Development of innovative silicon carbide detectors for radiation detection and dosimetry

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Material properties

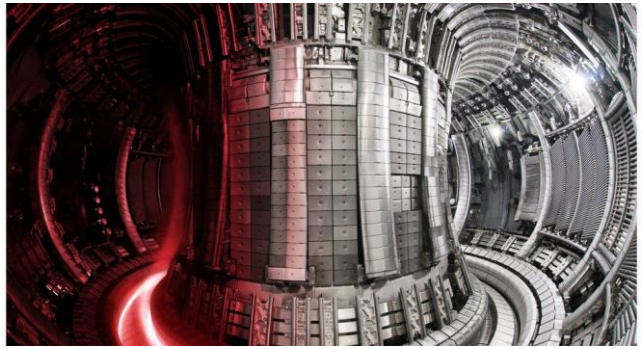
	Silicon	4H-SiC	CVD diamond
Band gap [eV]	1.12	3.23	5.5
Ionization energy [eV/e-h]	3.6	7.6 – 8.4	13.6
Atomic displacement threshold [eV]	13-15	30 – 40	43
Density [g/cm3]	2.33	3.22	3.52
Electron mobility [cm2/Vs]	1450	800 – 900	1700
Hole mobility [cm2/Vs]	450	115	2100
Electr. sat. velocity [1E7 cm/s]	1	2.2	2.7
Breakdown field [MV/cm]	0.3	3 – 4	10
Thermal conductivity [W/cmK]	1.5	5	20
Yield [fC/MeV]	44.4	21.0	11.8
Sensitivity [pC/mGy/mm3]	644	425	259
Wafer cost	O(<100€)	O(1,000€)	O(100,000€)*

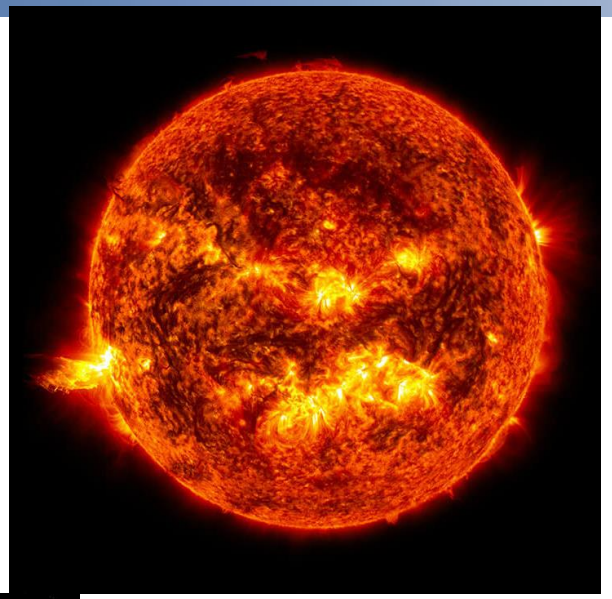
- Wide bandgap energy
  - Not affected by T variations
  - Low leakage current
  - Transparent to visible light
- High atomic displacement threshold energy
  - Radiation hardness
- High saturation velocity
  - Timing applications
- High breakdown voltage and high thermal conductivity
  - Power devices
- **Good price/performance ratio**

Many potential applications in sensors

Nuclear fusion reactors

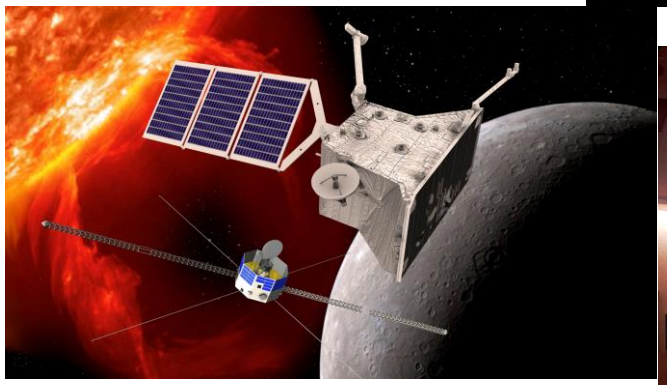
-Plasma diagnostics





Aerospace

-Sensors and electronics

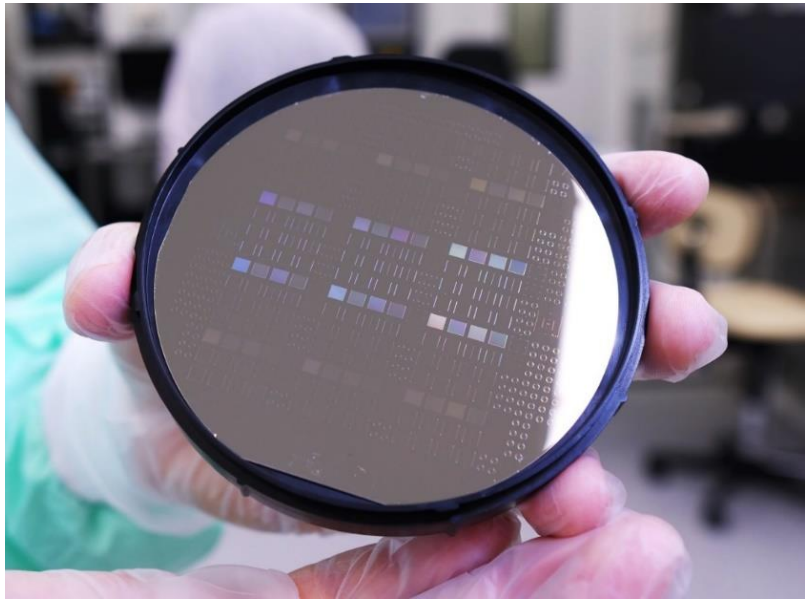


Medical

-Dosimetry and microdosimetry

SiC detector technology at IMB-CNM

- SiC based **PiN junction** diodes fabricated on 4H-SiC on a high resistivity n-type doped epilayer, 100 or 150mm wafers
- Technology based on our SiC rectifiers for space (ESA Bepi-Colombo & Solar Orbiter missions)
- Adapted for radiation detection with high temperature processes and optimized metal contacts

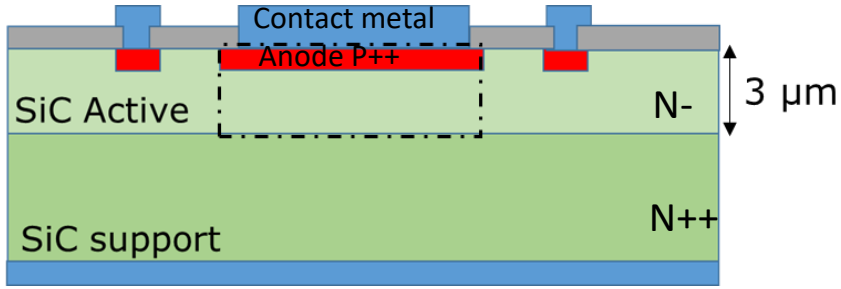


SiC diodes for UHDR dosimetry

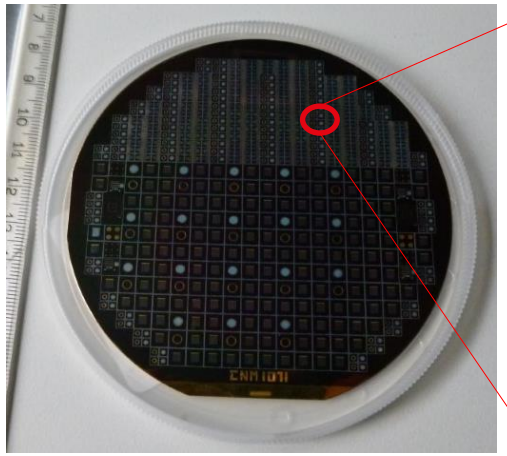
In the framework of UHDPulse WP3

- CNM-CSIC has designed and fabricated a set of SiC diodes for dosimetry
- *EU Patent pending*
- Devices tested: circular 1 mm diameter PiN diodes on 3 µm epitaxial 4H-SiC
- Encapsulated by PTW with their microSilicon housing for electrical connectivity

SiC diode schematic cross section

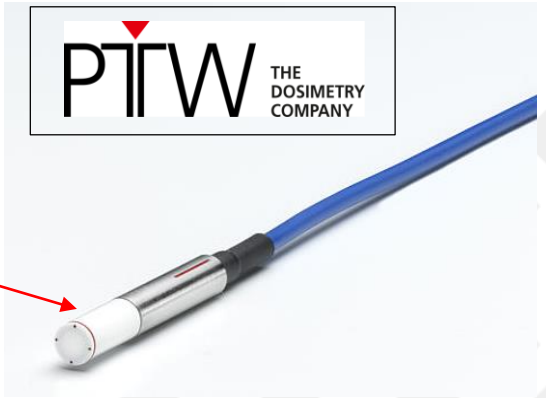


4" SiC wafer



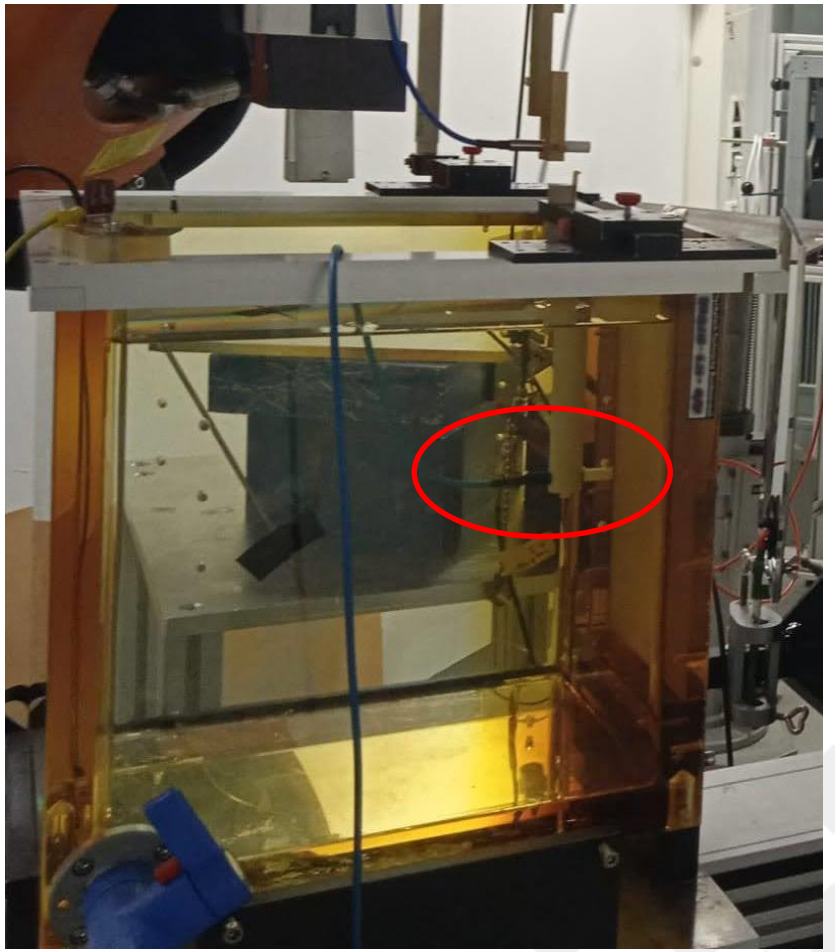
1 mm diode

Encapsulation



Tests with electron beams at PTB

- Measurements at PTB UHDPP 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
- SSDs 90 and 70 cm
- Reference dosimetry provided by Alanine and prototype flashDiamond*
- SiC diode operated without external bias



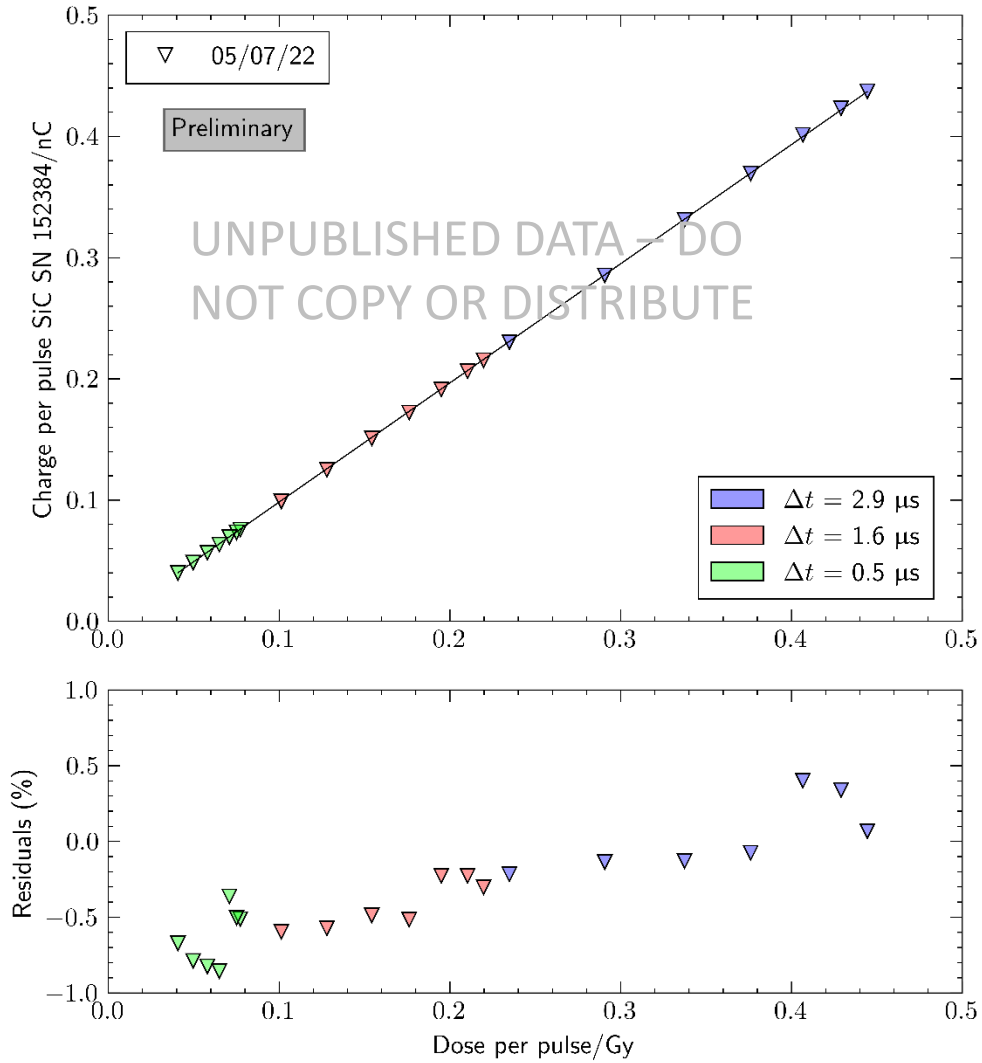
SiC diode in water phantom at PTB

(*) M. Marinelli et al. “Design, realization and characterization of a novel diamond detector prototype for FLASH radiotherapy dosimetry” Med Phys. 2022;49:1902–1910

Intermediate DPP range: 0.2 - 0.42 Gy

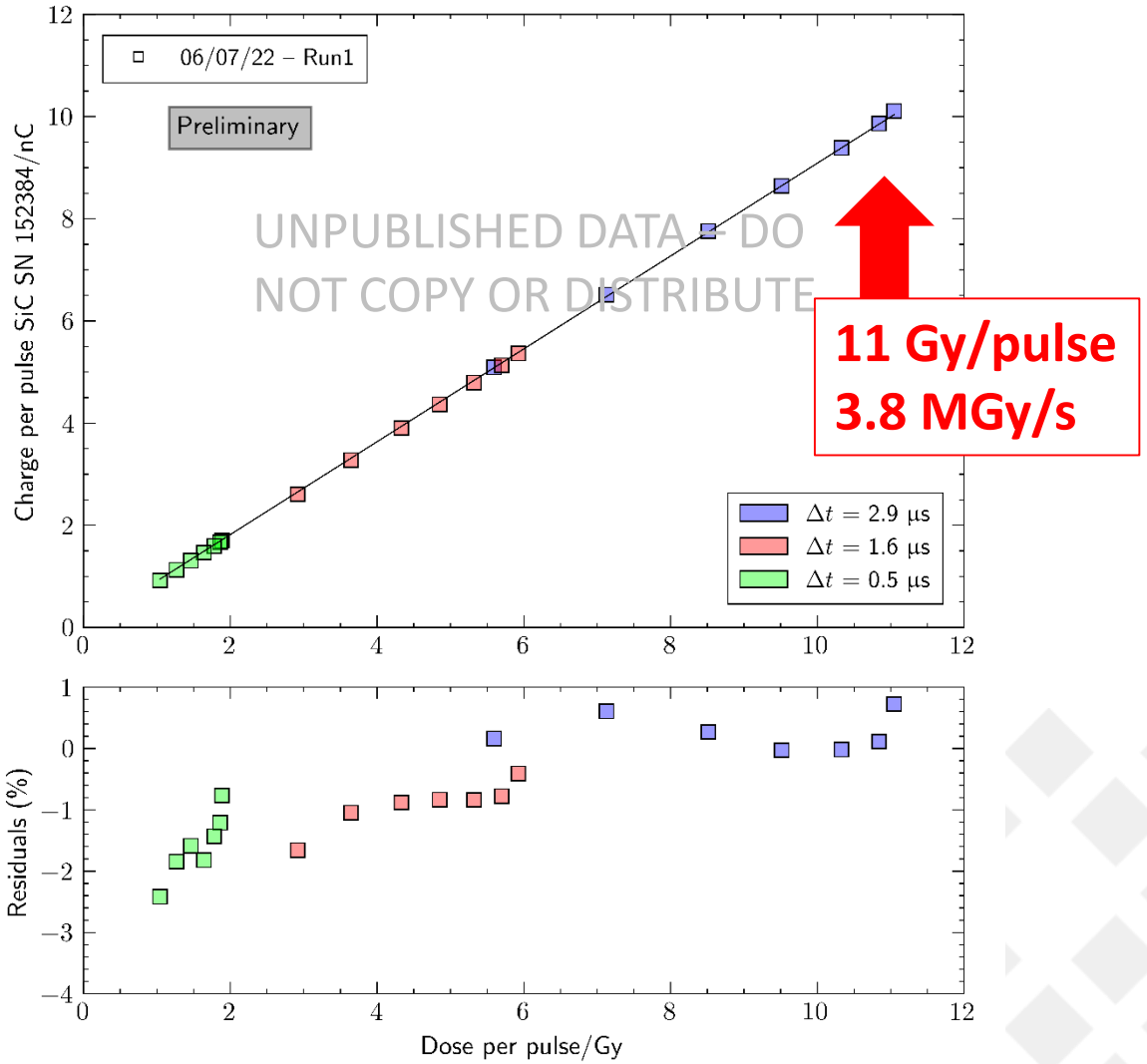
- Response independent both of DPP and of instantaneous dose rate
- Linearity deviation < 1 % *
- SiC diode sensitivity ~1 nC/Gy

(*) includes uncertainty of reference detector



Ultra-high DPP range: 1 - 11 Gy

- Signal linearity up to at least 11 Gy/pulse (3.8 MGy/s) with a relative deviation of < 3 %

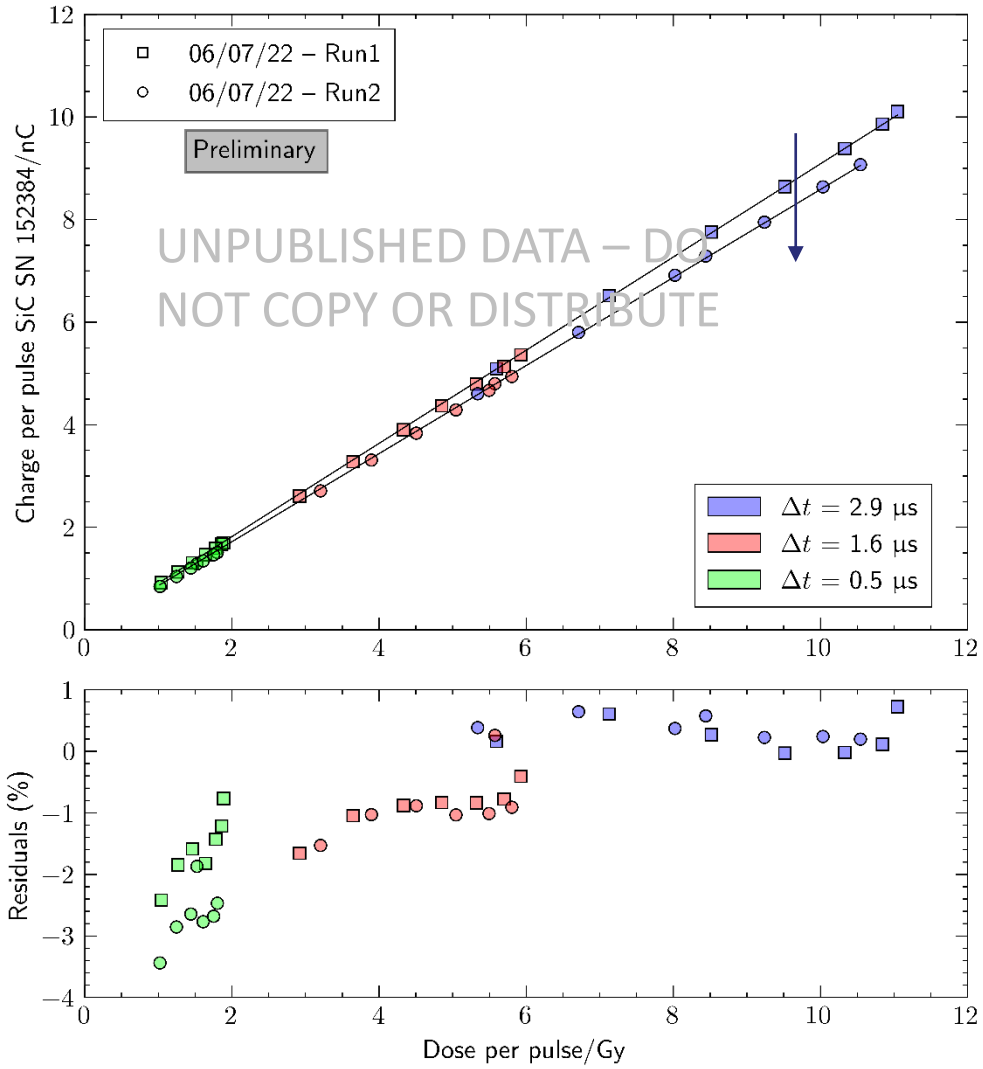


Effect of accumulated dose

- Two runs, around ~16 kGy accumulated dose between them
- Response linearity not affected
- Sensitivity variation with dose < 1%/kGy *

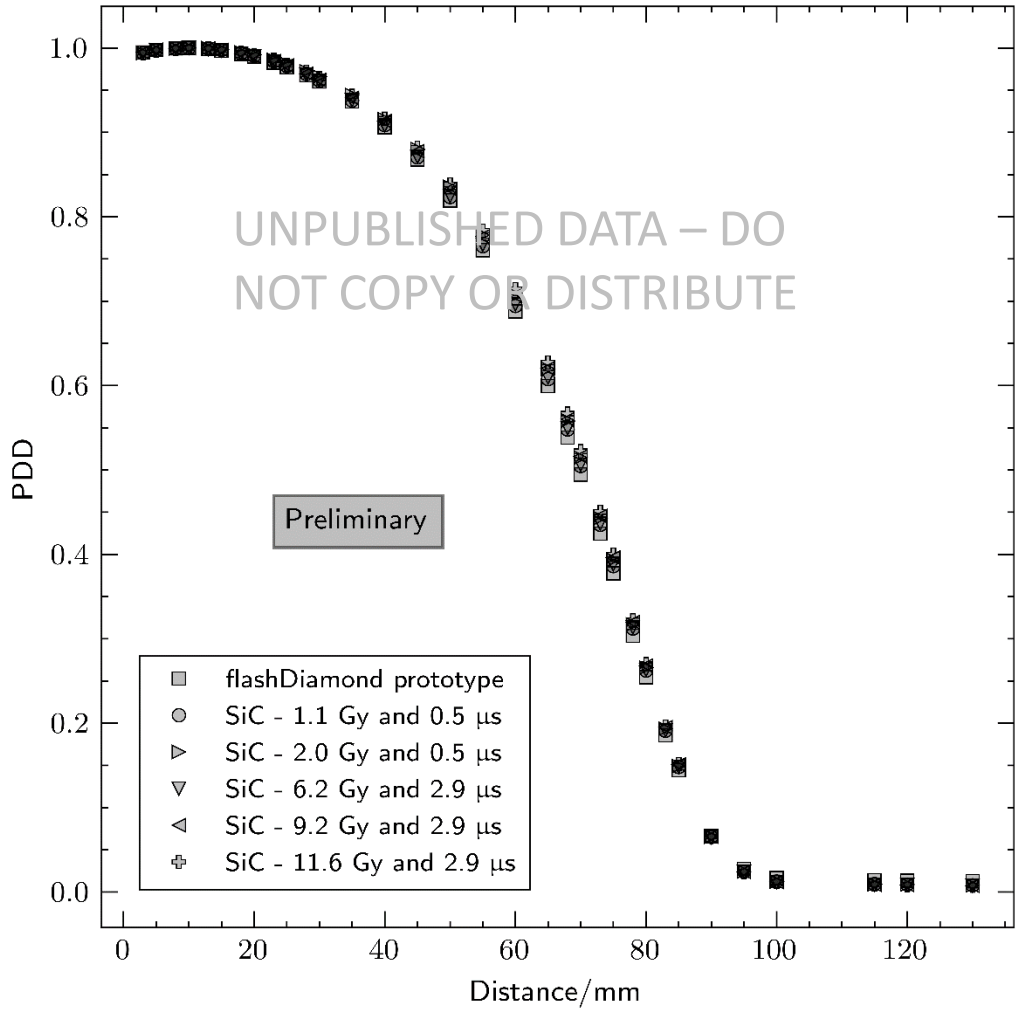
→ Not as radiation hard as diamond, better than silicon

* Worst case estimation (under analysis)



PDD measurement

- 5 consecutive runs of PDD curves obtained with the SiC diode:
  - Max. dose per pulse: 1.1 to 11.6 Gy
  - Pulse duration: 0.5 and 2.9 µs
- Performance comparable to reference flashDiamond



Conclusions

- Silicon carbide is an attractive material for radiation sensors
  - Mature technology, wafer-level production, large geometries
  - Many applications where silicon is not suitable (radiation damage, T sensitivity, …)
- Open topic
  - Radiation hardness

- In the framework of UHDPulse we have fabricated and validated the first SiC diodes for relative dosimetry in UHDR pulsed electron beams.
  - ✓ Operation without external bias
  - ✓ Response independent both of DPP and of instantaneous dose rate in the investigated range: up to 11 Gy/pulse, 3.8 MGy/s
  - ✓ More radiation robust than silicon
  - ✓ Performance comparable to flashDiamond in PDD measurement under UHDPP conditions

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Thanks for your attention

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