SILICON CARBIDE DIODES FOR ULTRA-HIGH DOSE RATE DOSIMETRY

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The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Context: FLASH radiotherapy

FLASH effect (*Favaudon et al., Sci Transl Med 6 (2014)*): Irradiations with con Ultra-High Dose Rate pulsed radiation reduce adverse effects in healthy tissues

- Need real-time, highly precise dosimeters
- CNM is a partner in the European project EMPIR-UHDPulse (2019-2023) for metrology in UHDR beams

UHDpulse

EMPIR EURAMET

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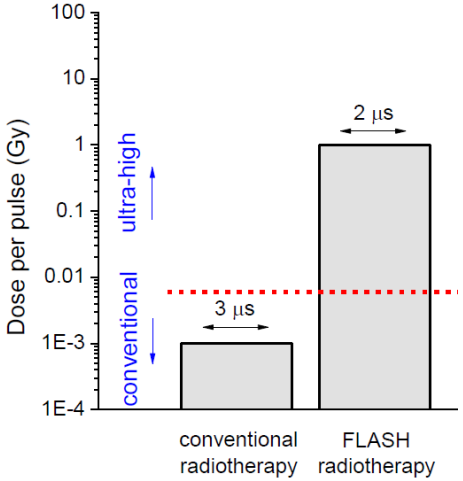
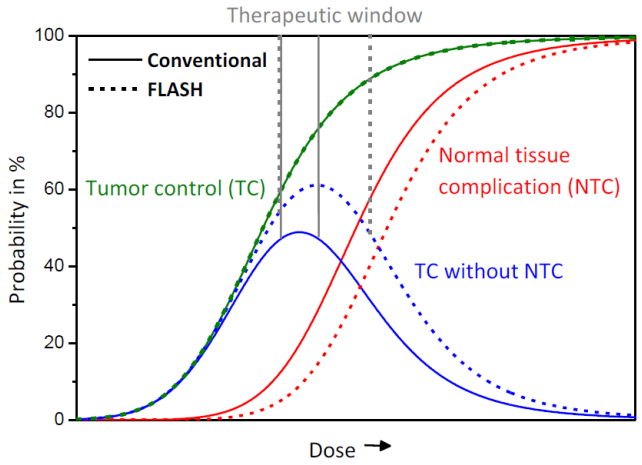
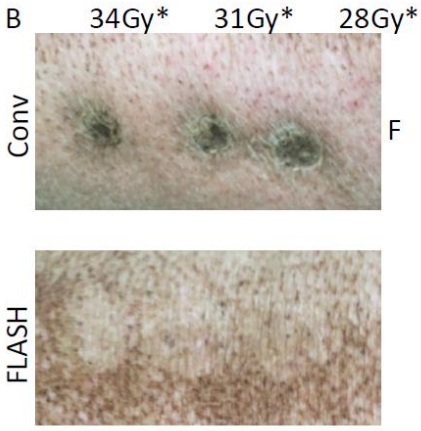
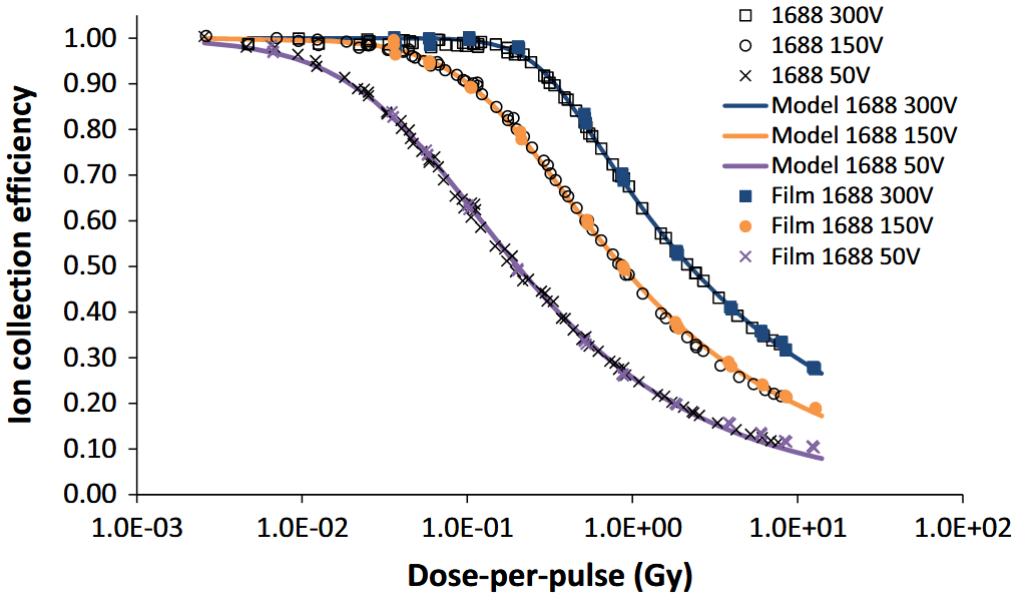
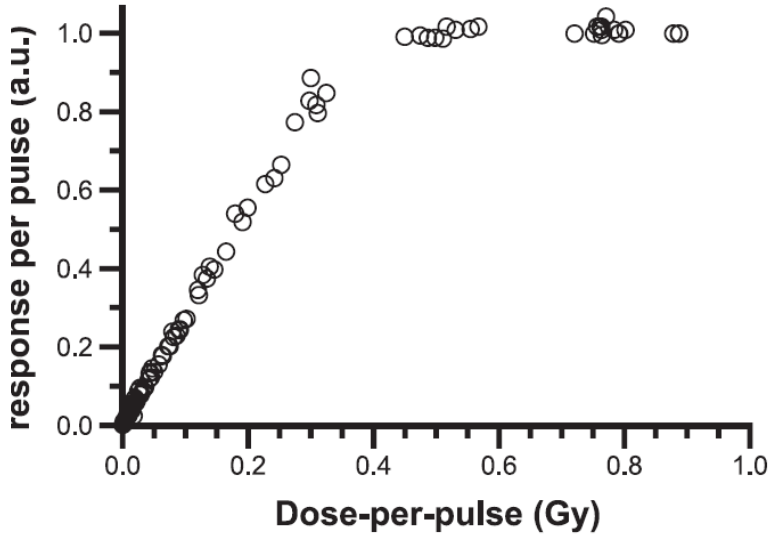






Limitation of conventional methods





Ref: *

Diamond is the standard for dosimetry in UHDR

Ref: **

*) K. Petersson et al., High dose-per-pulse electron beam dosimetry — A model to correct for the ion recombination in the Advanced Markus ionization chamber, Med. Phys. 44 (3), March 2017

**)Images from: E. Konradsson, et al., Correction for Ion Recombination in a Built-in Monitor Chamber of a Clinical Linear Accelerator at Ultra-High Dose Rates

URL: https://doi.org/10.1667/RADE-19-00012

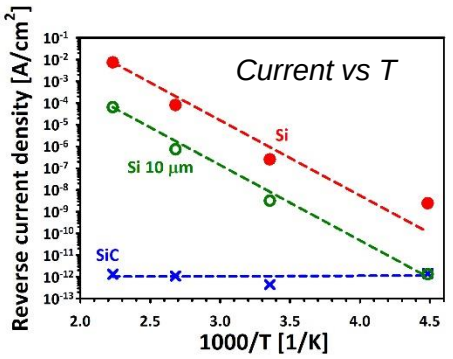
Silicon carbide diodes as real-time radiation dosimeters

Why SiC? **Wide bandgap semiconductors** (SiC and diamond), **compared to silicon**, have:

- Lower dark current
- Higher radiation hardness
- Tolerance to visible light and temperature variations

In addition, **SiC compared to diamond** has:

- More mature technology allowing to produce complex structures
- High quality substrate material available up to 200 mm wafers at a reasonable cost: good price-performance ratio

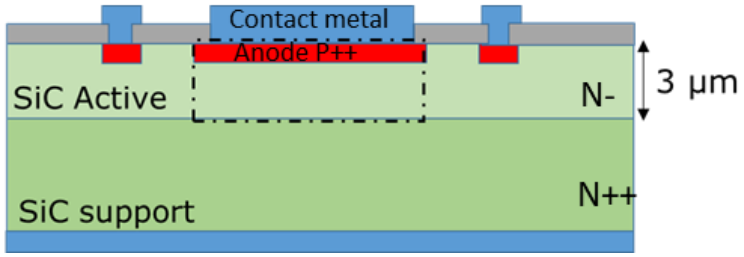


J. M. Rafí et al. JINST 13 C01045 (2018); IEEE Trans.Nucl.Sci. 67 (2020)

Devices (dosimeter)

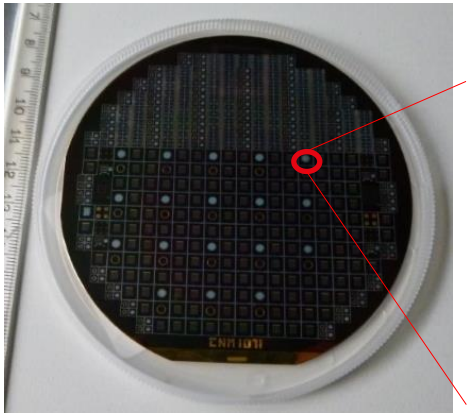
- Circular 1 mm diameter PiN diodes on 3µm epitaxial 4H-SiC
- Designed and fabricated by IMB-CNM-CSIC (EU Patent pending)
- Encapsulated by PTW with their microSilicon housing for electrical connectivity

SiC diode schematic cross section

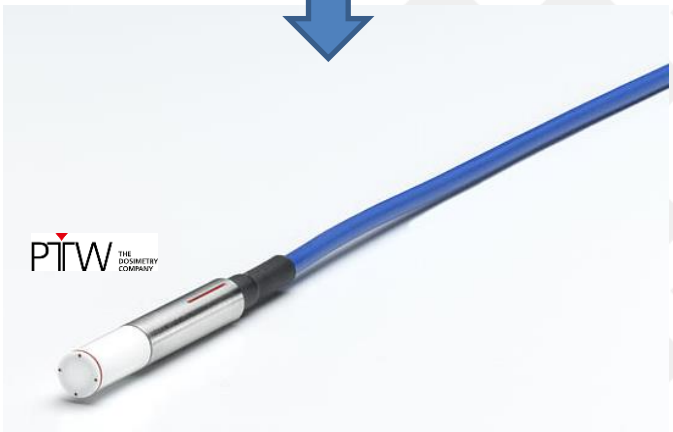


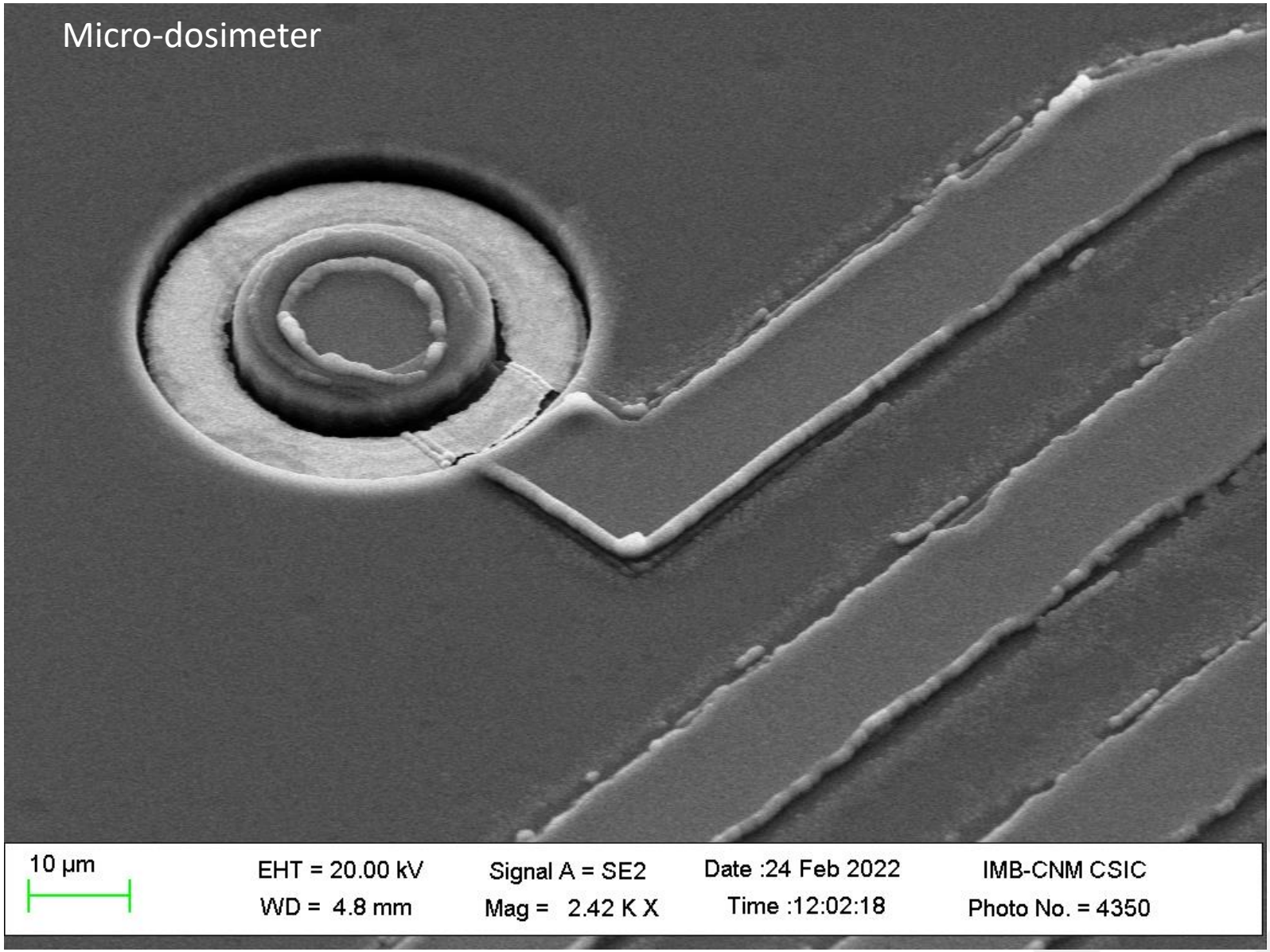
Encapsulated for electrical connectivity and for testing in water

4" SiC wafer



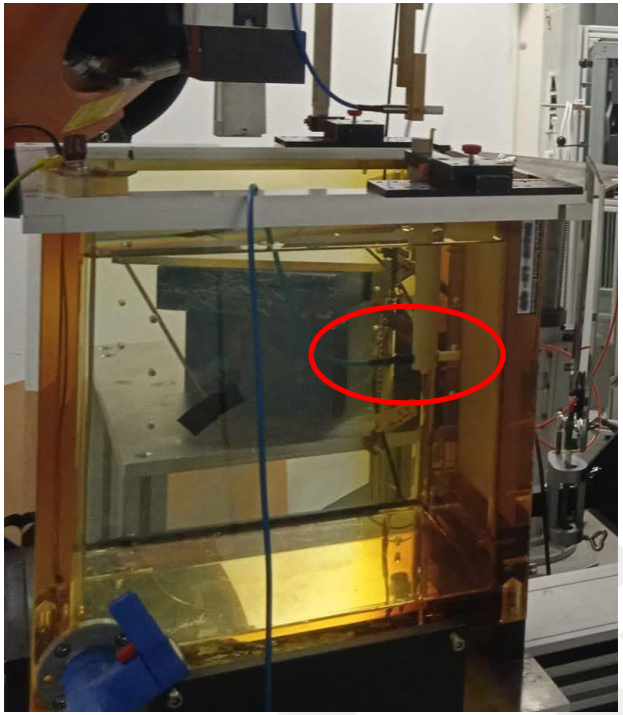
1 mm diode




Micro-dosimeter
10 µm
EHT = 20.00 kV
WD = 4.8 mm
Signal A = SE2
Mag = 2.42 K X
Date :24 Feb 2022
Time :12:02:18
IMB-CNM CSIC
Photo No. = 4350

Electron tests at PTB

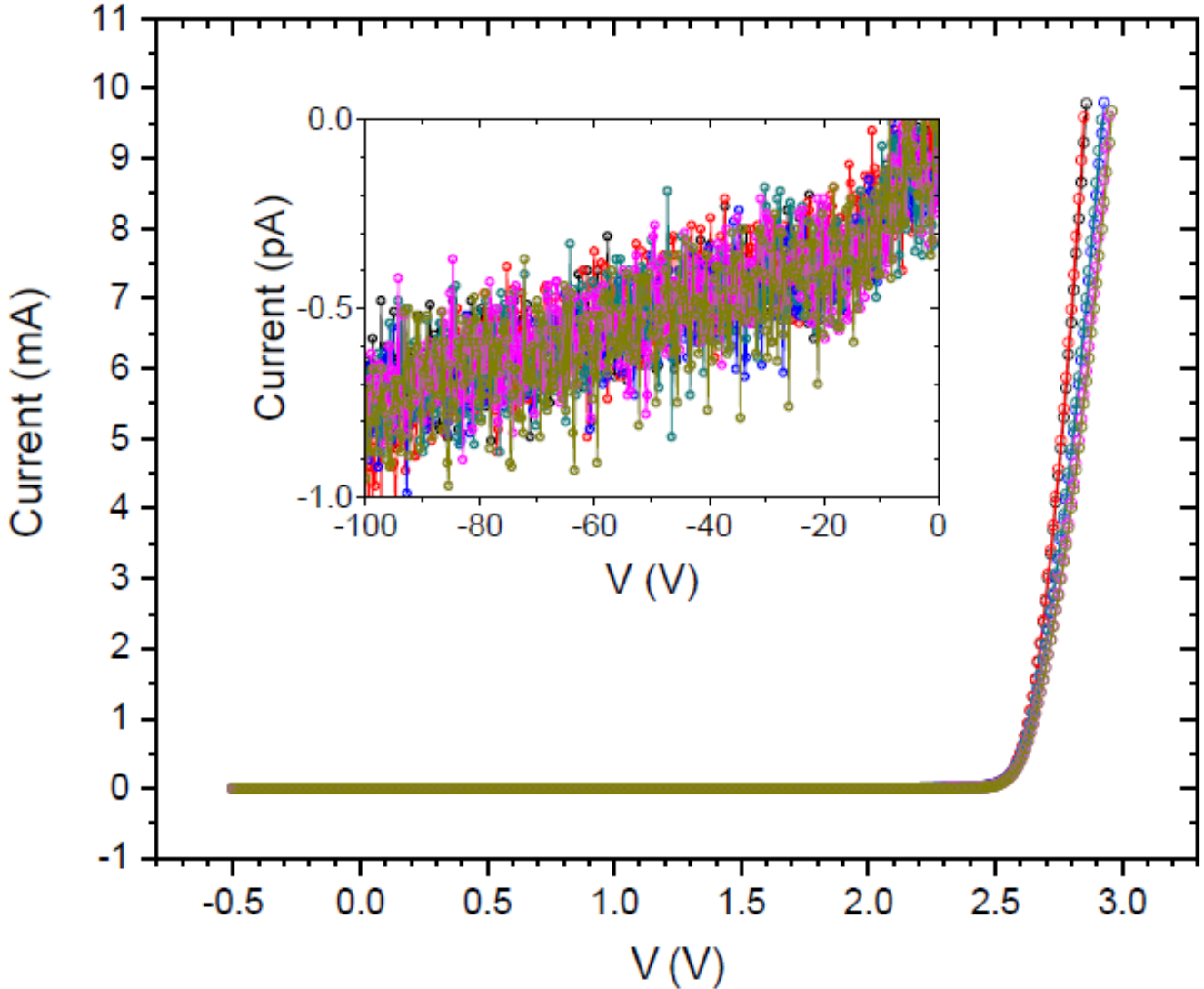
- Measurements at PTB UHDPP[1] electron beam
- Electron energy 20 MeV
- Repetition rate 5 Hz, pulse duration 0.6, 1.6 and 2.9 µs
- Measurements in PMMA water tank with a motorized positioning system
- Reference dosimetry provided by Alanine and prototype flashDiamond[2]
- SiC diode operated **without external bias**



SiC diode in water phantom at PTB

1. Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
2. M. Marinelli et al. “Design, realization and characterization of a novel diamond detector prototype for FLASH radiotherapy dosimetry” Med Phys. 2022;49:1902–1910

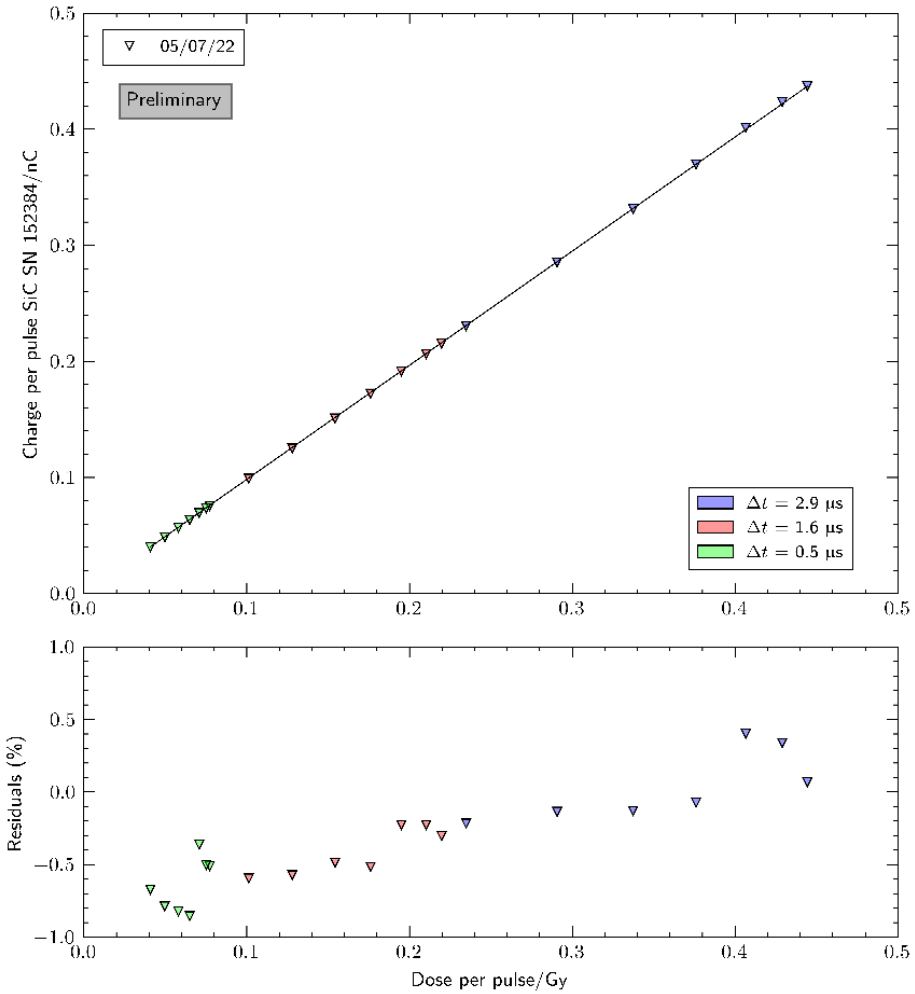
Electrical characterization



Results

Intermediate Dose Per Pulse (DPP) range: 0.42 Gy

- Response independent both of DPP and of instantaneous dose rate
- Linearity deviation < 1 % *
- SiC diode sensitivity ~1 nC/Gy

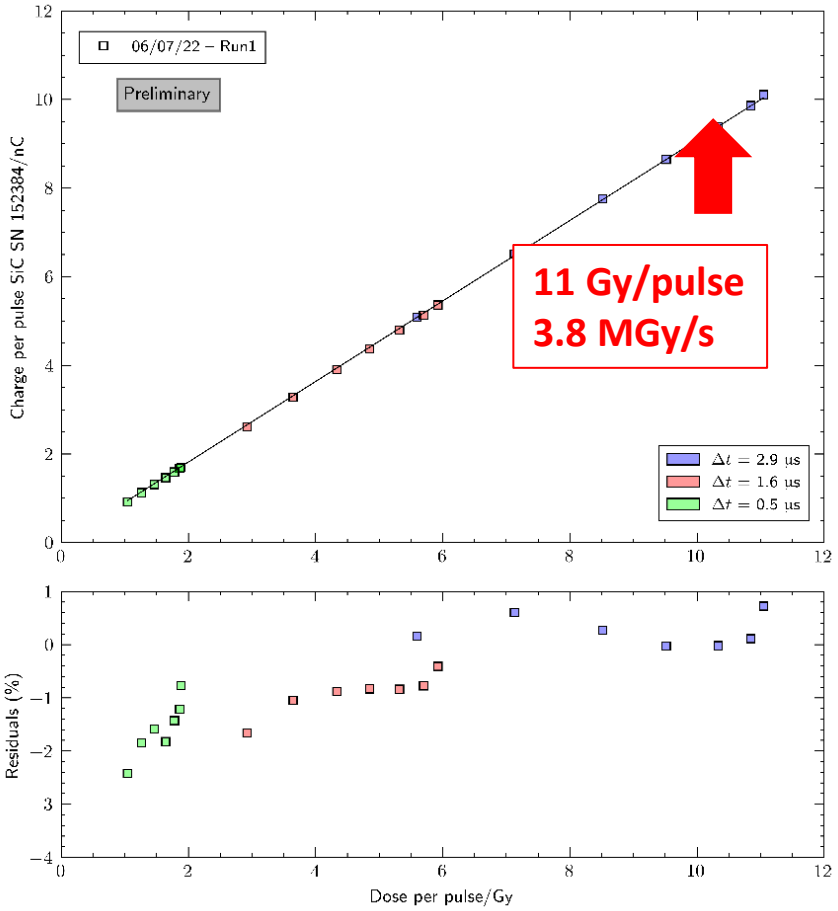


(*) includes uncertainty of reference detector

Results (UHDR)

Ultra-high Dose Per Pulse (DPP) range: 11 Gy

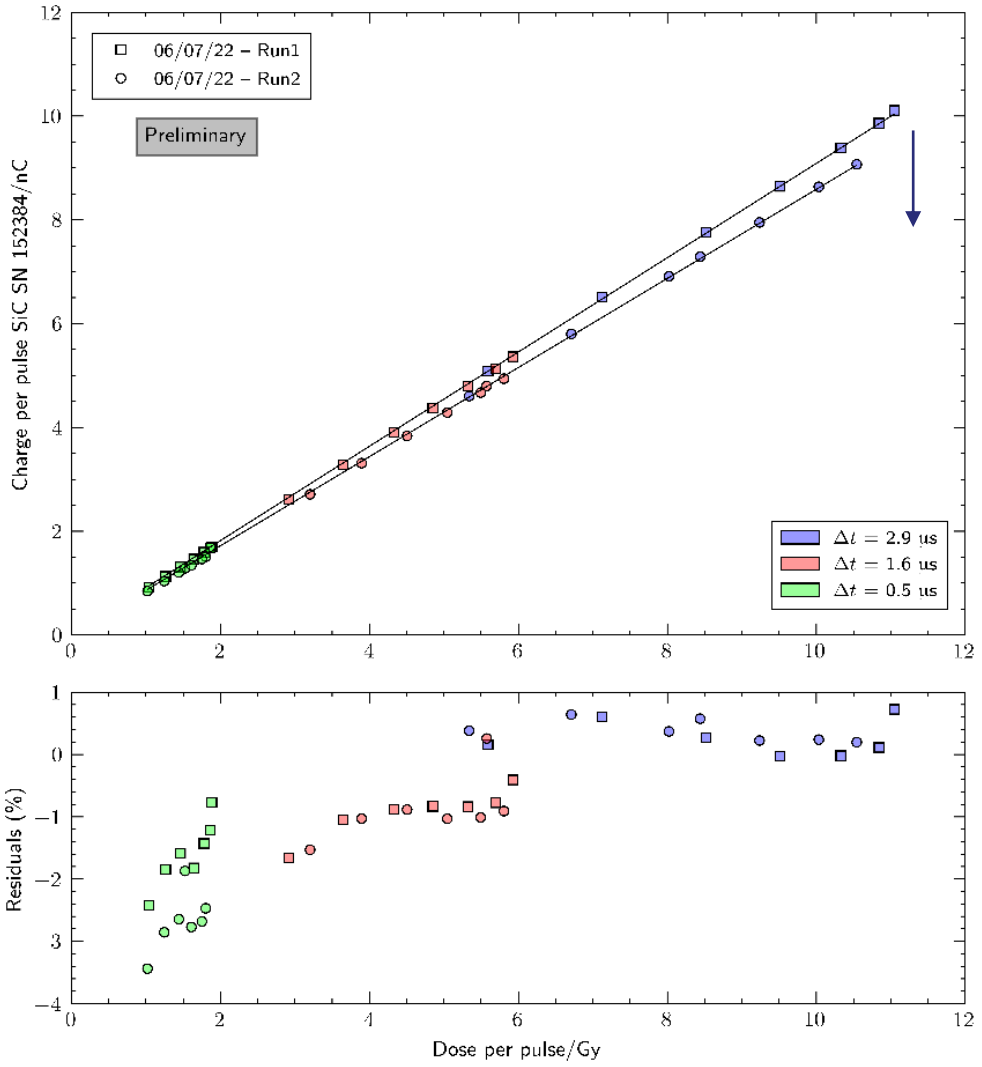
- Signal linearity up to at least **11 Gy/pulse** with a relative deviation of < 3 %



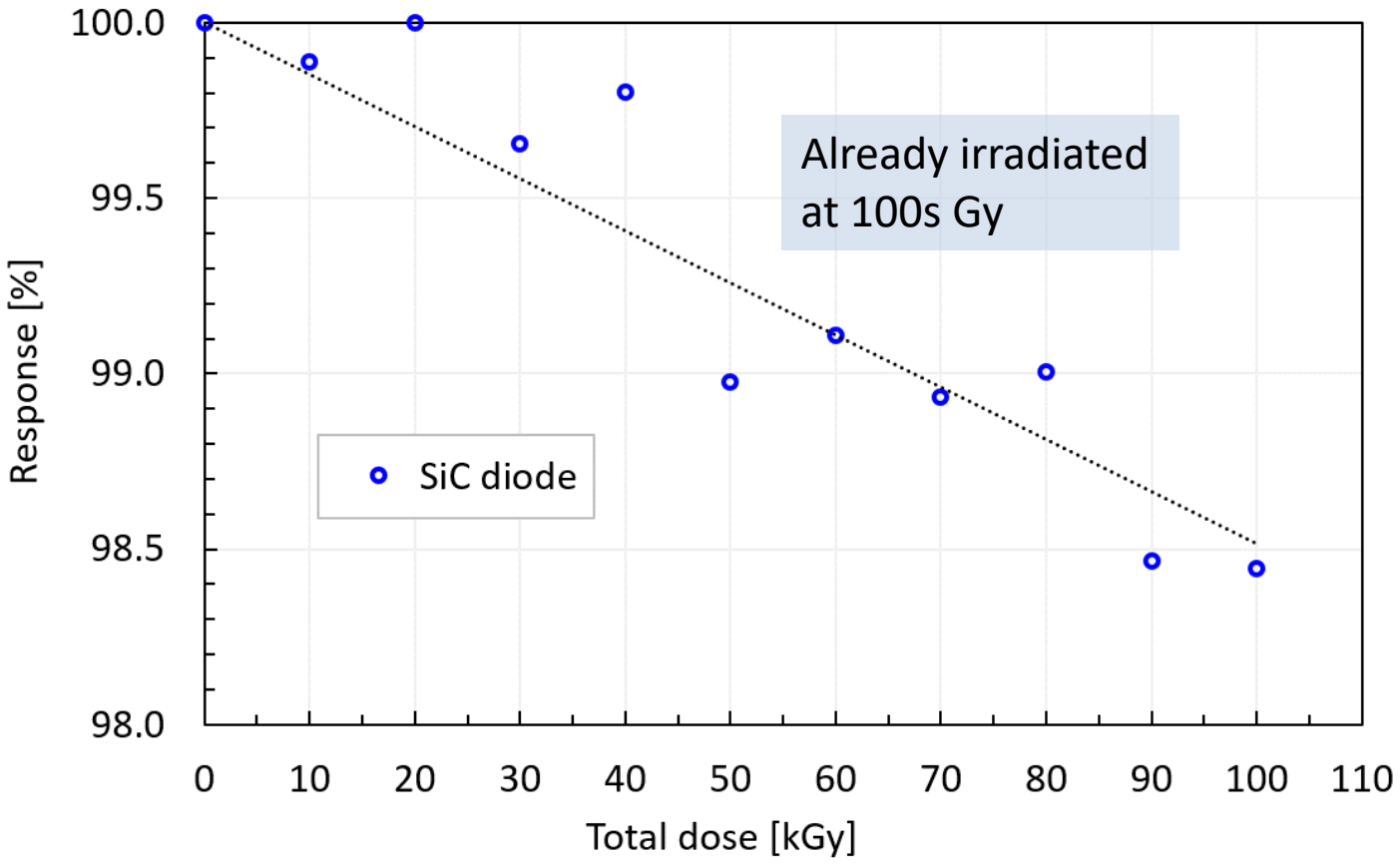
Results

Effect of accumulated dose

- Two runs, around ~26 kGy accumulated dose between them
- Response linearity not affected
- 5% reduction in sensitivity
- The saturation of the device response is associated to the series resistance –
- The higher the series resistance the lower the DPP value up to which the detector shows a linear response.



Pre-Irradiation

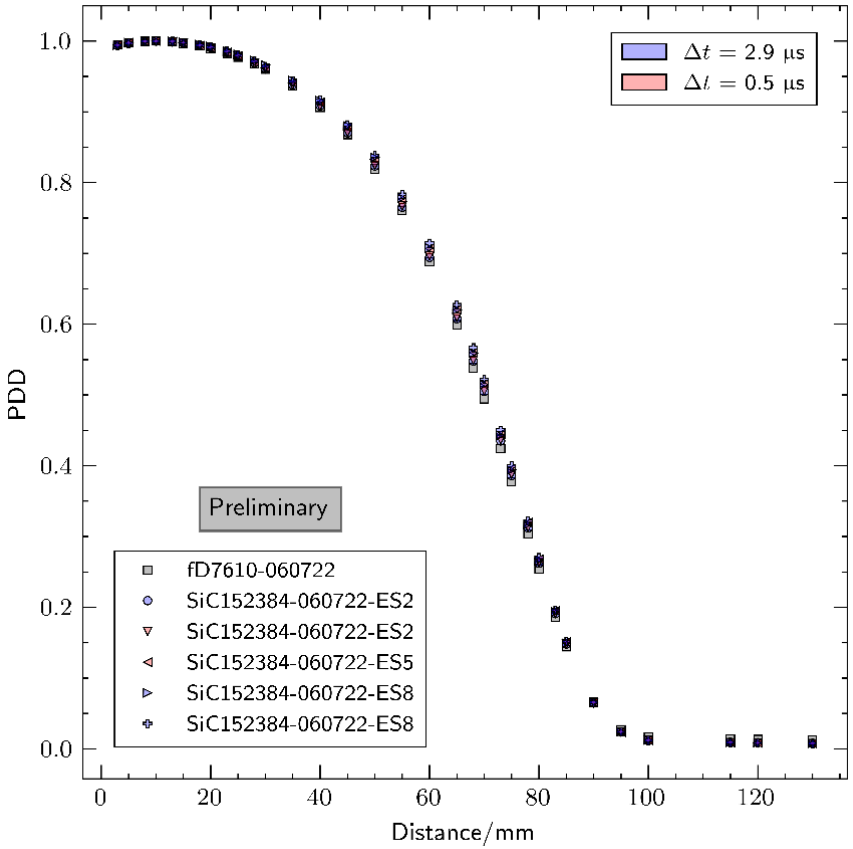


If pre-irradiated the sensibility of SiC its response is less sensible to variation

Results

Depth Dose Curves PDD measurement

- Several runs of PDD curves performed under UHDPP conditions with different dose per pulse and pulse duration irradiations
- SiC diode performance comparable to reference flashDiamond

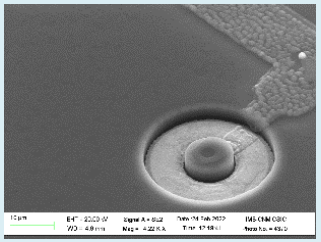


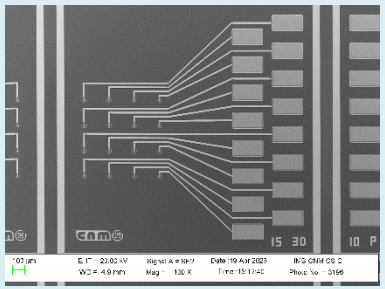
Conclusions and outlook

First SiC diodes for relative dosimetry in UHDR pulsed electron beams.

- ✓ Response independent both of DPP and of instantaneous dose rate in the investigated range: up to 11 Gy/pulse, 3.8 MGy/s
- ✓ Radiation robust: 5% sensitivity reduction over 26 kGy
- ✓ Performance comparable to flashDiamond in PDD measurement

- Future work:
  - Systematic characterization in a wide range of beam configurations
  - Validation of other detector structures fabricated: diodes with sidewalls removed for increased spatial and dose resolution, pixel configurations for 2D dose maps
  - Understand the radiation hardness of SiC in different beams.
  - Fabricate a new active dosimetry monitor based on the development of innovative SiC microdetectors able to quantify the dose delivered in FLASH effect in two dimensions.





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Thank you for your attention

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Disclosure

- Rafael Kranzer is a PTW employee.

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