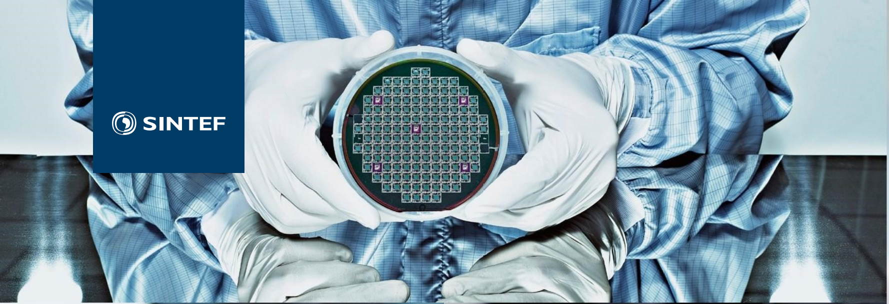

SINTEF

3D Silicon Sensors for radiation monitoring in space

Marco Povoli [1] A. Kok [1] O. Koybasi [1] A. Summanwar [1]
L. Tran [2] A. Rosenfeld [2]

[1] SINTEF MiNaLab,Gaustadalleen 23 C, 0314, Oslo, Norway
[2] Centre for Medical Radiation Physics, University of Wollongong, Wollongong, Australia

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Outline

- Introduction
- Silicon sensors for radiation monitoring in space
- 3D sensor technology
- Optimisation of sensor design
- Final wafer layout and sensor geometries
- Preliminary testing results
  - Electrical characterisation
  - Functional characterisation
- Outlook and future activities
- Conclusions

SINTEF MiNaLab

(Micro- and Nanotechnology Laboratory, Oslo)

- The new laboratory opened in 2005
- Shared facility with the University of Oslo
- Two separate cleanroom floors:
  - SINTEF: 800 m^2
  - University of Oslo: 600 m^2

- SINTEF:
  - Silicon production line with annual capacity of 10.000 wafers
  - 150mm wafers

- Situated on the University of Oslo campus

- QA System apprved ISO 9001:2008

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SINTEF MiNaLab Space Heritage

- Gas monitor development for future manned space flight based on diffraction micro optics (ESA - CDOE project)

- Photodiode chips for AME/OSIO space detectors 1988 - 2010:
  - Star sensor for ISO mission (operating at 2 °K)
  - Virgo LOI detector for SOHO mission
  - Sun sensors for European and Indian communication satellites (several deliveries 1991 – 2009, new delivery expected 2011/12)
  - Detectors for European and Indian Metrological satellites
  - VIS and NIR detectors for NPOES (US) and GalileoSat missions
  - VIS SLSTR detector units for Sentinel-3 mission (launch 2012)
  - VIS and NIR detectors for Aeolus mission (expected launch 2013)
- Strip detectors for INFN Trieste for Pamela mission

- MEMS sensor chips for PRESENS space qualified pressure transducers:
  - Low pressure transducer for Aeolus mission
  - High pressure transducer for Prisma (S) and Aeolus Mission

ESA SINTRA project

Three Dimensional Low-Voltage Silicon Detectors

- Project funded by ESA within the Technology Research Program (TRP)
- The work is carried out at SINTEF MiNaLab in Oslo
- Consulting offered by ESA and by some of our other partners
- **Objectives:**
  - To develop a sensor prototype that is:
    - Based on 3D technology
    - Low mass, low cost and low power
    - Intended for use in radiation monitoring for space applications
  - To verify the performances of the developed prototype using radiation sources

SINTEF CENTRE FOR MEDICAL RADIATION PHYSICS UNIVERSITY OF WOLLONGONG AUSTRALIA

Sensor requirements and possible improvements

Radiation in space

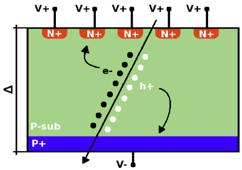
- The sensor must be able to work in a mixed radiation environment
- Charged particles (e.g. electrons and protons)
- X-rays and γ-rays
- Neutrons

Additional requirements

- Compact and low weight
- Low power consumption
- Radiation hardness (e.g. long lifetime)

3D sensor technology can overcome some of these shortcomings

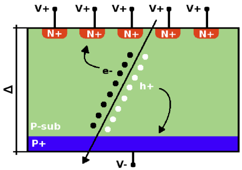
3D sensor technology

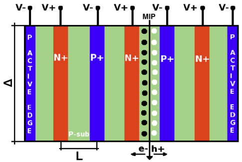


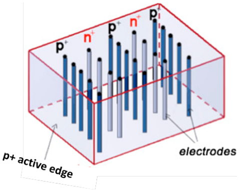
Planar (standard)

- Well know fabrication process
- Excellent detectors with high yield
- Thicknesses in the range 300μm - 1mm (2mm possible but not standard)
- Inter-electrode distance limited by the wafer thickness
- Large operating voltages
- Sensitive to radiation damage
- Relatively inexpensive

3D sensor technology







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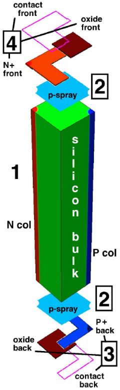
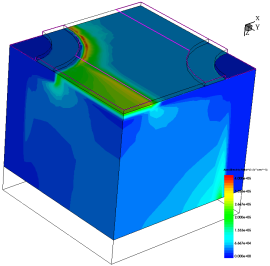
3D

- First proposed by S. Parker and collaborators in the mid ’90s [NIMA 395 (1997), 328]
- Decouple the inter-electrode distance from the wafer thickness
- Low full depletion voltage (<10V)
- Short charge collection distance (<50μm)
- Increased radiation hardness
- Expensive and complicated fabrication

Optimisation of sensor design

Numerical simulations

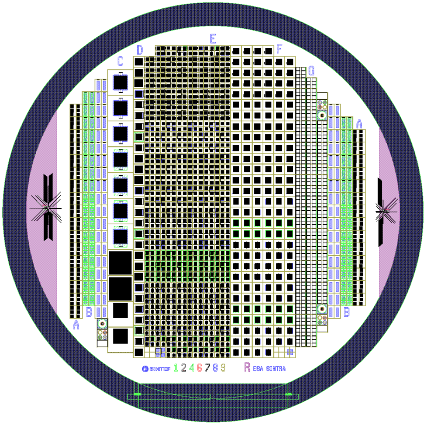


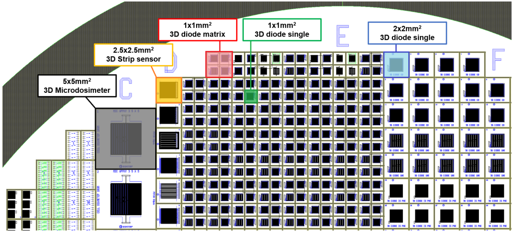


Numerical simulations

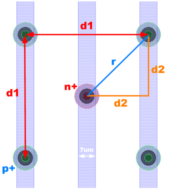
- Modern simulation tool allow for a great level of detail
- Both process and device simulation
- Include all the structures part of the device
- Electrical properties (currents, capacitance, electric field distribution etc...)
- Sensor response to impinging radiation (alpha particles, heavy ions, lasers etc...)

Final wafer layout and sensor geometries



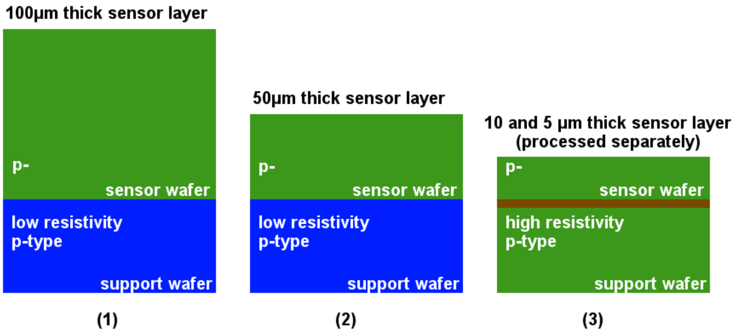


- Square basic cell (1 n^+ and 4 p^+ electrodes)
- Variable inter-electrode distance (d1 = [25, 50, 100] μm)
- Multiple sensor sizes to account for different radiation fluxes
- PAD diodes and strip detectors
- Additional test diodes with non-standard structures (cylindrical cells, slim-edges etc...)
- > 1500 device per wafer



Fabrication

Starting wafer material

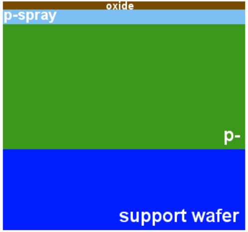


- 3D detector fabrication requires a support wafer
- Main choice: Si-Si wafers from ICEMOS, 50 and 100 μm active layers
- Additional option: SOI wafers from ICEMOS, 5 and 10 μm active layers (to test innovative structures)
- Support wafer thicknesses of 300 and 500 μm

Fabrication (1)

Isolation layer

- First oxidation
- Uniform Boron implantation
- Necessary to ensure electrode isolation



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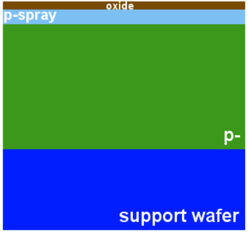
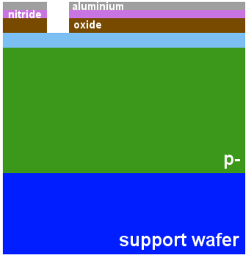


First Photolithography (n^+ electrodes)

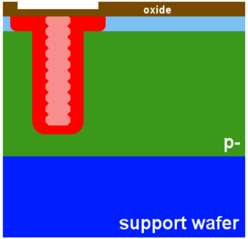
- Deposit nitride and aluminium layer to protect the wafer surface during etching
- Creation of opening corresponding to the desired electrode position and diameter

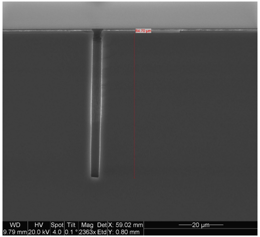


Fabrication (2)

Creation of n-type electrodes

- Deep Reactive Ion Etching (DRIE)
- Doping using Phosphorus gas diffusion
- Polysilicon filling and etching
- Final oxidation
- NOTE: n-type electrodes are not etched all the way through!

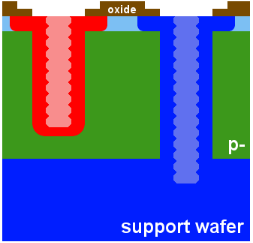




Fabrication (3)

Creation of P-type electrodes

- Same as for the N-type electrodes
- Doping using Boron gas diffusion
- Etched all the way through



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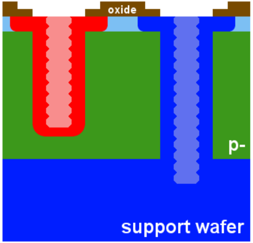
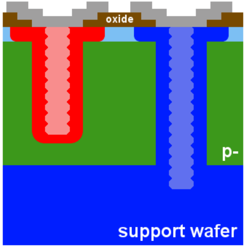
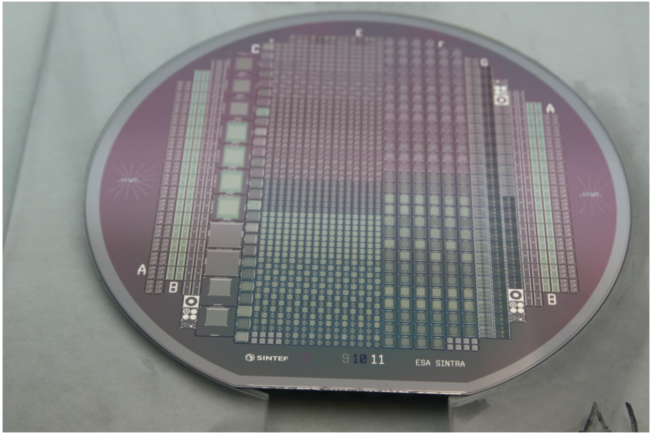


Contact opening, metal deposition and etching

- The contacts are opened over the electrodes with a standard photolithography
- Aluminium sputtering performed uniformly on all wafers
- Metal lithography and etching
- The final passivation layer is deposited after preliminary electrical verification

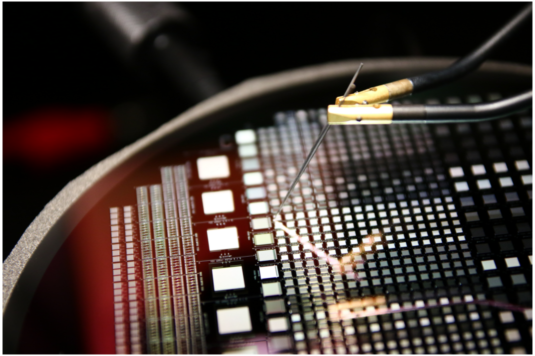


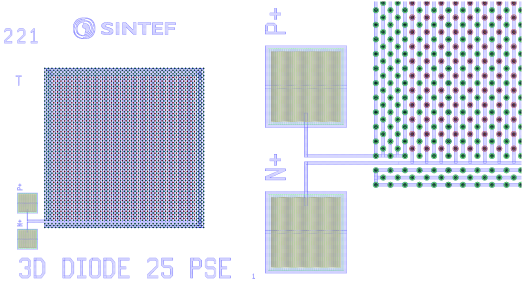
Completed wafer



Electrical characterisation

Testing configuration

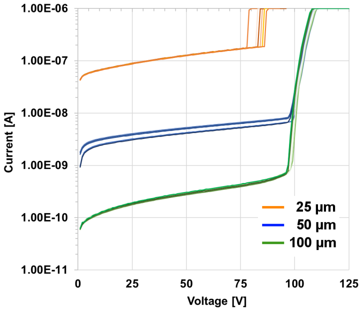




- Electrical characterisation performed at wafer level using a manual probe station
- Needles are positioned using micro-manipulators to contact the sensor pads (140x140 μm^2)
- The probes are connected to a semiconductor parameter analyser

Electrical characterisation

Preliminary results

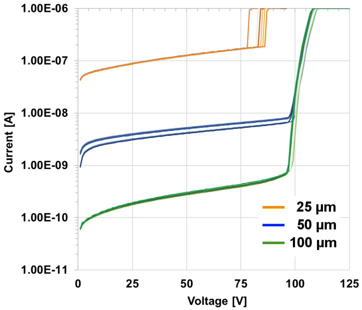


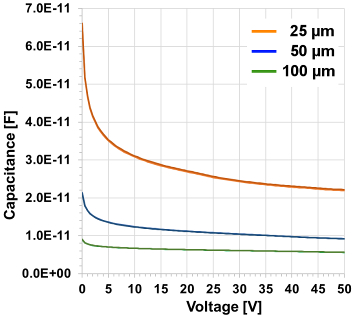
Current-Voltage (I-V)

- Scaling correctly with electrode pitch
- 25μm pitch exhibits some criticality
- Breakdown voltage >85 V

Electrical characterisation

Preliminary results





Current-Voltage (I-V)

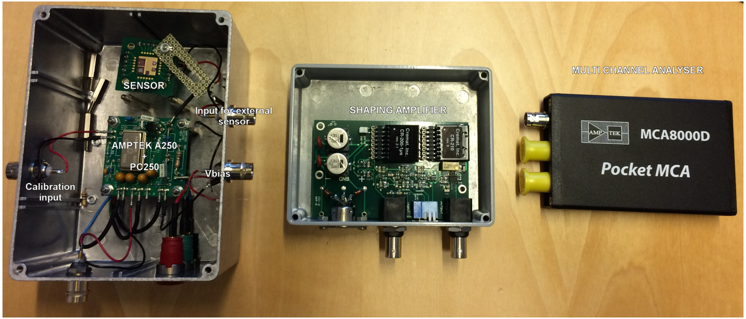
- Scaling correctly with electrode pitch
- 25μm pitch exhibits some criticality
- Breakdown voltage >85 V

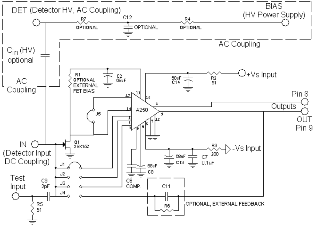
Capacitance-Voltage (C-V)

- Capacitance values scale correctly with electrode pitch
- P-spray makes it difficult to extract full depletion voltage
- Clear change in curve trend before 5-10 V

Functional characterisation

Testing setup





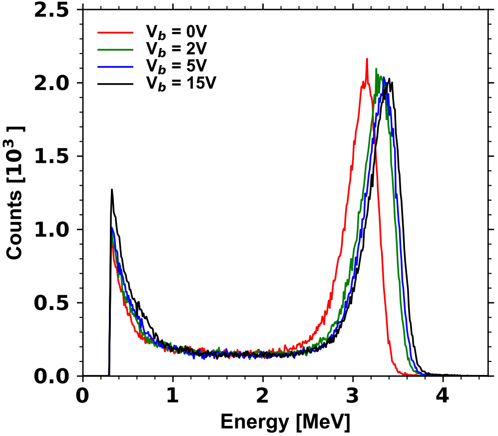
- Sensor is AC coupled to the AMPTEK A250 charge sensitive amplifier
- Semi-gaussian shaping amplifier from Cremat (shaping time 25ns to 1μs) with baseline restorer
- Multi Channel Analyser ”Pocket MCA” from AMPTEK
- Relatively inexpensive setup / easily accessible / good noise characteristics can be achieved

Functional characterisation

Preliminary results - ^{241}Am alpha particle source (5.5 MeV)

Results

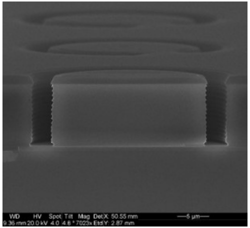
- Experiment carried out in air (some energy loss in air)
- Source to sensor distance about 0.5 cm
- Calibration performed with a pulse generator (A250 test input, 2pC capacitor)
- Spectrum acquired at different operating voltages to confirm low voltage operation
- Easy to distinguish the primary peak of the spectrum
- Very little influence of the bias voltage
- Non-negligible amount of low energy events
  $\Rightarrow$ hits in the edge region (? under investigation)
- Further test will be carried out with X-ray and a Proton beam at TIFPA (Trento, Italy)

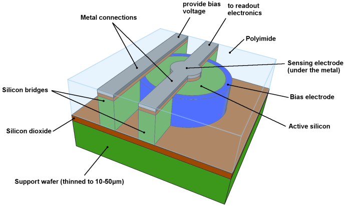


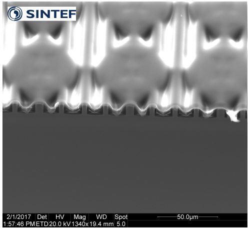
Outlook and future activities...

Outlook and future activities (1)

Tissue Equivalent 3D Micro-dosimeters



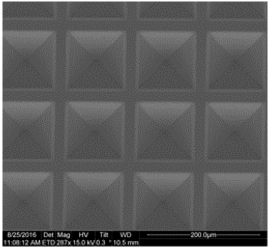


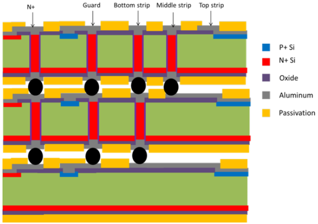


- Developed in collaboration with CMRP (Wollongon, Australia)
- Create isolated structures comparable in size to human cell
- Remove the excess silicon by plasma etching
- Replace silicon with a tissue-equivalent material (PMMA, polyimide...)
- Allows operation in mixed radiation field
- Allows to calculate all microdosimetry quantities and extract the Radio Biological Effectiveness of the radiation field
- Based on a patent from CMRP (US patent No. 8421022 B2)
- This technology is in its early stages and requires additional development

Outlook and future activities (2)

Neutron detectors and multiple chip stacking





Neutron detectors

- Create microstructures on the back of the sensor
- Fill them with neutron converting materials (e.g. LiF, ^{10}B, B_4C)
- Increase the detection efficiency of the neutron conversion by-products

Through Silicon Vias (TSV)

- Developed from 3D sensor technology
- Allows to stack multiple sensor layers
- Each layer can be dedicated to a specific type of radiation

Conclusions

- We have produced a new batch of 3D silicon radiation detectors
- The devices exhibit very good electrical characteristics and the yield is high
- Preliminary radiation source test confirmed that the sensors are operational
- Additional test will follow in the new year to complete the sensor characterisation
- New sensor geometries and technologies are being developed that should result in additional improvements to 3D sensors for space applications

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