Development of novel 3D silicon microdosimeters at IMB-CNM

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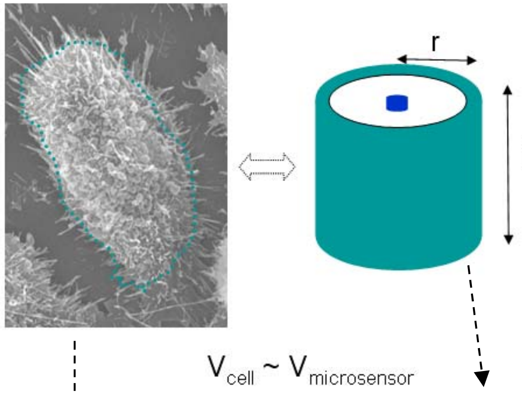
Microdosimetry



HeLa cell
(700 µm^3)

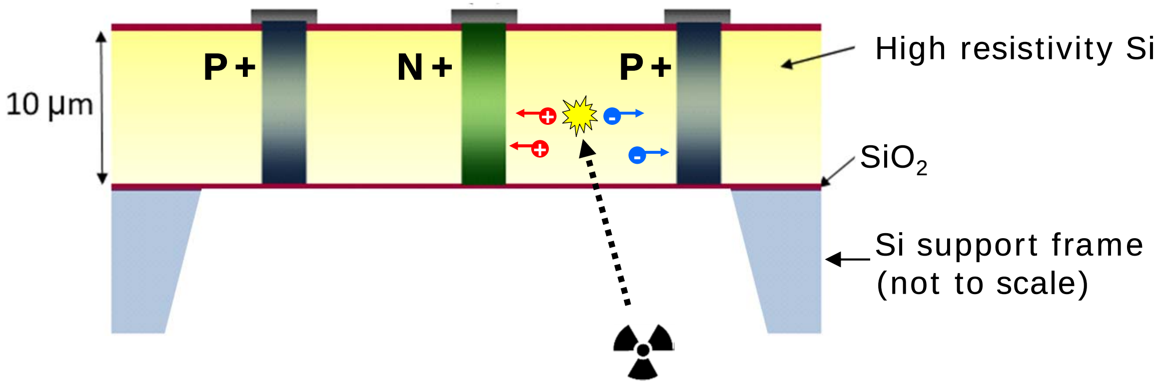
Unit cell (minimum sensitive volume) of sensor

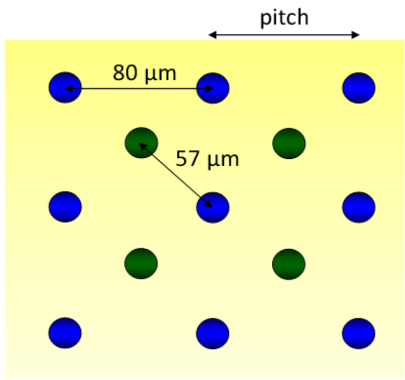
- Measure energy deposition in microscopic (*cellular*) volumes
- Applications:
  - treatment planning in hadrontherapy;
  - biological risk assessment for radiation-exposed people;
  - microelectronics (SEUs)

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

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:
  - ☺ µm-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

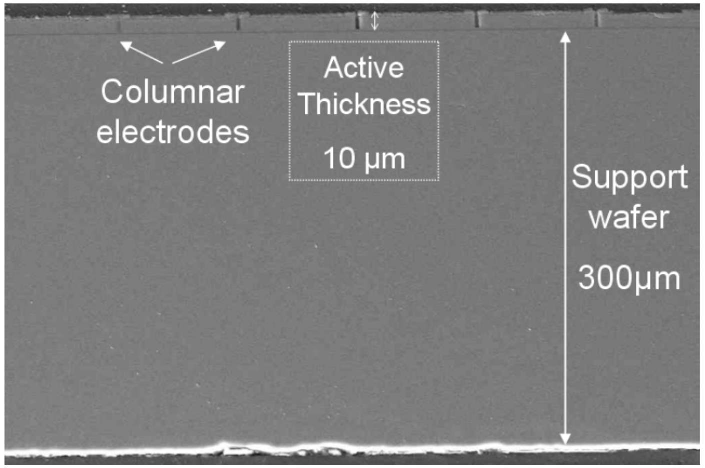
1- C. Guardiola et al., Phys. Med. Biol. 58 (2013) 3227
2- F. Garcia et al., IEEE NSS-MIC (2011) 199

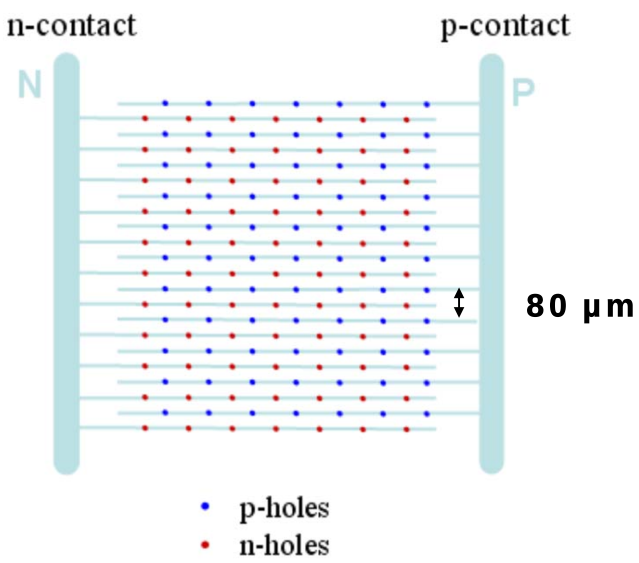
Design and fabrication

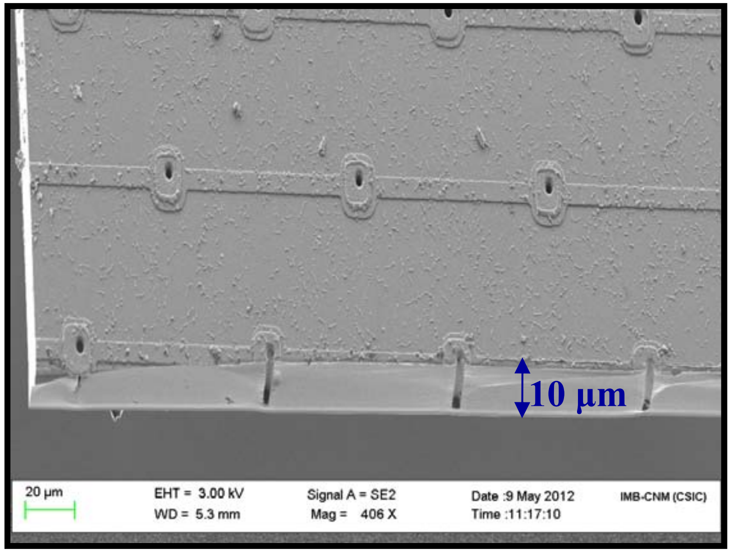
- Design and fabrication done in-house at IMB-CNM
- Columnar electrodes 5 µm diameter
- SOI wafer 10 µm active thickness

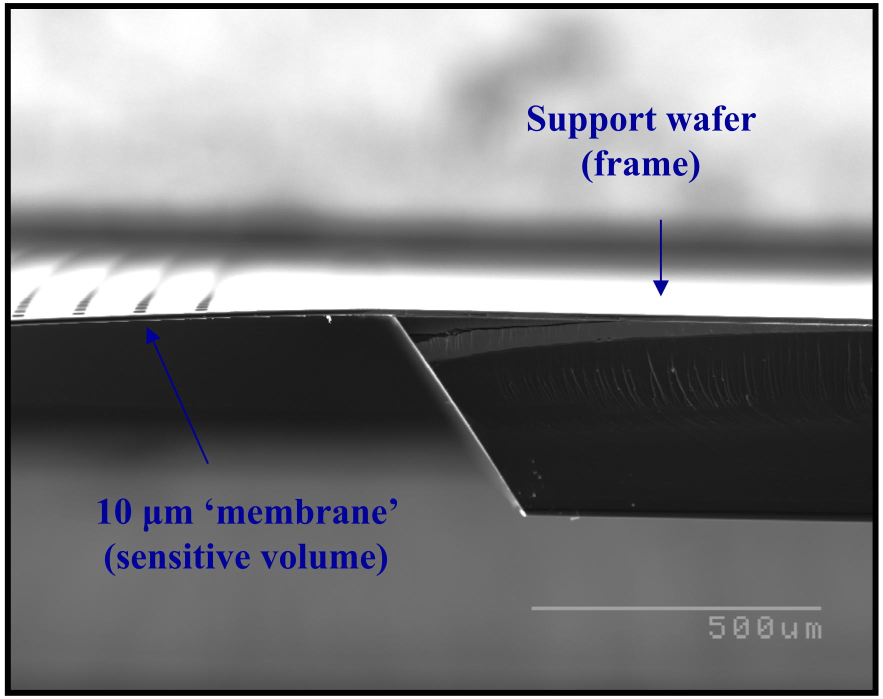
Fabrication sequence:

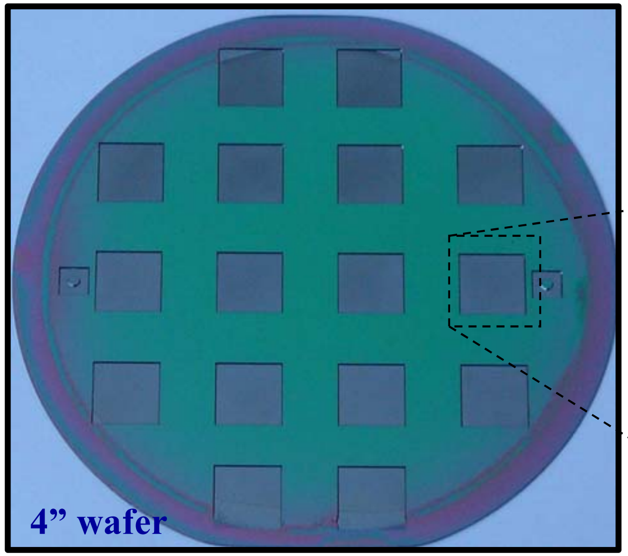
1. Electrode fabrication
   - ICP etching with ALCATEL 601-E
   - Filled with LPCVD polysilicon
   - Doped with P or B
   - Passivated with SiO_2
2. Same type electrodes connected by metal lines for electrical contact
3. Surface passivation with SIO_2/Si_3N_4
4. Support wafer etch (optional)

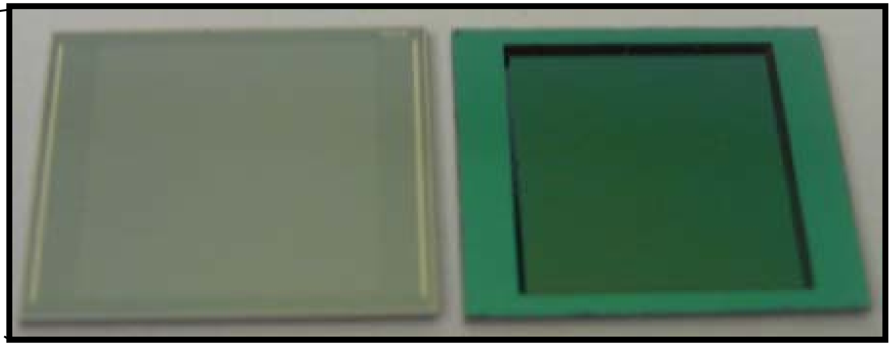




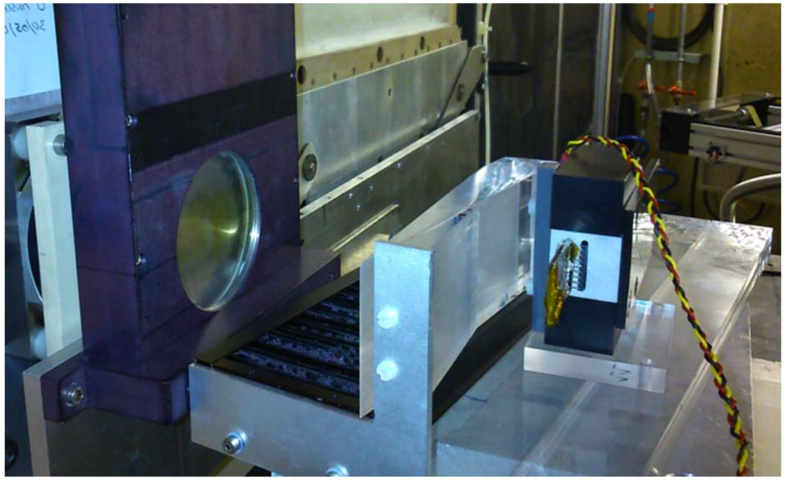

10 µm
20 µm
EHT = 3.00 kV
WD = 5.3 mm
Signal A = SE2
Mag = 406 X
Date :9 May 2012
Time :11:17:10
IMB-CNM (CSIC)


Support wafer
(frame)
10 µm 'membrane'
(sensitive volume)
500um

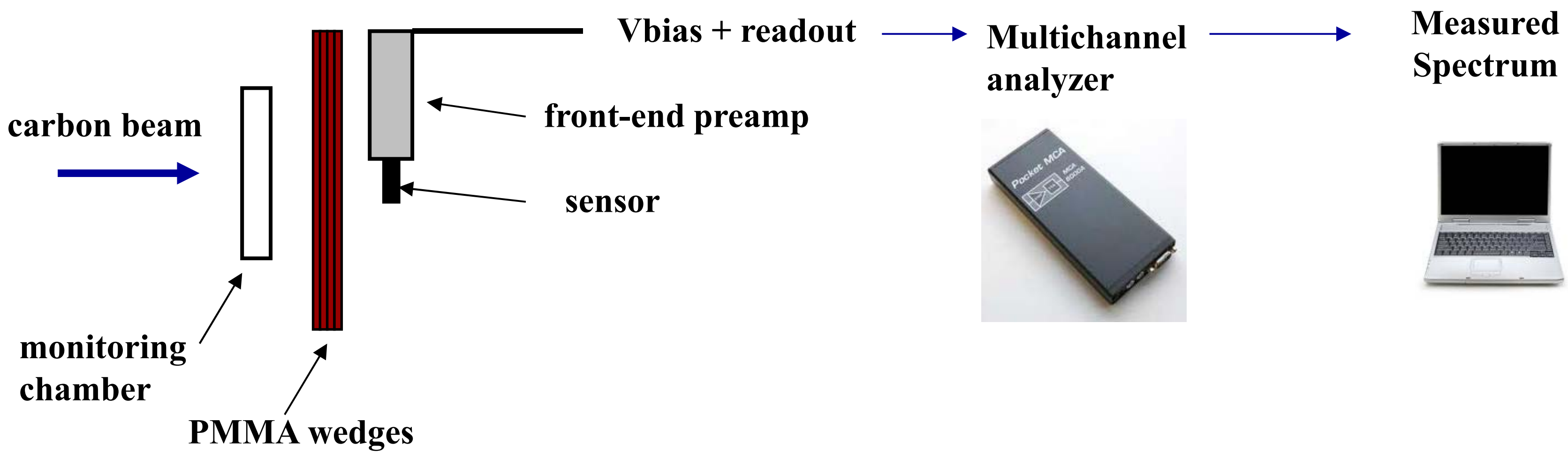

4" wafer



Validation with carbon beam

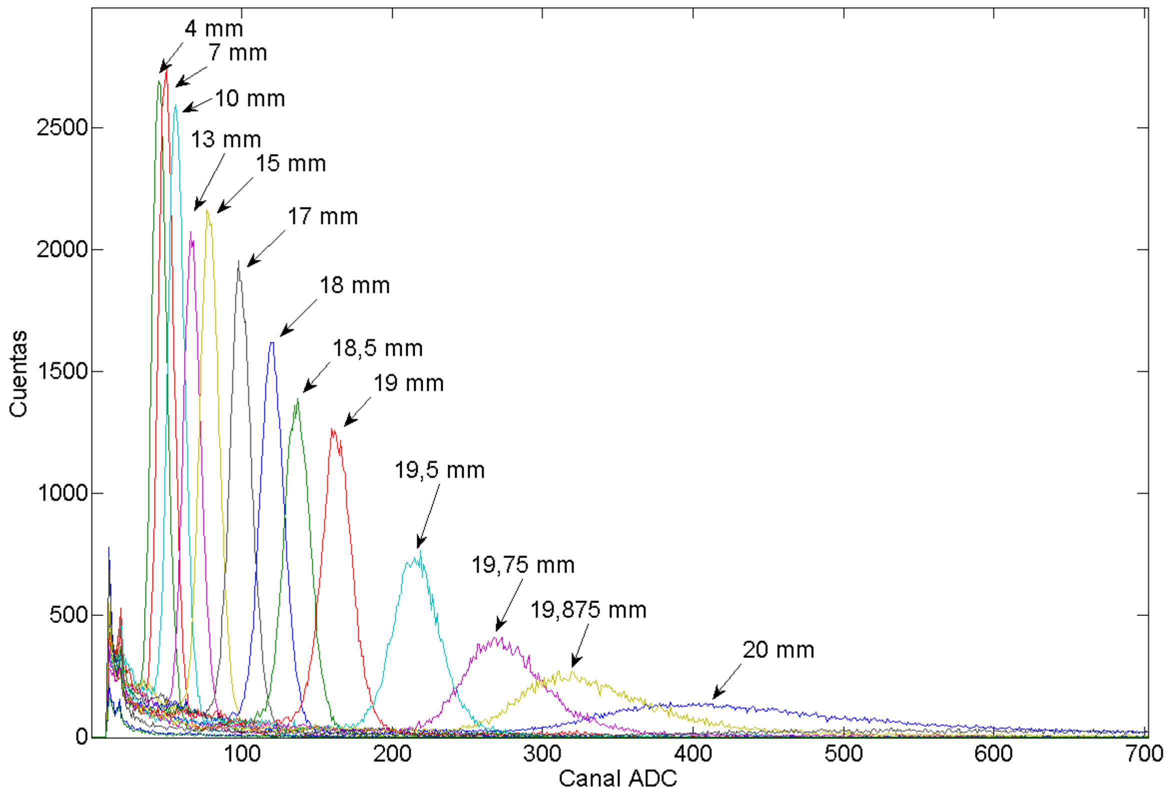


- ^{12}C 95 MeV/A beam @ Ganil
- Measurement of the spectra and Bragg curve with depth of PMMA

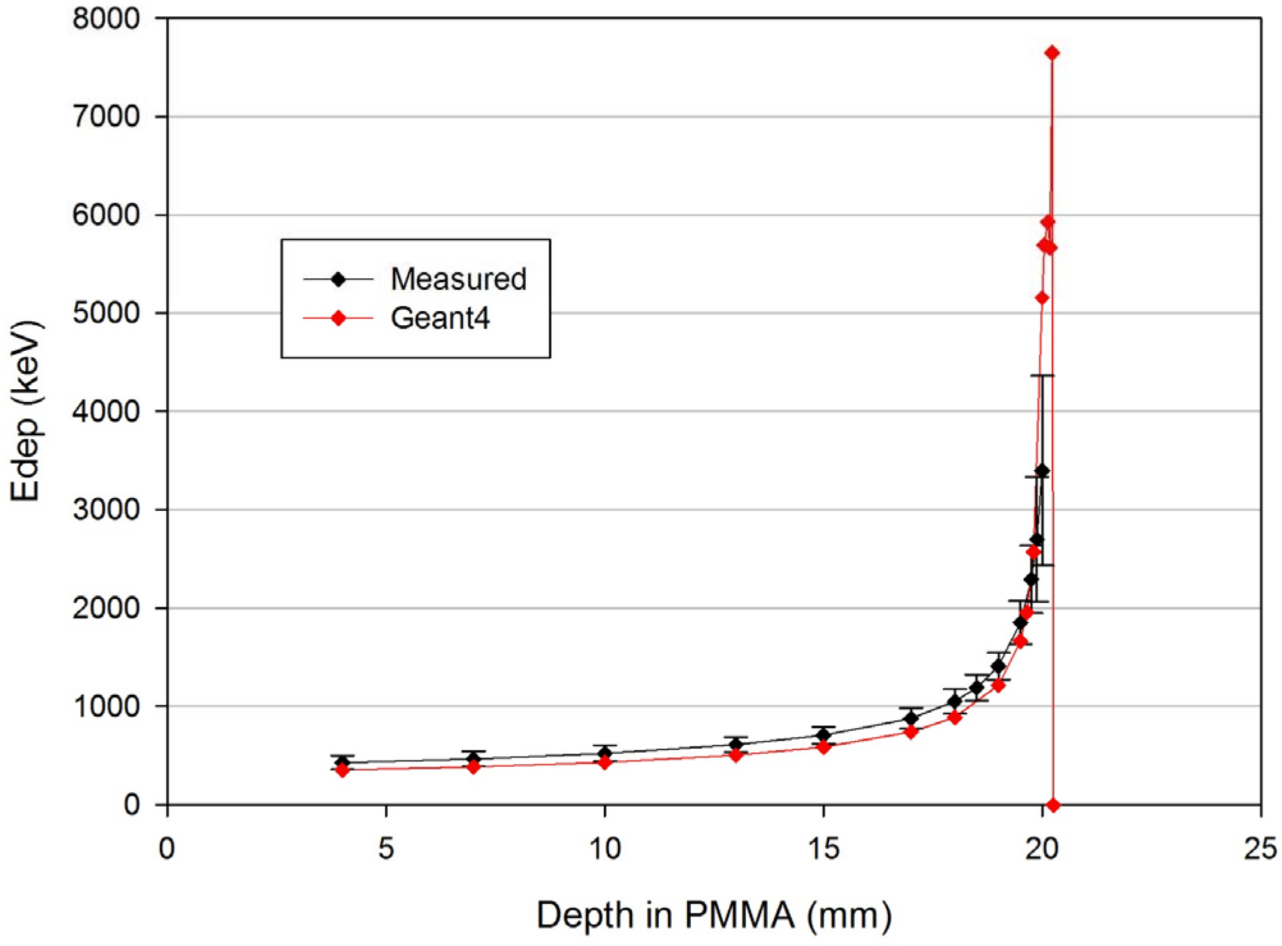


Pulse height spectra in the PMMA along the Bragg curve

- 10 um thick sensor, 1x1 mm^2 area, 0V bias
- ^{12}C energy 95MeV/A, range 25mm in PMMA



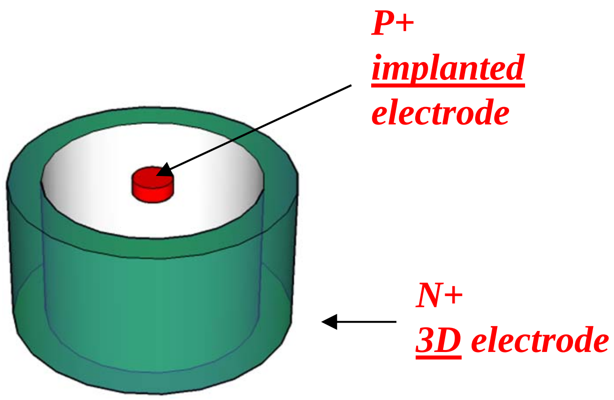
Bragg curve: measured vs Geant4

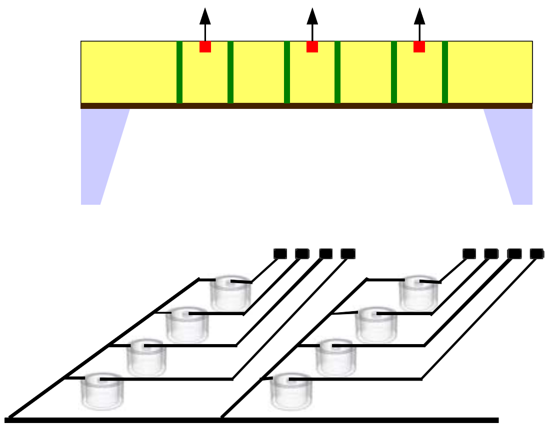


New generation microdosimeters

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA — cnm Centre Nacional de Microelectrònica IMB — Penn Medicine

- Use IMB-CNM'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



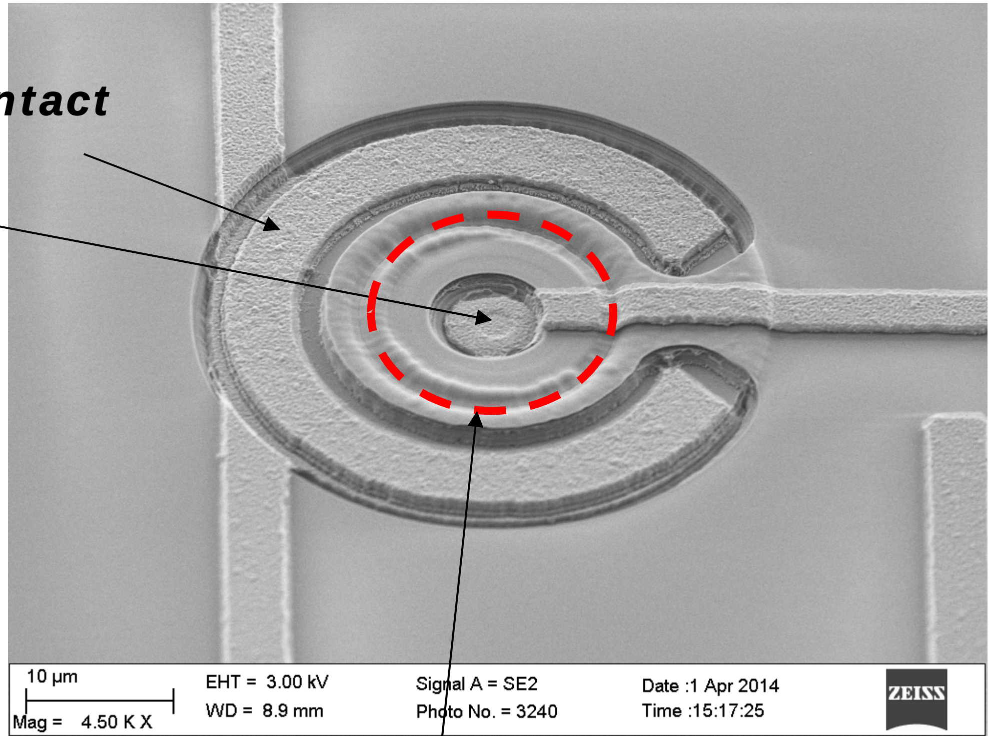


Fabricated devices: 6, 10, 20 µm thick

FINAL

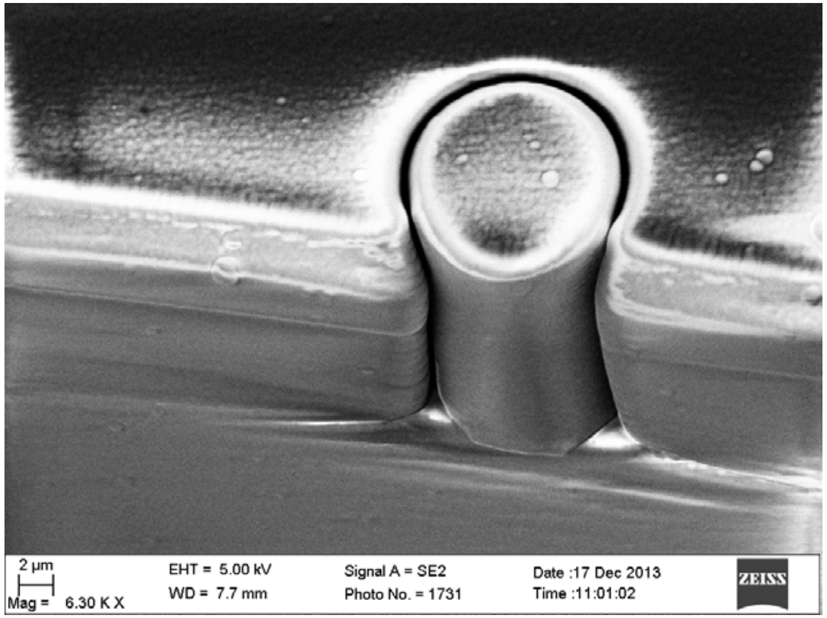
N-contact

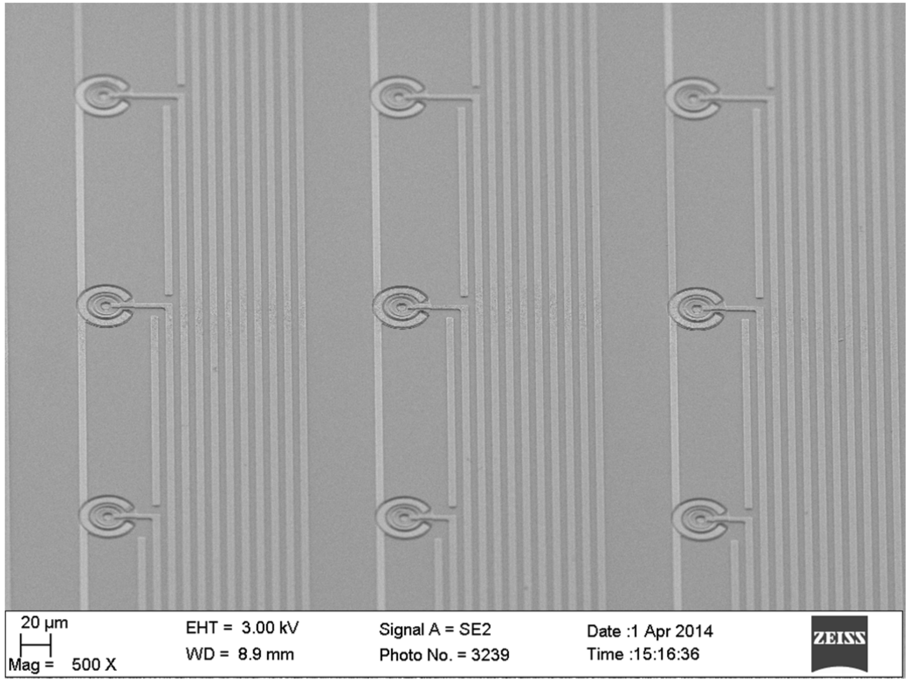
P-contact

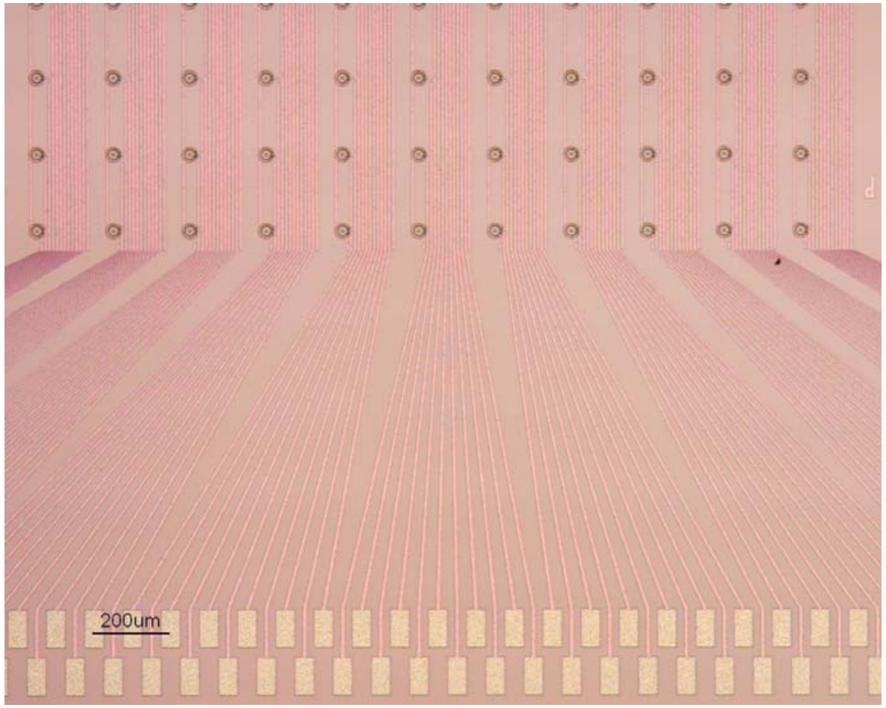


Active diameter (10µm)

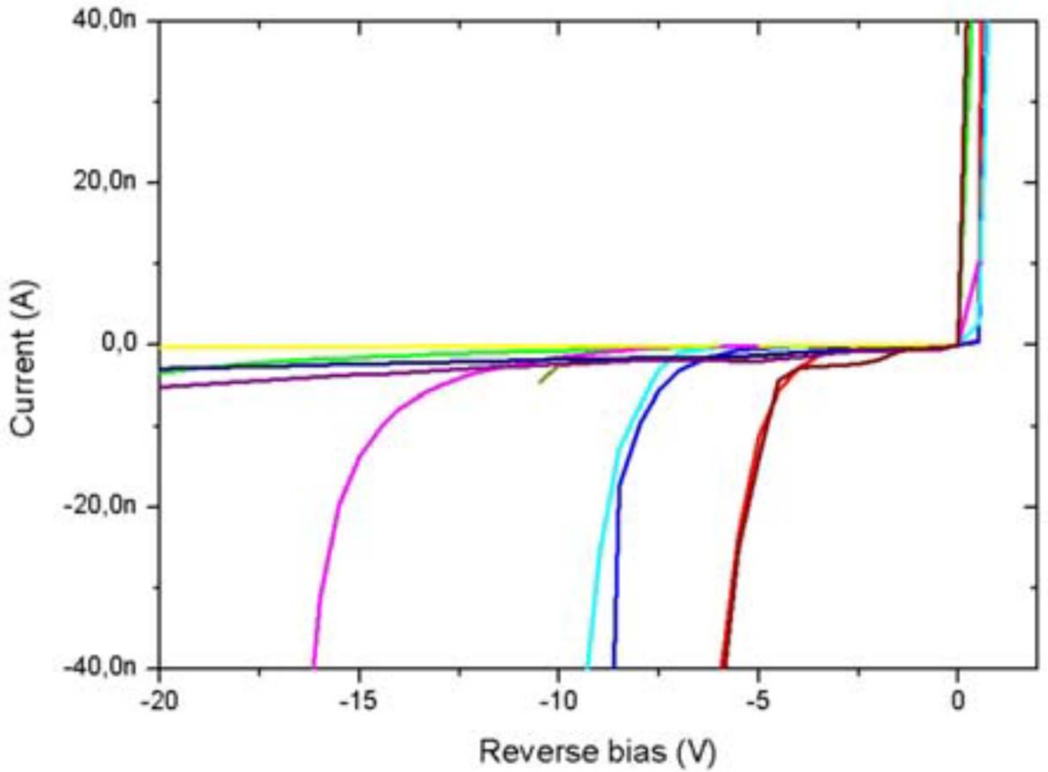
IN-PROCESS




20 µm
Mag = 500 X
EHT = 3.00 kV
WD = 8.9 mm
Signal A = SE2
Photo No. = 3239
Date :1 Apr 2014
Time :15:16:36

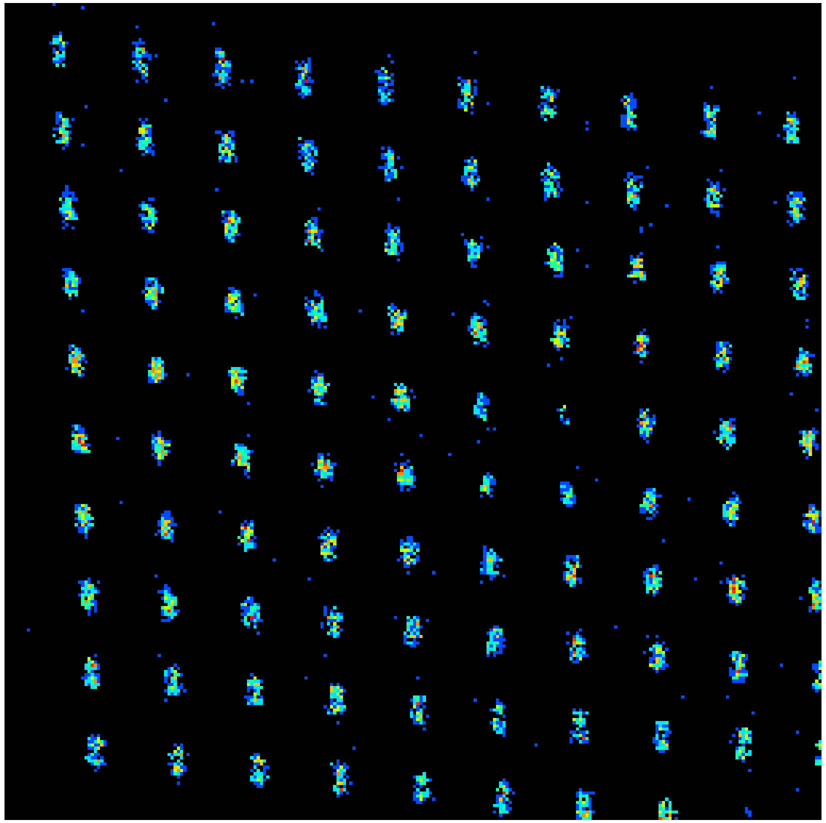

200um

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.

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