UiO University of Oslo

# Simulation and testing of thin silicon micro dosimeters realised with planar technology


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**10$^{th}$ "Trento" Workshop on Advanced Silicon Radiation Detectors (3D and p-type)**
**19/02/15**


UNIVERSITAS OSLOENSIS MDCCCXI SINTEF ESRF The European Synchrotron Centre for Medical Radiation Physics MANCHESTER 1824 The University of Manchester UNIVERSITAS BERGENSIS

# Outline

## Si-3D-MiMic Collaboration

## Background

- Silicon micro dosimeters designed at CMRP

## Thin silicon micro dosimeters produced at SINTEF

## Testing

- Electrical measurements
- Functional measurements

## Next step: 3D micro-dosimeters

## Conclusions

# Si-3D-MiMic Collaboration

- **Si**licon-based **3D Mi**ni and **Mic**rodosimetry
- 6 project partners (R&D) + users
- Objectives:
  - Development of improved mini- and micro-dosimeters using 3D and micro-machining technologies through prototyping
- Project founded by the Research Council of Norway within the NANO2021 program

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**1. MINI dosimetry**

Beam monitoring for the MRT using micromachinig

(*not discussed here)

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**1. MINI dosimetry**

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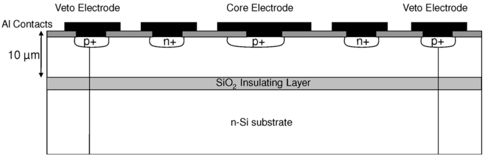
**2. 3D Micro dosimetry**

**Improve current status of silicon based microdosimetry using micromachining**

# Silicon micro dosimeters designed at CMRP

## SOI planar technology




**[J. Livingstone et. al, IEEE TNS, VOL.60, N.6, 2013]**

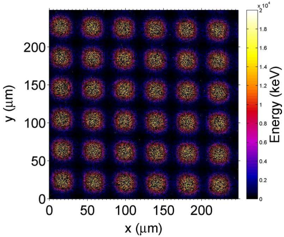
**Previous technology (CMRP)**

- n-type SOI, high resistivity, 10 $\mu$m thickness
- Single sided, bulk contact (n+) on the front side
- Inner core (p+)
- Outer guard (p+) to shield the active volume from charge generated outside

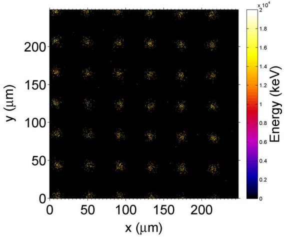
**Results**

- Measurements $\Rightarrow$ ANSTO (AUS) with 20 MeV $^{12}$C Ions
- Integrator + shaping at 1 $\mu$s + ADC $\Rightarrow$ MCA spectra
- Core and Ring biased at -6V
- Standard IBIC $\Rightarrow$ rather large active area
- Anti-coincidence $\Rightarrow$ active area better defined

Standard IBIC

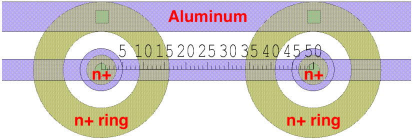


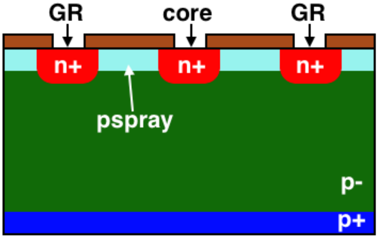

Anticoincidence IBIC



# Silicon micro-dosimeters produced at SINTEF

## Layout1




### New generation of devices

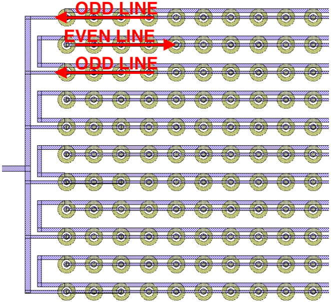
- Double sided n-on-p
- Different resistivities available (5, 100, $10^4$ $\Omega \cdot cm$ )
- Active area thinned down to $\sim$10-20 $\mu$m

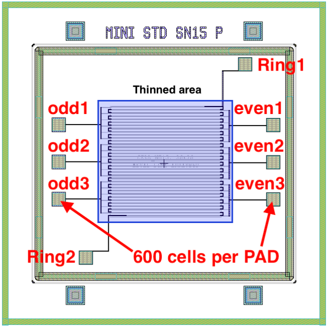
### Layout

- Device composed by several circular planar cells
- Central n+ core
- Precise definition of the active volume using an n+ ring
- Need for p-spray isolation on the front side

# Silicon micro-dosimeters produced at SINTEF

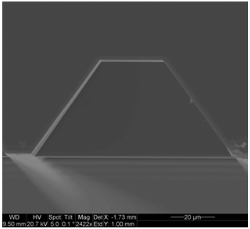
## Layout2



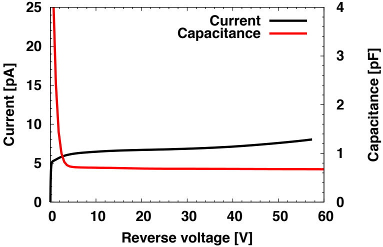

### Connection and geometry

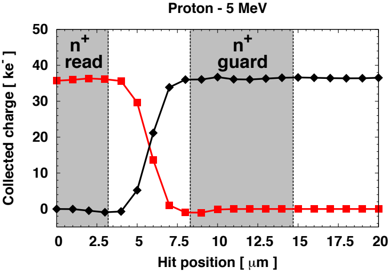
- Cells arranged in strips (100 cells per strip)
- Odd/Even strips readout separately
- All GUARDS connected together
- Bulk contact on the backside (p+)
- Active area thinned to 10 $\mu$m using TMAH



# Silicon micro-dosimeters produced at SINTEF

## Numerical simulations



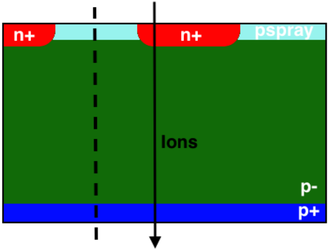




**Electrical simulations**

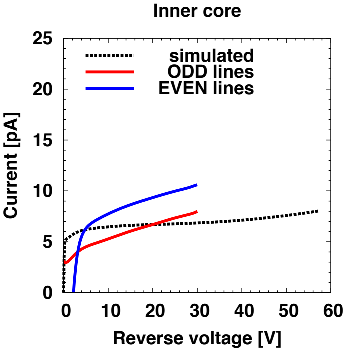
- Low current and capacitance
- Full depletion is almost immediate
- Breakdown around 50V on guard

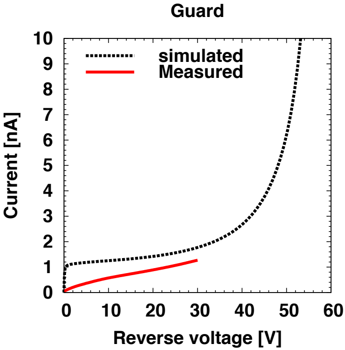
**Functional simulations**

- 5 MeV protons (charge vs. hit position)
- The ring limits the active volume of the cell
- Expected radius of the active volume ~6 μm (diameter=12 μm FWHM)



# Electrical measurements

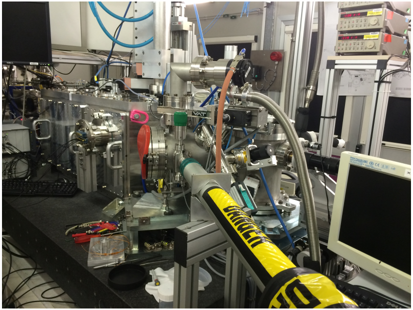


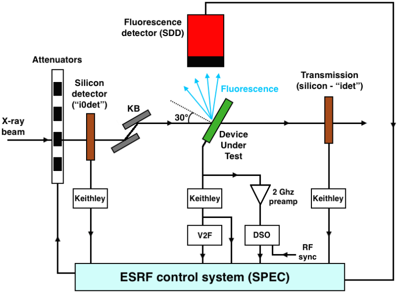



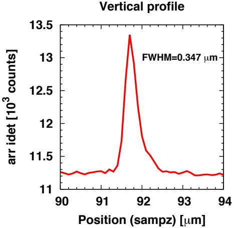

- Devices fabricated at SINTEF MiNaLab and completed in May 2014
- Measurements performed at the probe station for sensor selection and repeated after assembly with Keithley electrometers
- Minimum compliance was still too large $\Rightarrow$ measurement stopped at 30 V
- Acceptable agreement with simulations
- The slope of the currents is probably due to the heavy p-spray dose

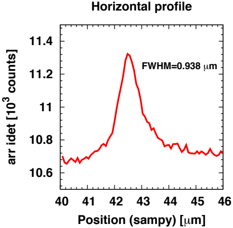
# Functional measurements

## Beam Line ID21 at ESRF - Scanning X-Ray Microscope (SXM)





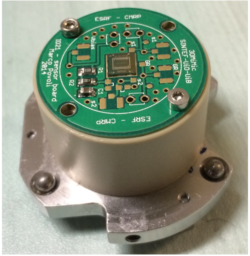



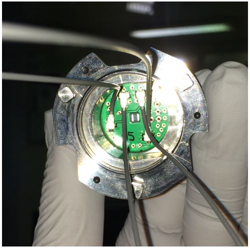




- Beam monitored with many detectors
- Fluorescence detector also available
- Hit angle 30°
- Energy range 2 - 9.2 keV
- Absorption length at used energies:
  - 2.7μm @2.5keV
  - 51.0μm @7.2keV
- Beam spot: $0.94 \times 0.35\ \mu m^2$ (@7.2 keV)
- 1D scans → readout Keithley
- 2D scans → readout V2F (speed)
- Data post-processing required (account for possible beam variations)

# Functional measurements

## Sensor assembly and mounting



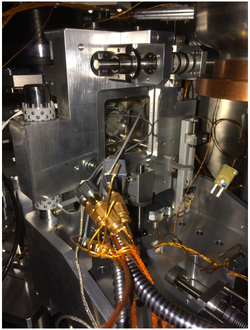


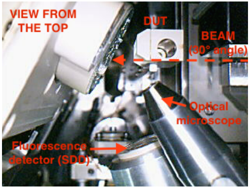
**⇐ Sensor assembly**

- PEEK support
- Magnetic metal holder
- PCB Diameter ∼ 31 mm
- Silver epoxy + wire bonding
- On-board bias filter
- Micro-coax cables exit from the backside

**Sensor mounted in the SXM ⇒**

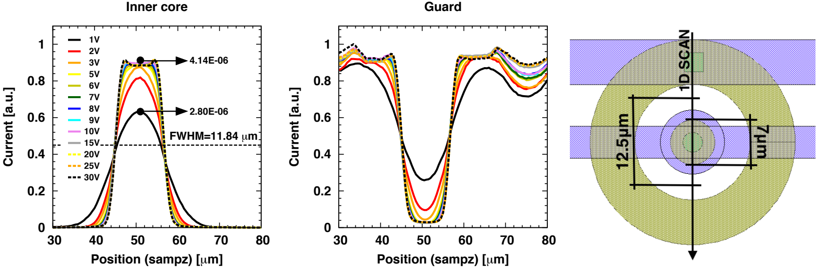
- Support inserted from the back of the piezo stage
- Kept in place by magnets
- Cables are brought out of the chamber through a flange
- **Measurements were mostly performed in vacuum**





# Functional measurements

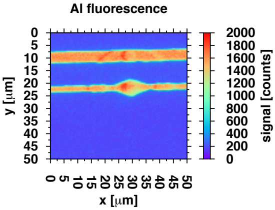
## 1D scan results - 7.2keV, $6.9\times10^{10}$ ph/s - step 0.5$\mu$m

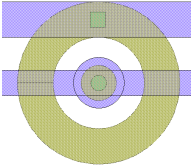


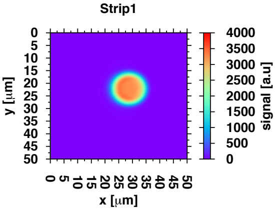

- Sensor ID: A9-27, 100 $\Omega cm$ resistivity (LOW)
- Very sharp sensor response
- Measured FWHM of the core signal is 11.84 $\mu$m at 30V (expected $\sim$12 $\mu$m)
- Signal lowering in the middle $\Rightarrow$ implantation depth not negligible
- Same lowering observed on the guard signal
- Full charge saturation at roughly 6V
- Thickness measured through X-ray transmission $\Rightarrow$ $\sim$14 $\mu$m

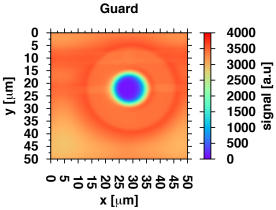
# Functional measurements

## 2D scan at 30V - 7.2keV, $6.9\times10^{10}$ ph/s - step 0.5$\mu$m



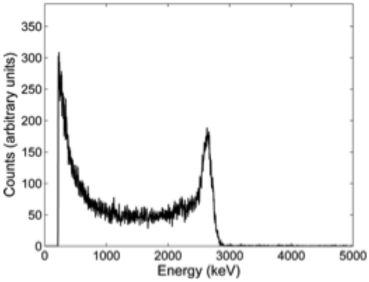


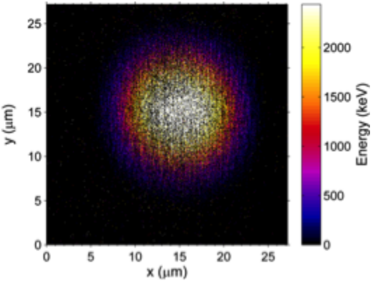




- Aluminum fluorescence
- Lithography not perfect (close to limit)
- Well defined signal from the inner core of the cell
- n+ implant visible in the GUARD signal)
- NOTE: slight blurring and misalignment due to the beam hit angle 30°(worse at low intensity)

# Functional measurements

## ANSTO (Australia) - IBIC - 5.5 MeV Alpha particle beam




[L. Chartier et al., sent for presentation at the NSREC2015 (July)]

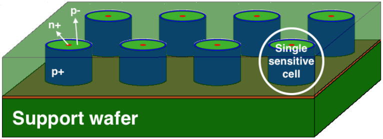
- Spectral peak at 2.8 MeV
- From SRIM simulations this translates into a thickness of ~17 µm
- FWHM of roughly 12 µm is confirmed also with this method
- The guard delimits the active volume well
- Charge sharing between core and ring causes the low energy tail (expected)
- Better definition of the sensitive volume is possible using 3D technology...

# Next step

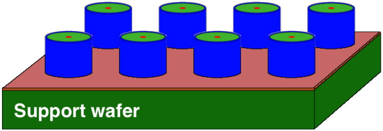
## SOI, 10$\mu$m thick, 3D micro-dosimeters (high resistivity)

1. Thin SOI as starting material (high resistivity)

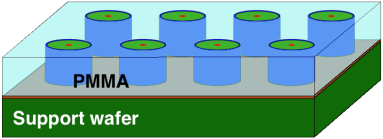

2. 3D or Planar Active Edge single cells (DRIE)




3. Removal of excess silicon (DRIE)




4. Deposition of tissue equivalent material




5. Final, localised TMAH etching of the support wafer

# Conclusions

- The experience from previous silicon micro-dosimeter technologies led to the fabrication of a new batch of devices
- The fabrication proved to be relatively easy with a good yield
- Electrical characteristics were found to be in agreement with the numerical simulations performed during the design phase
- Functional tests were performed at the ID21 beam line at the ESRF with a 7.2 keV X-ray micro beam
- The charge collection dynamics were thoroughly studied and were found to agree with numerical simulations
- The same behaviour was also observed with a 5.5 MeV Alpha particle micro beam at ANSTO (Australia)
- Better definition of the sensitive volume can be achieved using 3D technology
- The layout of the next batch is complete and fabrication is starting
- Devices should be available by early autumn 2015

# Thank you!

(questions..?)