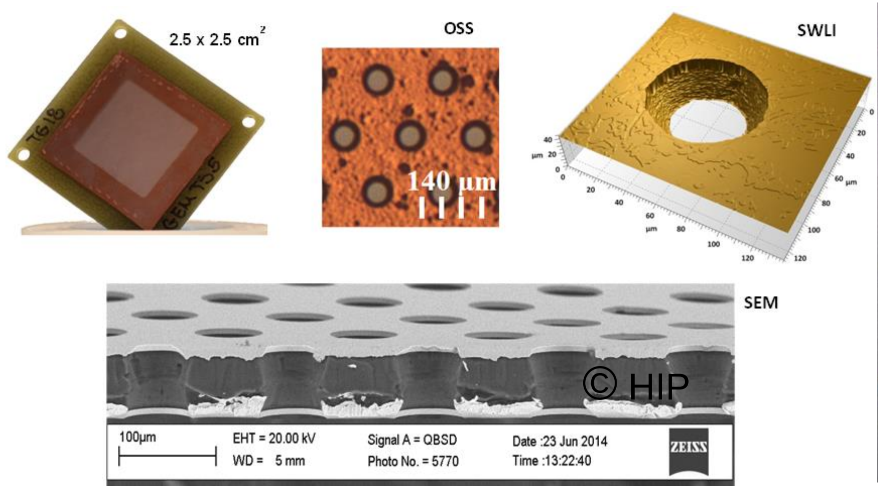


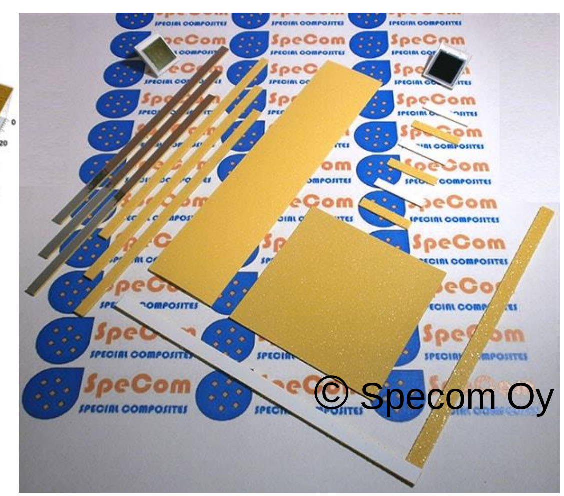
Types of radiation detectors

1. Semiconductor detectors, eg. Si, Ge, GaAs, CdTe;
2. Gaseous detectors, eg. propotional counters, Gas Electron Multiplier (GEM) detectors;
3. Scintillators, e.g. metamaterials (SMM).









Applications of radiation detectors

- Science
  - particle physics (e.g. CERN)
  - nuclear physics (e.g. FAIR)
  - material physics (e.g. ESRF, XFEL)
  - astrophysics (e.g. satellites, ESO, ESA)
  - dating, archeology (e.g.C-14)
- Health
  - medical imaging (e.g. CT, PET, MRI)
  - nuclear medicine
- Safety, security and safeguards
- Industry (e.g. food preservation, imaging)

Challenges in science

- Increased radiation hardness, due to increased luminosity;
- Decreased physical dimensions of detector segmentation, i.e. increased granularity;
- Custom-made detector solutions;
- Demands for cheaper prizes, longer lifetime, consistent detectors and less maintenance (cost-effectiveness);
- Consecutive demands for read-out electronics, data acquisition, interconnection technologies, and quality assurance;
- Long project timelines:
  - projects and upgrades typically appear in 5-10 year cycles;
  - thus, no steady cash flow industrial partners;
  - and, gained expertise does not accumulate (brain drain).

Trends in science / semiconductor detectors

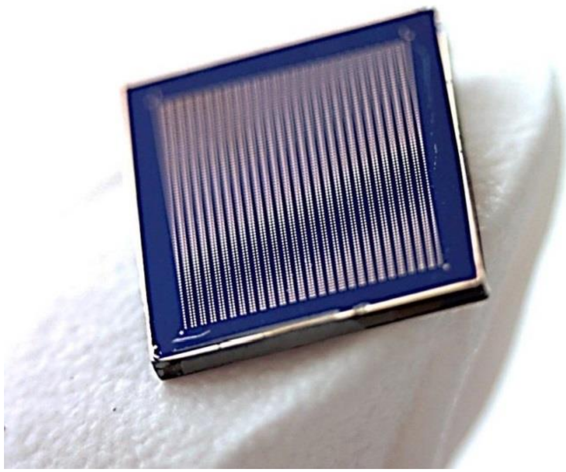
- Detector technologies foreseen to improve **radiation hardness**:
  - from n-type detectors to p-type detectors ($\mu_e > \mu_h$, no SCSI);
  - availability of p-type Magnetic Czochralski silicon (p-MCz Si);
  - p-MCz Si is radiation hard due to high oxygen concentration;
- Technologies foreseen provide **finer segmentation**:
  - deep submicron Atomic Layer Deposition (ALD) technology provides very high densities of capacitance and resistance;
  - in addition, ALD helps to resolve the accumulation of positive oxide charge in Si-oxide interface in p-type detectors;
- Ultra-fast silicon detectors with timing resolution, based on the concept of Low Gain Avalanche Detector (LGAD).

Trends in science / gaseous detectors

- Picosecond Micro Patterned Gas Detectors (MPGDs):
  - i.e. hybrid detectors combining micro-pattern gaseous detectors with Cherenkov light detection via a photocathode;
  - objective is large surface detectors capable of timing resolution of few tens of picoseconds;
- Time Projection Chambers (TPC);
- Large area detectors for muon detection;
- R&D ongoing to better understand the physics of gaseous detectors and to develop new exotic detectors for rare events (e.g. dark photons).

Trends in medical imaging

- Requirement for increased accuracy and decreased radiation dose;
- Direct detection of X-rays (i.e. without scintillator) -> significant improvement in cancer diagnostics and treatment (Spectral/Color imaging);
- Silicon NOT suitable for direct x-ray detection (limited stopping power);
- CdTe still with challenges in crystal growth (commercialization requires significant R&D from scientific community);
- GaAs, especially for the increased need of mammography, still with challenges in semiconductor manufacturing process;
- Commercialization of CdTe and GaAs still requires significant R&D from scientific community.



Trends in safety, security and safeguards

- 2D/3D imaging;
- User-free sensing:
  - non-attended operations (safeguards);
  - remote sensing (security);
  - automated analysis;
- Increased amount of sensing:
  - hidden sensors;
  - diffused networks;
- Muon imaging:
  - penetrating radiation;
  - e.g. loaded nuclear fuel casks, cargo containers, train cars.

Trends in quality assurance (QA)

- Reliable quality assurance (optical and electrical) prior to installation is essential to guarantee reliable performance of detectors, interconnections and electronics;
- Increased detector granularity calls for increased granularity in QA;
- Trends in the future:
  - traceable nanometrology with novel measurement techniques and standards (ref. EURAMET / MIKES);
  - super-resolution technologies with e.g. super-resolution microscopy and image processing (ref. Nobel Prize in Chemistry 2014);
  - neural networks to process vast amount of data.

Summary

- Detector technologies developed for particle and nuclear physics are widely applied in:
  - medical imaging;
  - safety, security and safeguards;
- Trends in radiation detectors:
  - improved radiation hardness;
  - decreased physical dimensions;
  - semiconductor materials p-MCz Si, GaAs, CdTe.
- Consecutively, decrease in physical dimensions sets demands for:
  - read-out electronics & data acquisition;
  - interconnection technologies;
  - QA (nanometrology, super-resolution, neural networks).