N-on-N iLGAD for X-ray detection

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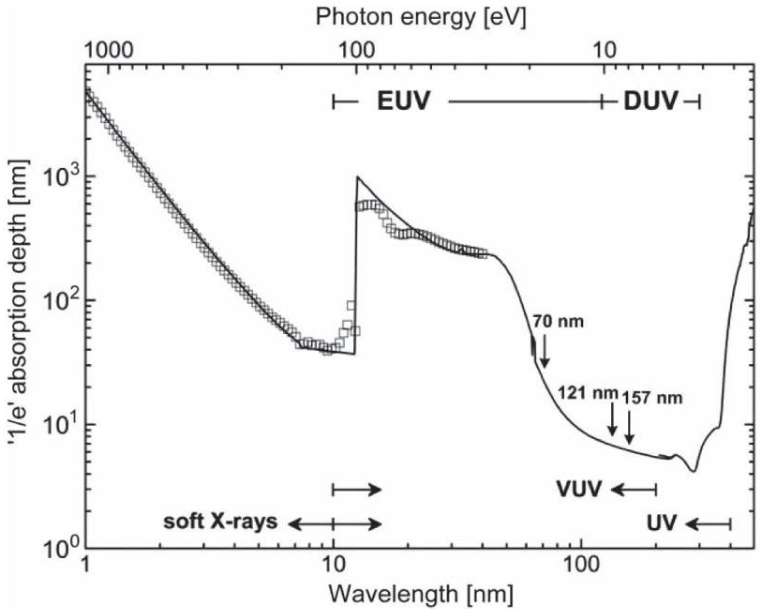
Overview

- Motivation for the technology
- Design
- Fabrication
- Preliminary results
- Ongoing developments
  - Thin entrance window
  - P-type iLGAD
- Outlook

Motivation

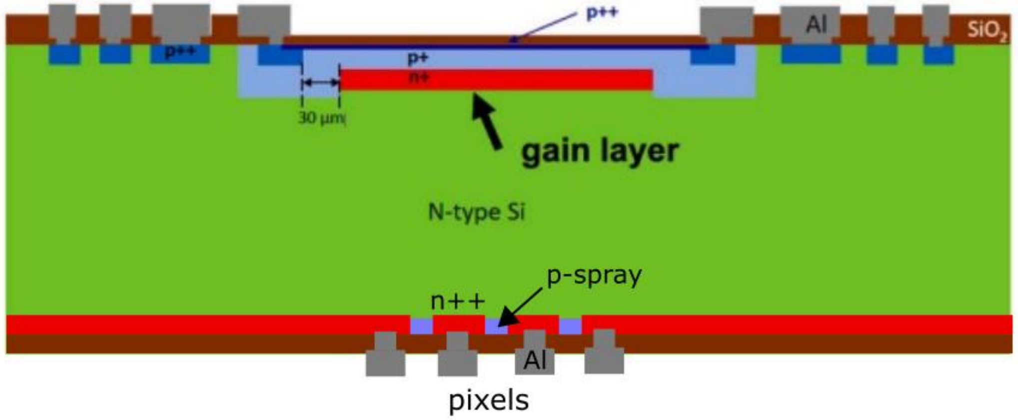
- New XFELs require detectors capable of measuring soft X-rays
  - LCLS-II delivers photon energies down to 250 eV.
  - FERMI and FLASH reach lower energies (down to 30 eV)
- Challenges with soft X-ray detection
  - Interactions occur close to the silicon interface
  - Only a few electron-hole pairs are created
  - Signals can be smaller than the noise of front-end electronics.
- Similar challenges for UV photo detection, low-energy ion and electron detection.
- Possible solutions
  - Detectors with shallow entrance window
  - Sensors with internal signal amplification to raise small signals above noise level

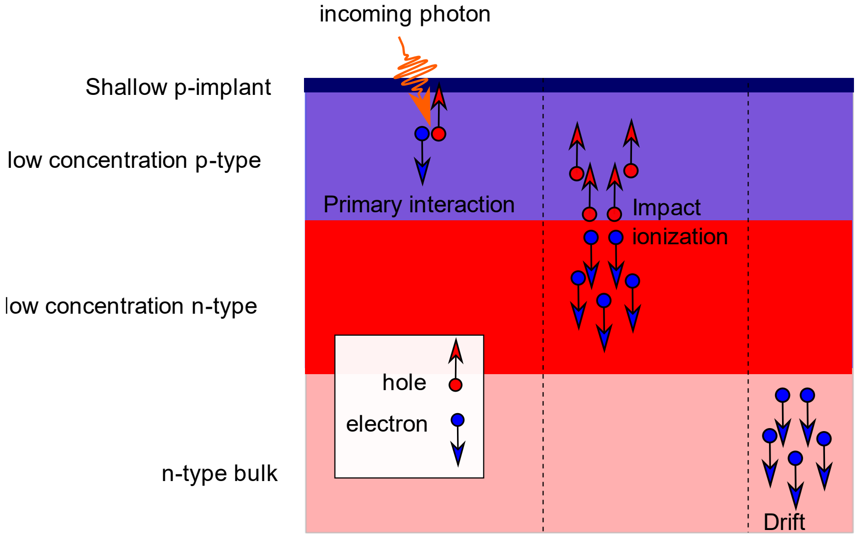


L. Shi et al. «Surface-Charge-Collection-Enhanced High-Sensitivity High-Stability Silicon Photodiodes for DUV and VUV Spectral Ranges", 2012

Concept

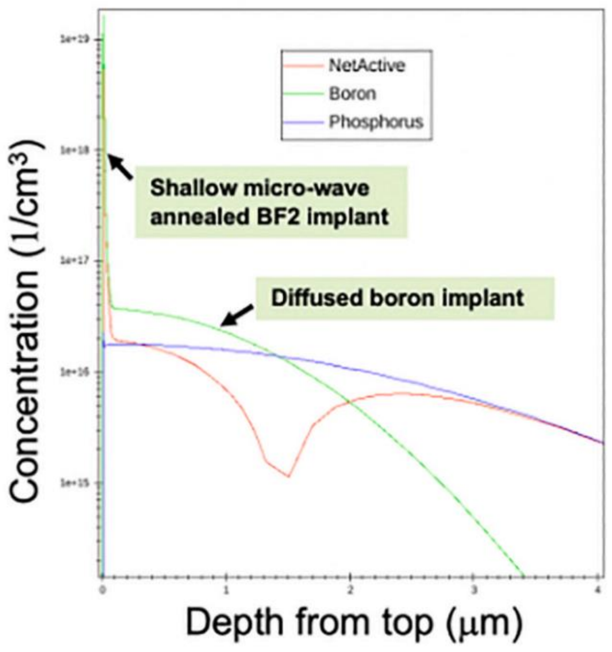
- N-type iLGAD: Shallowly generated electrons drift through a gain region.
  - Doping polarities are inverted compared to conventional LGAD
- Key features:
  - **Shallow entrance window**
    - Ultra-shallow p++ doping
    - More charge is collected by the electric field
  - **Junction and high field peak is ~ 1 µm into the active area**
    - Charge multiplication is not limited to the shallowest depositions
  - **Inverse LGAD configuration**
    - 100% fill factor

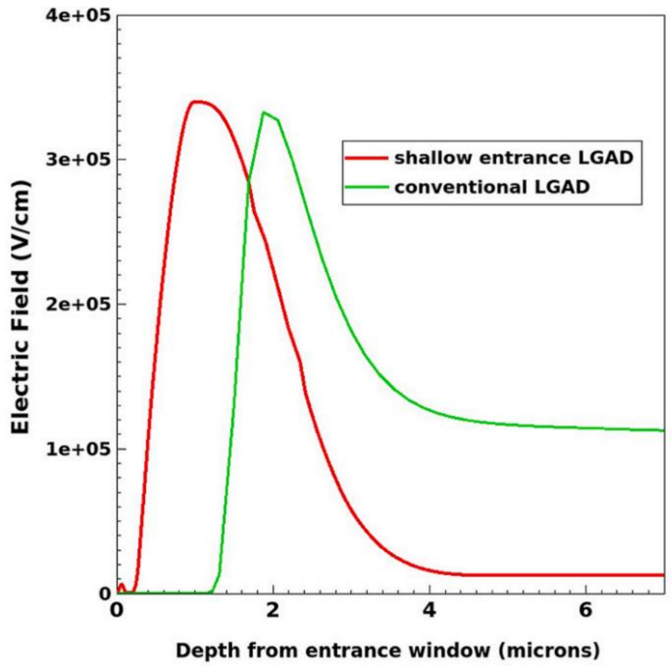




Design of gain region and entrance window

- Interplay between three doping profiles
  - Shallow boron profile.
    - Shallow BF_2 implant, activated through microwave annealing
  - Deep boron profile
    - Low-dose implant
    - Deep diffusion
  - Deep phosphorus profile
    - Low-dose implant
    - Deep diffusion
- Electric field
  - Up until the shallow p++ implant
  - Peak ~1 µm into the active area





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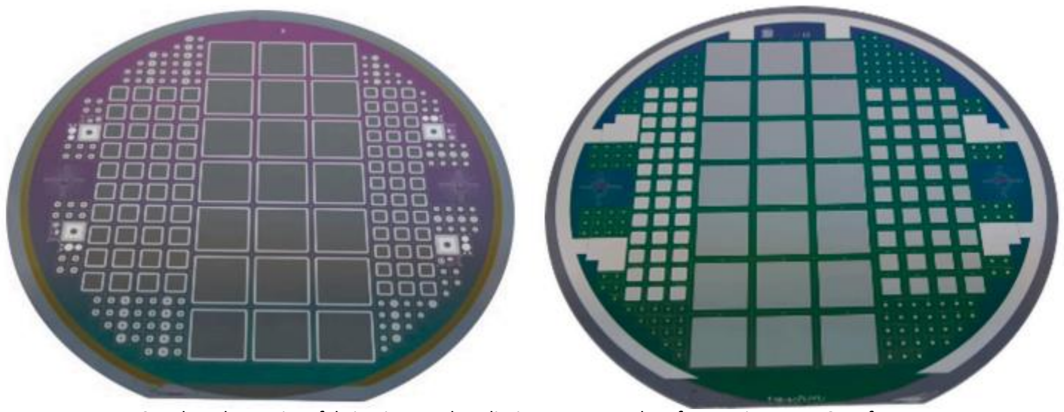
First fabrication run

- 300 µm high-resistivity n-type wafers
- 11 mask layers
  - 7 on the window side
  - 4 on the readout side
- Layout includes multiple test structures and pixelated devices.
  - With and without gain layer
- Process splits in deep boron and phosphorus profiles.



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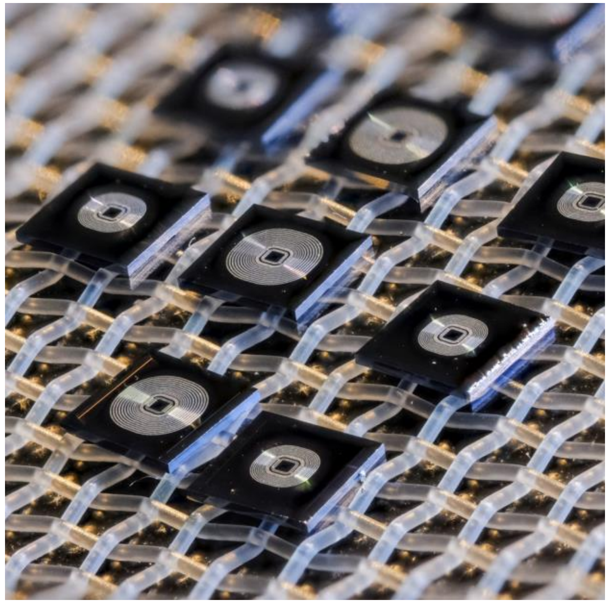

Photo: Paul Thrane

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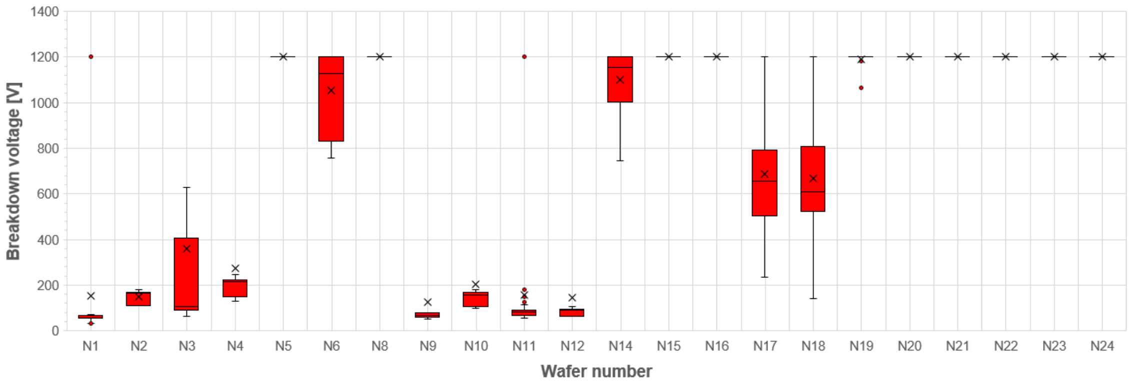
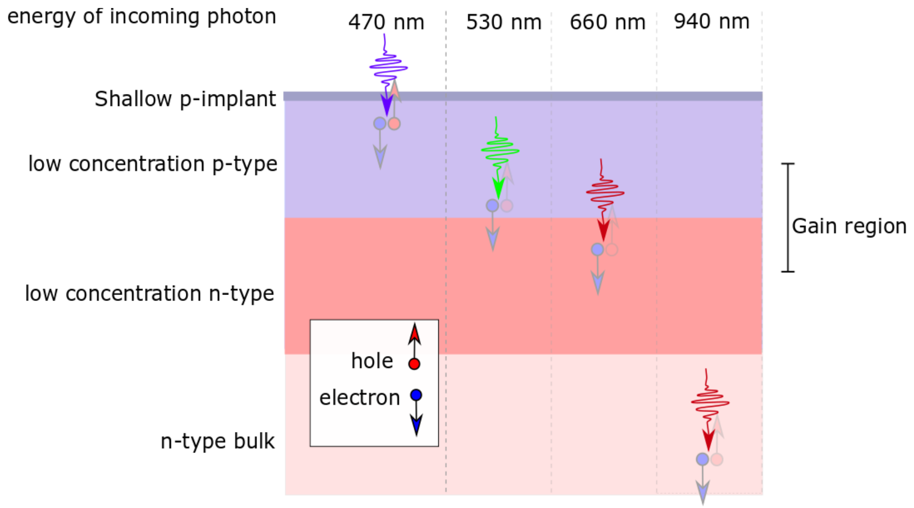
Electrical testing

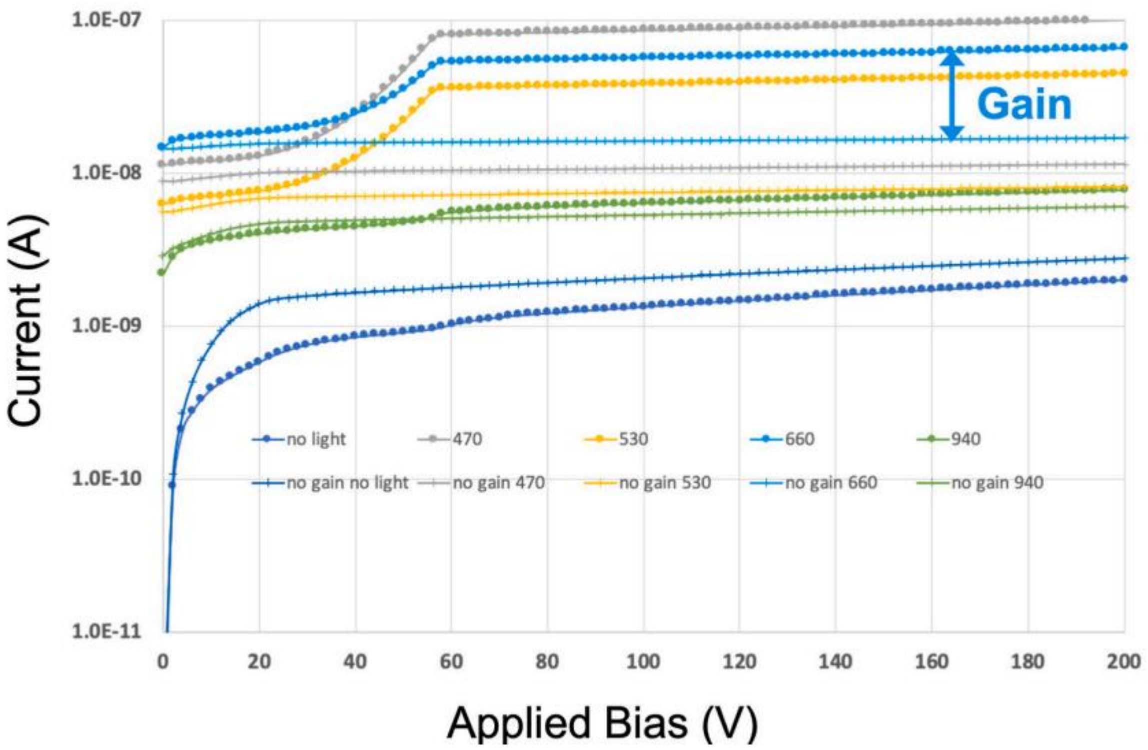
- Breakdown analysis:
  - Process splits covered the range from premature breakdown to no gain.
- Gain measurements on good wafer
  - LED exposure during IV measurements used to estimate gain factor.
  - Different wavelengths generate charges at different depths in the sensor
    - Study impact of holes vs electrons crossing high field region





Gain measurements at SLAC

- 470 nm
  - Shallow interactions → Electrons traverse the gain region
  - Highest gain of 7
- 530 nm
  - Somewhat deeper interactions → Mostly electrons traverse the gain region
    - Gain of 4.8
- 660 nm
  - Deeper interactions → Mostly holes traverse the gain region
    - Gain of 3.3
- 940 nm
  - Much deeper interactions → Holes traverse the gain region
    - Gain of 1.4
- No light
  - Bulk generation→ Holes traverse the gain region
    - Gain of 1.4



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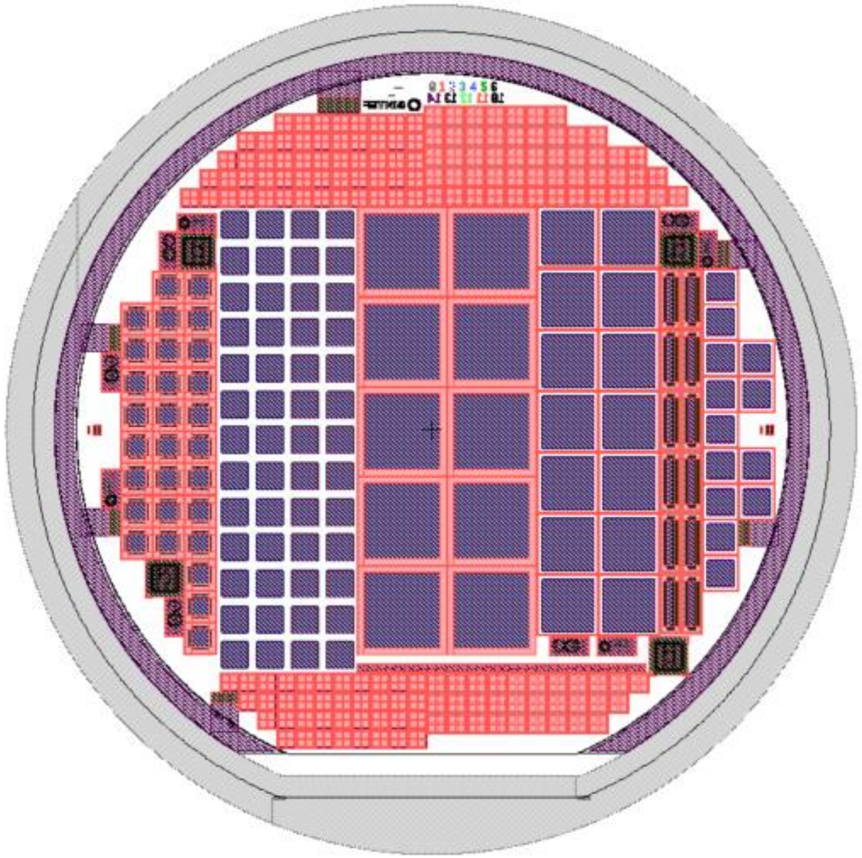
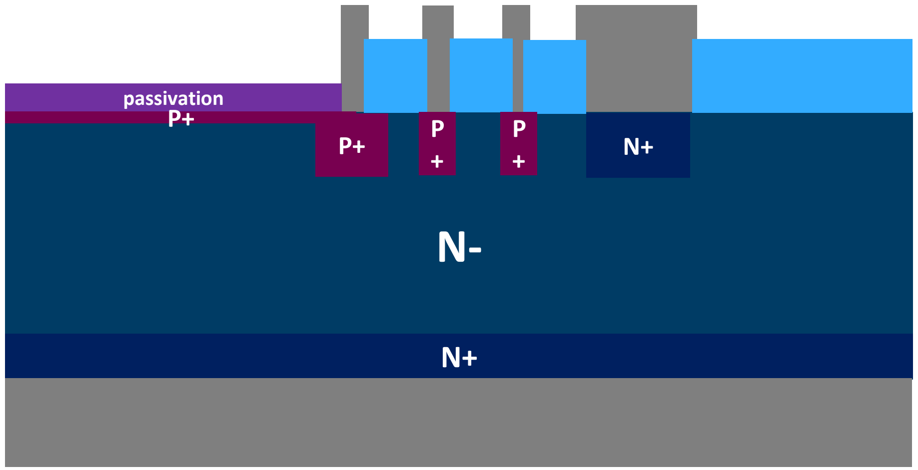
A second batch is soon to be finished

- Structures
  - LGAD diodes and diode arrays
  - Strip sensors
  - Medipix sensors and other pixel sensor geometries
- Finer splits in gain-layer process parameters
- New approaches for shallow p++ doping
  - Longer gain region and thinner entrance window
  - Approaches:
    - BF_2 implantation with microwave annealing
    - Low energy B implant with furnace annealing
    - Plasma-immersion ion implantation with laser annealing



Ongoing developments: Shallow p++ implant technologies

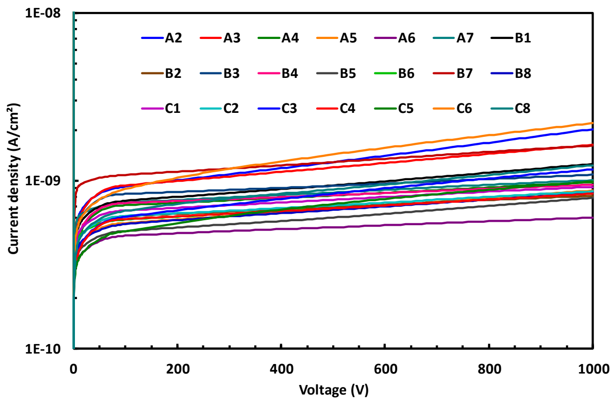
- Goal: Make implants as shallow as possible
  - Target depth: ~20 nm
  - Peak concentration >1e19 at./cc
- Methods of doping
  - Plasma-immersion Ion Implantation (BF_3)
  - Beamline Ion implantation (BF_2 and B)
- Methods of activation
  - Furnace annealing
  - Microwave annealing
  - Rapid thermal annealing
  - Laser annealing
- Passivation important for quantum efficiency
  - Aluminium oxide can suppress recombination at interface
    - «Dead area» can become more sensitive



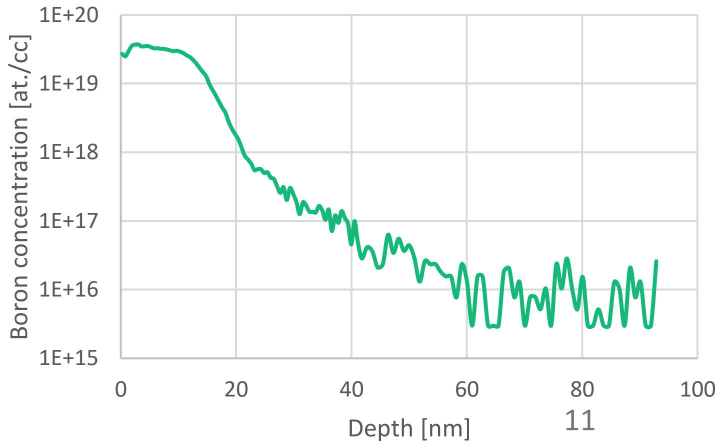
Boron beamline and plasma-immersion ion implantation

Implant Process	Annealing process	Passivation	Effective Carrier Lifetime [ms]	Med. Leakage current @ 200V [nA/cm²]
Low energy Boron implant	Medium temp. furnace	Imp. ox.	2.2	0.3
Low energy Boron implant	High and low temp. furnace	Imp ox.	2.2	4.4
Low energy Boron implant	High and low temp. furnace	ALD Al_2O_3	2.8	1.6
PIII	Laser anneal	PECVD SiO_2	0.3	0.5
PIII	Laser anneal + low temp. furnace	PECVD SiO_2	0.7	0.6
PIII	Laser anneal	ALD Al_2O_3	1.4	0.4
PIII	**Laser anneal + Low temp. furnace**	**ALD Al_2O_3**	**2.3**	**0.7**

- SINTEF has produced wafers with shallow-junction diodes
  - Process splits
    - Implantation technique
    - Annealing processes
    - Passivation
  - Ongoing measurements, analysis and interpretation of results.
    - Effective carrier lifetime (PCD)
    - Leakage current
    - Quantum efficiency
- Promising candidate:
  - PIII combined with laser annealing
    - Diodes display low leakage current
    - High lifetime for sample with Al_2O_3 passivation
- Next steps
  - Quantum efficiency measurements planned soon.

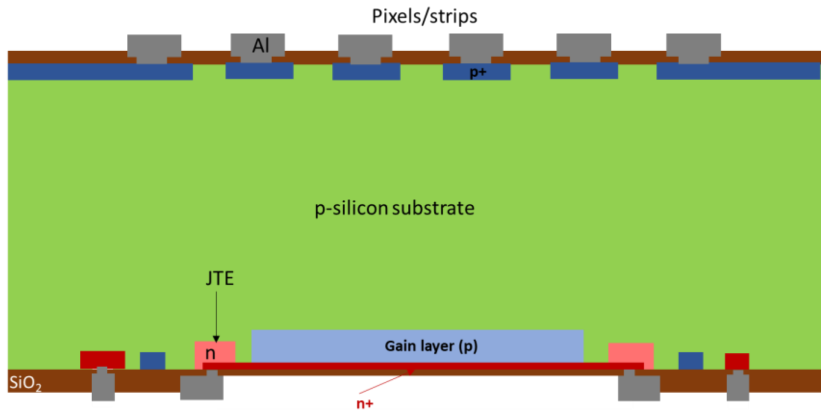


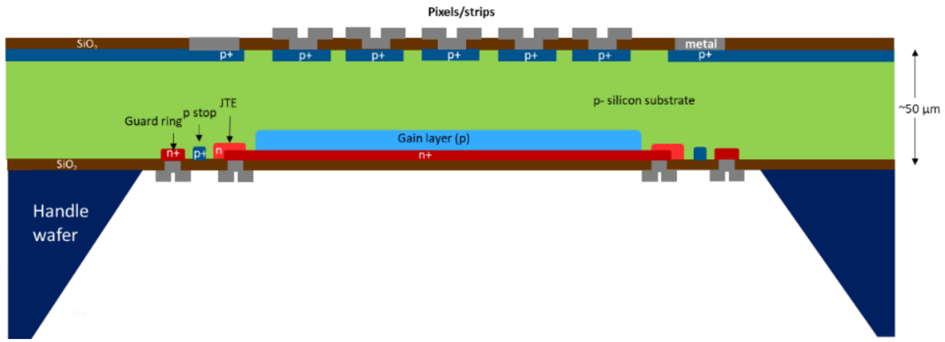
SIMS, BF3 PIII and LA



Ongoing developments: P-type iLGADs

- Design
  - Deeply implanted p+ gain layer
  - Shallow n++ region
- Two versions under development
  - Thick iLGAD for x-ray detection
  - Thin iLGAD for particle physics applications





Summary and acknowledgements

- SINTEF has in collaboration with SLAC developed and produced an **N-on-N iLGAD tailored for soft X-ray detection**
- LED based measurements estimate a **gain of 7**
- A **second batch** of N-on-N type LGADs is **soon to be completed**
- SINTEF is developing methods for **ultrashallow p++ doping profiles**
- P-type LGAD development is ongoing

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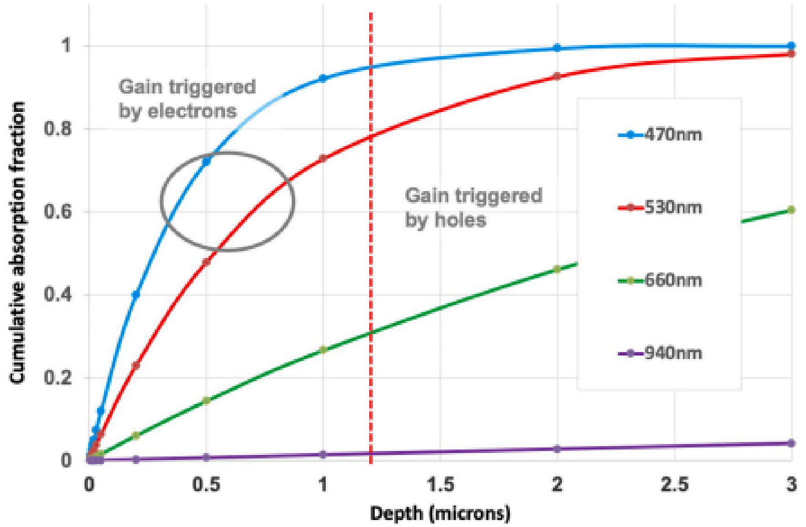
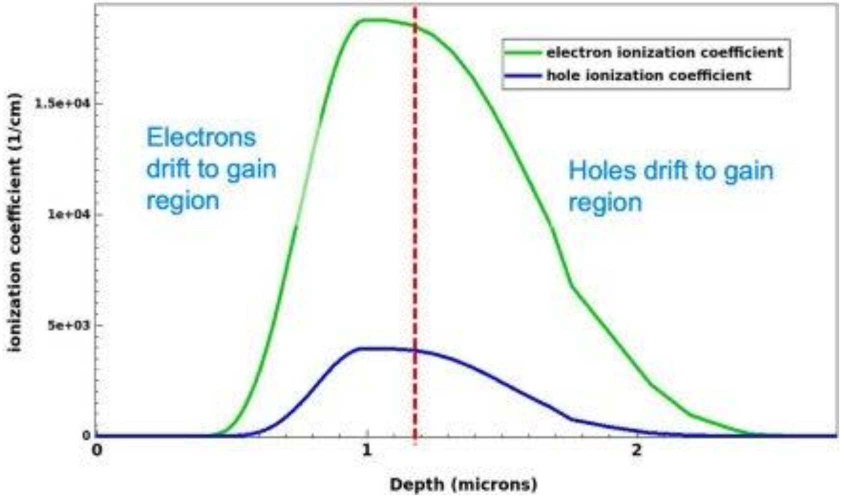
Backup





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