Development of novel 3D silicon microdosimeters at IMB-CNM

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**Microdosimetry**

- Measure energy deposition in microscopic (cellular) volumes
- Applications:
  - treatment planning in hadrontherapy;
  - biological risk assessment for radiation-exposed people;
  - microelectronics (SEUs)

**Why silicon?**

- Ability to produce tailor-made micrometer-scale structures using micromachining techniques.
- Do not require a gas supply
- Light, shock-resistant and easily portable
- Low bias and power consumption
- Fast response and low dead times
- Well established technology – mass-production

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HeLa cell (700 μm³)

Unit cell (minimum sensitive volume) of sensor

\[ V_{\text{cell}} \approx V_{\text{microsensor}} \]
**Version 1: Ultra-thin 3D silicon detectors**

- **3D diode sensors based on SOI wafers**, with passing through columnar electrodes
- **Technology developed and patented by CNM in 2009**
- Originally developed for neutron detection\(^1\) and plasma diagnostics\(^2\)
- Advantages for microdosimetry:
  - \(\mu\)m-thin active volume, well defined
  - Reduced charge sharing due to the confinement of the electric field
  - Support wafer can be removed to avoid backscattered particles
  - Lateral depletion, few V operation
  - Easy pixellation for spatial resolution

2. F. Garcia et al., *IEEE NSS-MIC* (2011) 199
Design and fabrication

- Design and fabrication done in-house at IMB-CNM
- Columnar electrodes 5 µm diameter
- SOI wafer 10 µm active thickness

Fabrication sequence:

1. Electrode fabrication
   - ICP etching with ALCATEL 601-E
   - Filled with LPCVD polysilicon
   - Doped with P or B
   - Passivated with SiO₂
2. Same type electrodes connected by metal lines for electrical contact
3. Surface passivation with SiO₂/Si₃N₄
4. Support wafer etch (optional)
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Support wafer (frame)

10 μm ‘membrane’ (sensitive volume)

4” wafer

Symposium “Advanced Semiconductor Detectors for Medical Applications”, 13th February 2015
Validation with carbon beam

- $^{12}$C 95 MeV/A beam @ Ganil
- Measurement of the spectra and Bragg curve with depth of PMMA
Pulse height spectra in the PMMA along the Bragg curve

- 10 μm thick sensor, 1x1 mm² area, 0V bias
- $^{12}$C energy 95MeV/A, range 25mm in PMMA
Bragg curve: measured vs Geant4
New generation microdosimeters

- Use IMB-CNMs’s 3D-thin technology to create **micrometer-scale cylindrical structures** that completely confine the active volume – “cell-like”
- P+ implanted electrode surrounded by N+ cylindrical 3D electrode (trench)
- SOI wafer with backside removed
- Array of independent active volumes with individual (pixel) or serial (strip) readout – **spatial resolution**
Fabricated devices: 6, 10, 20 µm thick

P-contact

N-contact

Active diameter (10µm)
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**Electrical test**

- 6µm wafer
- Arrays of 100x100 pixels
- Good diode behaviour
- <pA/pixel currents
CCE characterization

CNA @ Seville, this week

IBIC map with 5MeV alphas

Counts in full E peak (100% CCE) vs position

100% yield in sensor
Summary

- IMB-CNM’s ultra-thin 3D technology is able to produce micrometer-scale radiation sensors on thin silicon substrates.
- A first generation of 10 µm thin, 3D silicon sensors with columnar electrodes has been validated in a microdosimetry experiment, measuring accurately the LET distribution of 12C ions in PMMA even at 0V bias.
- A new generation of cylindrical 3D silicon structures that confine completely the active volume have been successfully manufactured. First tests with alpha particles show 100% CCE in sensor area.