SiCILIA - Silicon Carbide detectors for nuclear physics and Applications

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On behalf of SiCilia project

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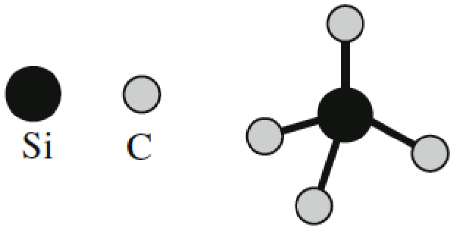
SiCILIA

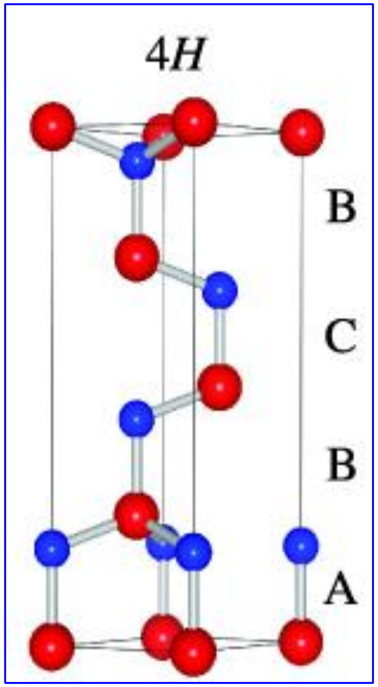
Silicon Carbide Material

- Was discovered in 1824 by **Jons Berzelius (**Swedish scientist) in the same year when he also discovered elemental Silicon

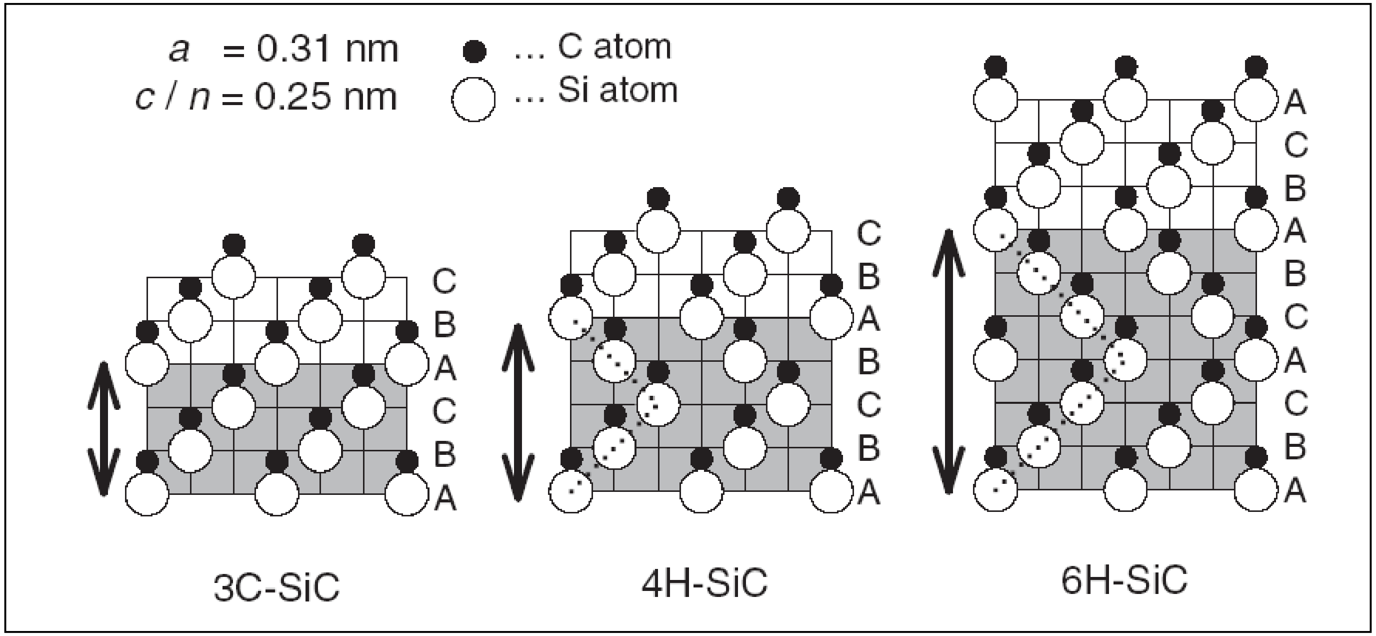
Tetrahedra of Carbon and Silicon atoms with strong bonds in the crystal lattice. **Very hard and strong material**!



strong bonds !



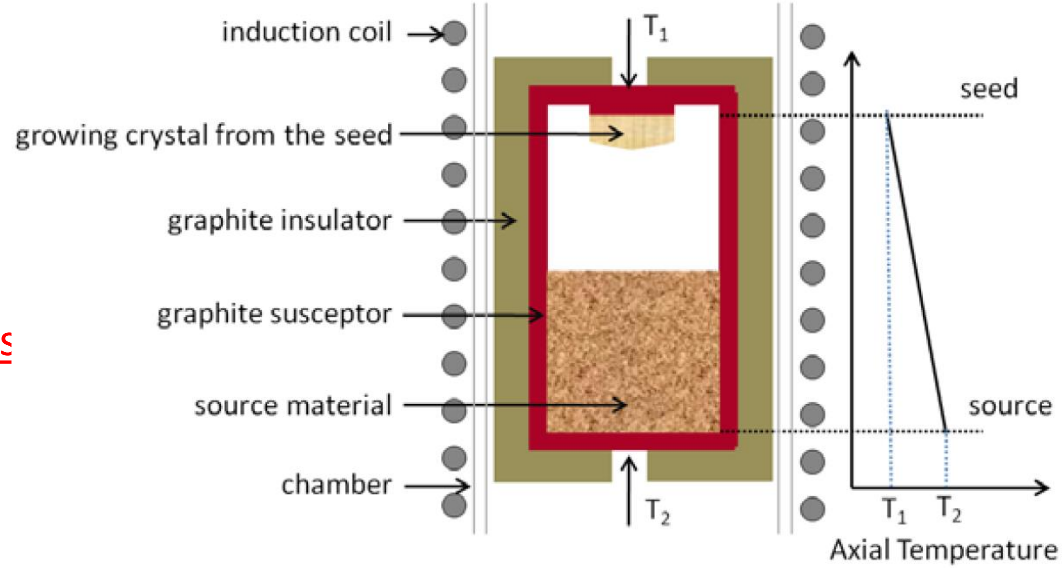
Lattice structure



SiC - Polytypism

SiC growth

Unlike of Si, **SiC** does not show a liquid phase, The only way to synthesize, purify and grow SiC raw material is by means of gaseous phases



General Properties of SiC

- **high thermal conductivity**
- **low thermal expansion**
- **high strength (hardness)**
- **chemical inertness**

→ **Exceptional thermal shock resistant qualities**

Applications on ELECTRONIS DEVICES

- High power
- High frequency
- High temperature
- Radiation detectors

SiC wide-band-gap semiconductor

Energy gap => E_{SiC}=3.28 eV > E_{Si}=1.12 eV
Breakdown Field => BF_{SiC}=3-4 MV/cm > BF_{Si}=0.3 MV/cm
Saturated electron velocity => $v_{SiC} > v_{Si}$

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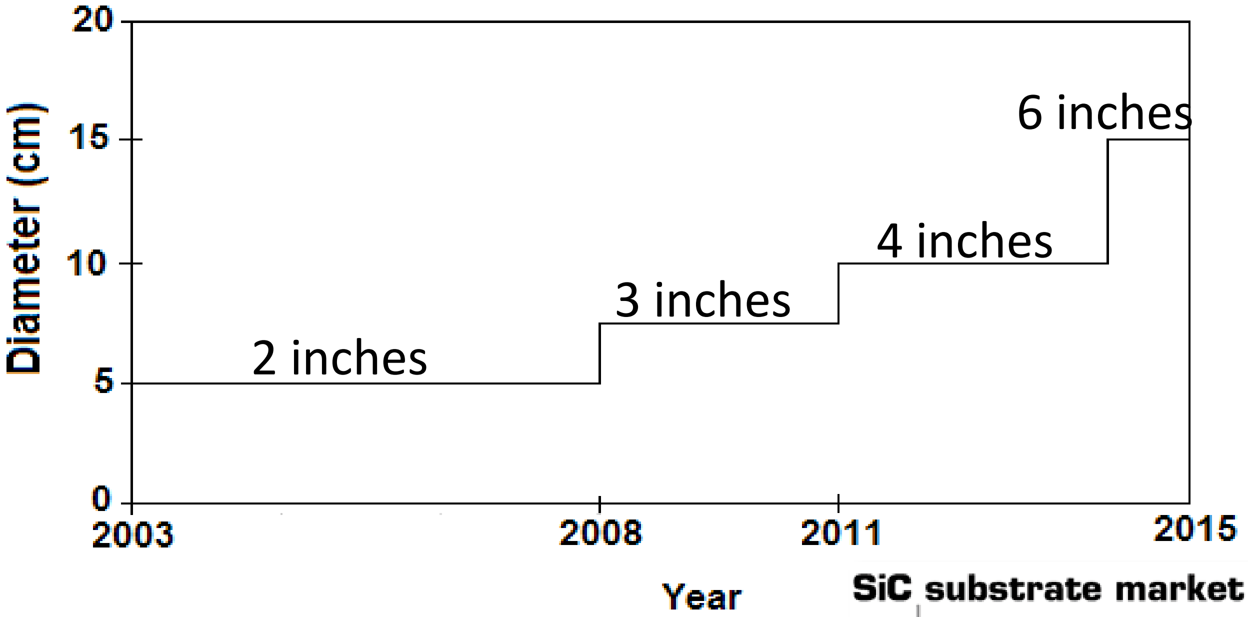
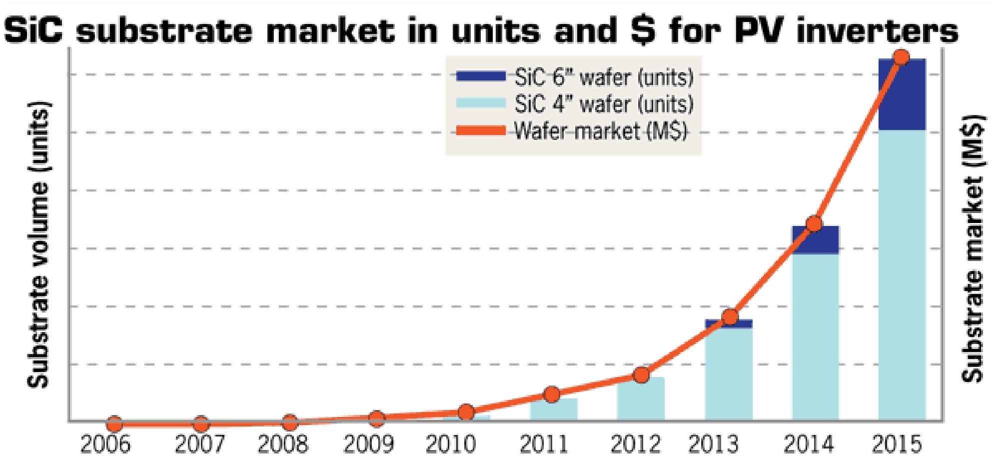
SiC market



High wafer size

High volume



SiC for radiation detectors

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	**5.5**	**3.39**	**3.28**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4\cdot10^6$	$3\text{-}4\cdot10^6$	$3\cdot10^5$
m_e [cm^2/Vs]	1800	1000	800	1450
m_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2\cdot10^7$	-	**$2\cdot10^7$**	**$0.8\cdot10^7$**
Z	6	31/7	14/6	14
e_r	5.7	9.6	9.7	11.9
e-h energy [eV]	**13**	**8.9**	**7.6-8.4**	**3.6**
Density [g/cm3]	3.515	6.15	3.22	2.33
Displacem. [eV]	**43**	**^{3} 15**	**30-40**	**13-15**

- Wide band-gap (3.3eV)

⇒ Visible blind

⇒ Lower Leakage current

- High Breakdown

⇒ Advantage for Radiations hardness

- Different e-h mobility

⇒ Charge Identification pulse shape analysis

- Fast devices

⇒ Timing applications

- Signal

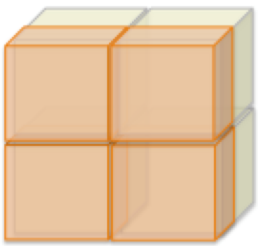
⇒ Less charge than Si, SiC≈Si/2

- Higher displacement threshold

⇒ Radiation harder then Silicon

R&D on SiC *Technology*

Radiation Hard detectors for Nuclear Physics experiments and Nuclear applications



ΔE-E telescopes

- ✓ Active area 1 cm^2
- ✓ *ΔE* stage thickness 100 μm
- ✓ *E* stage thickness 500 μm

R. H. → 10^{14} ions/cm^2 in ten years of activity

(Si detector dead @ 10^9 implanted ions/cm^2)

20x100 cm^2

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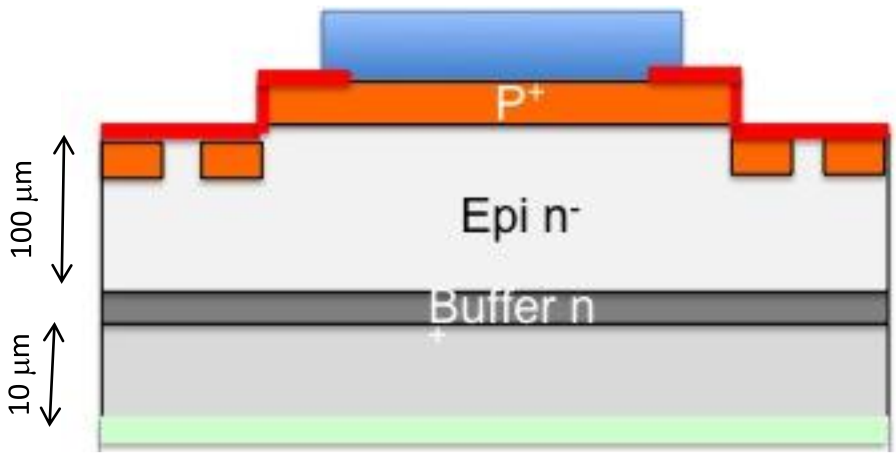
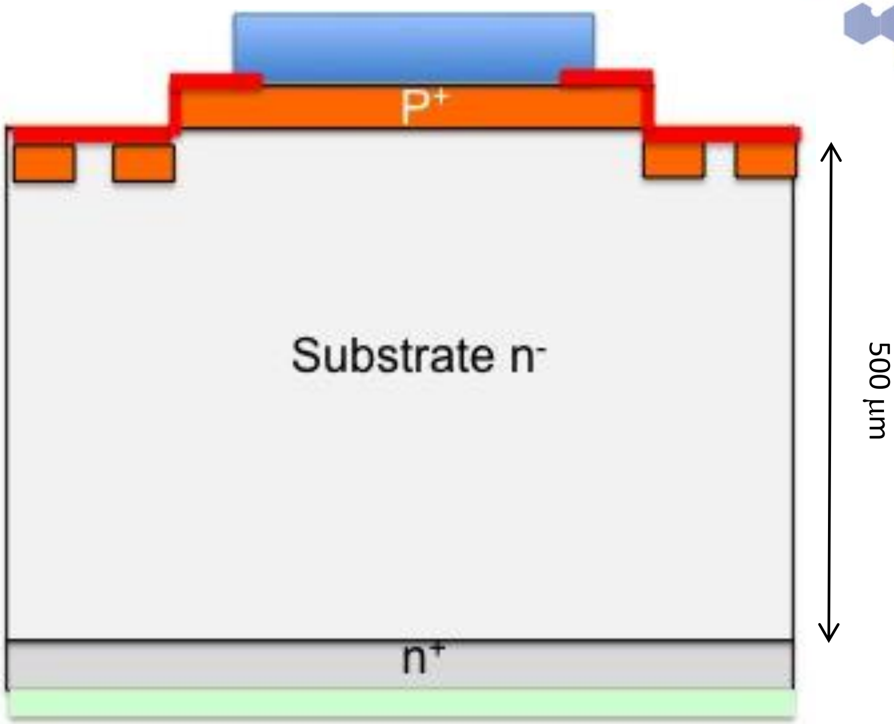
ΔE and E detectors

ΔE detector

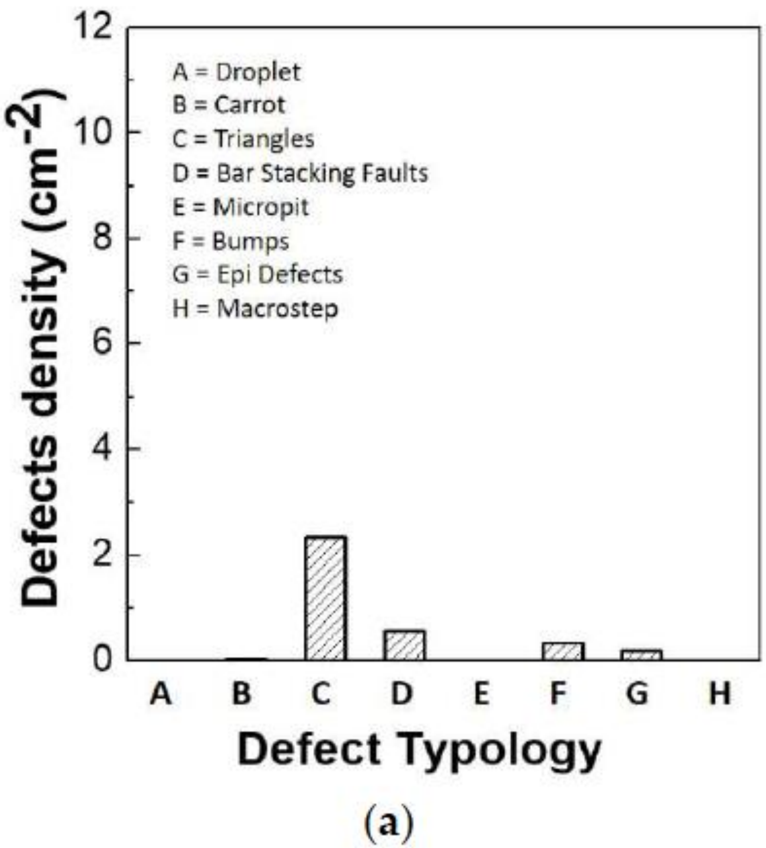


E detector

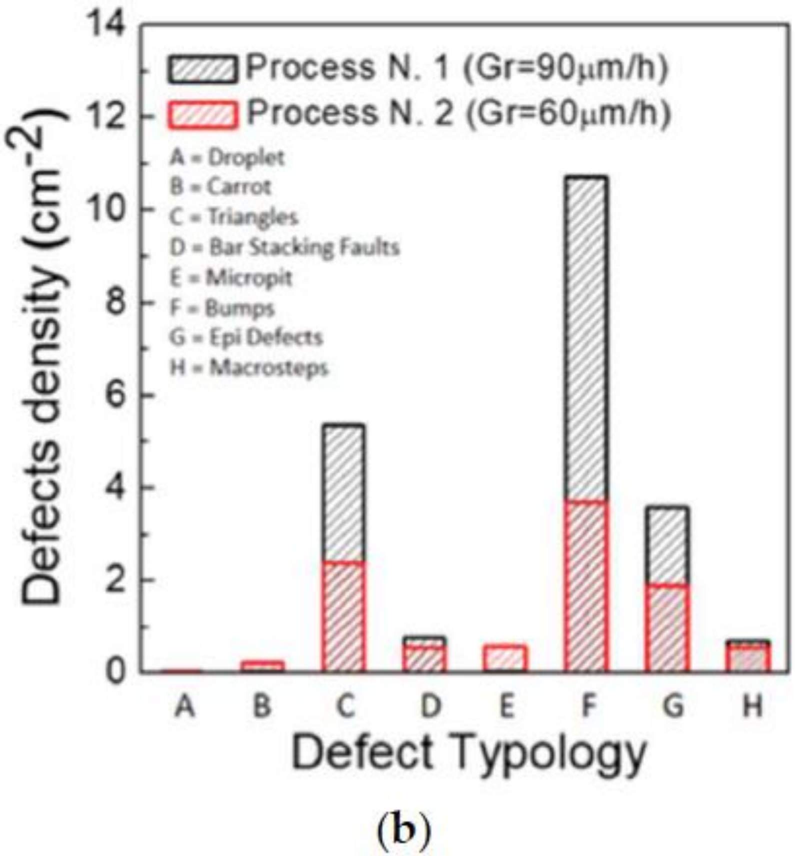


Defect density vs. epitaxial layer thickness

10 μm epitaxial layer thickness

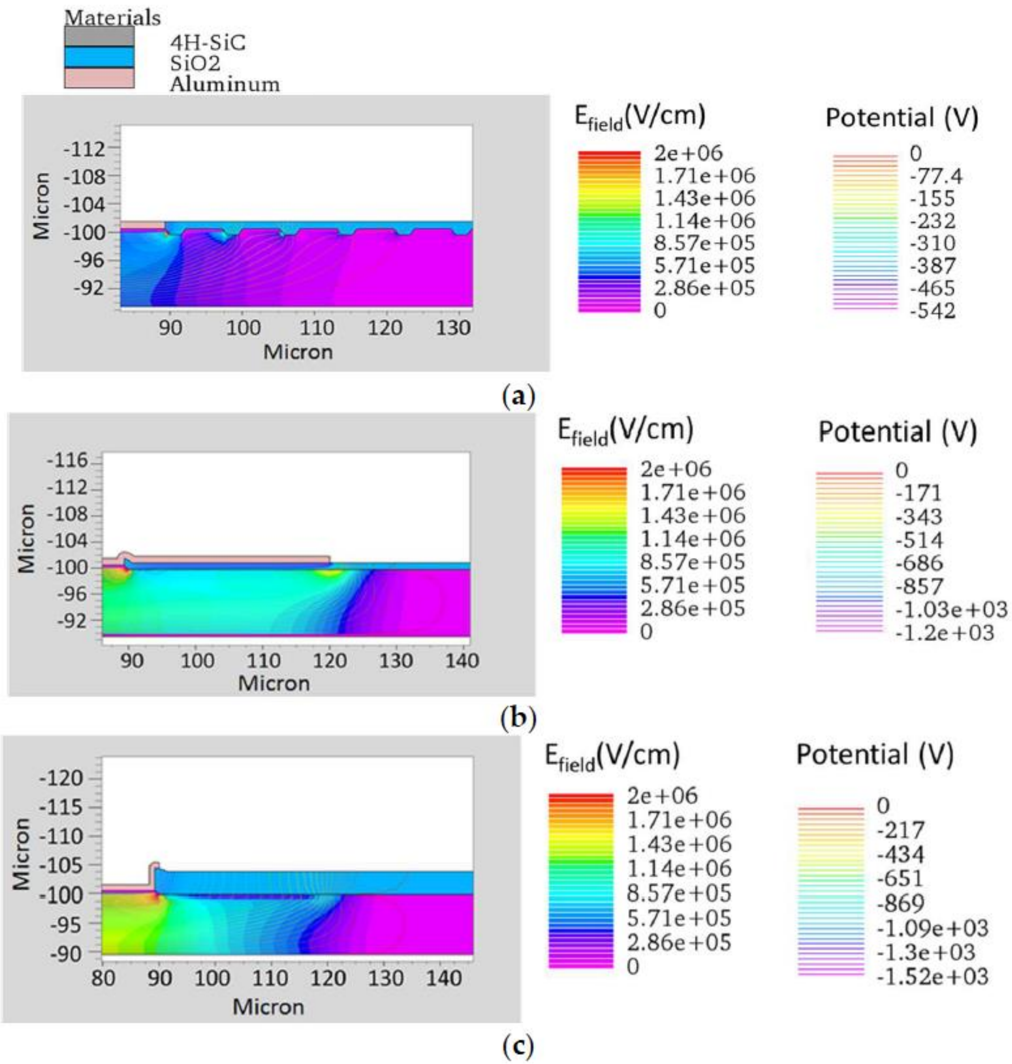


100 μm epitaxial layer thickness



S. Tudisco, F. La Via et al. Sensors 2018, 18, 2289; doi:10.3390/s18072...

ΔE edge structure



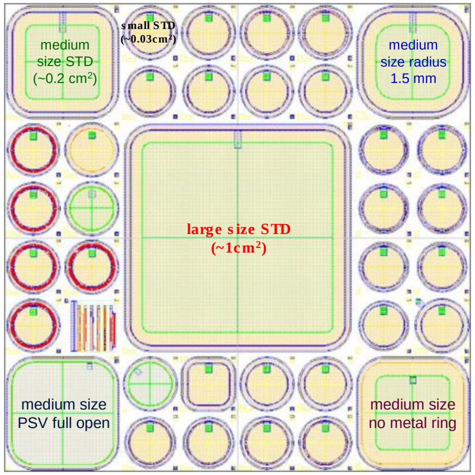
Three different edge structures have been simulated to find the optimal solution to have a breakdown voltage higher with respect to the voltage necessary to deplete all the epitaxial layer.

100 μm epitaxy ⟶ 750 V

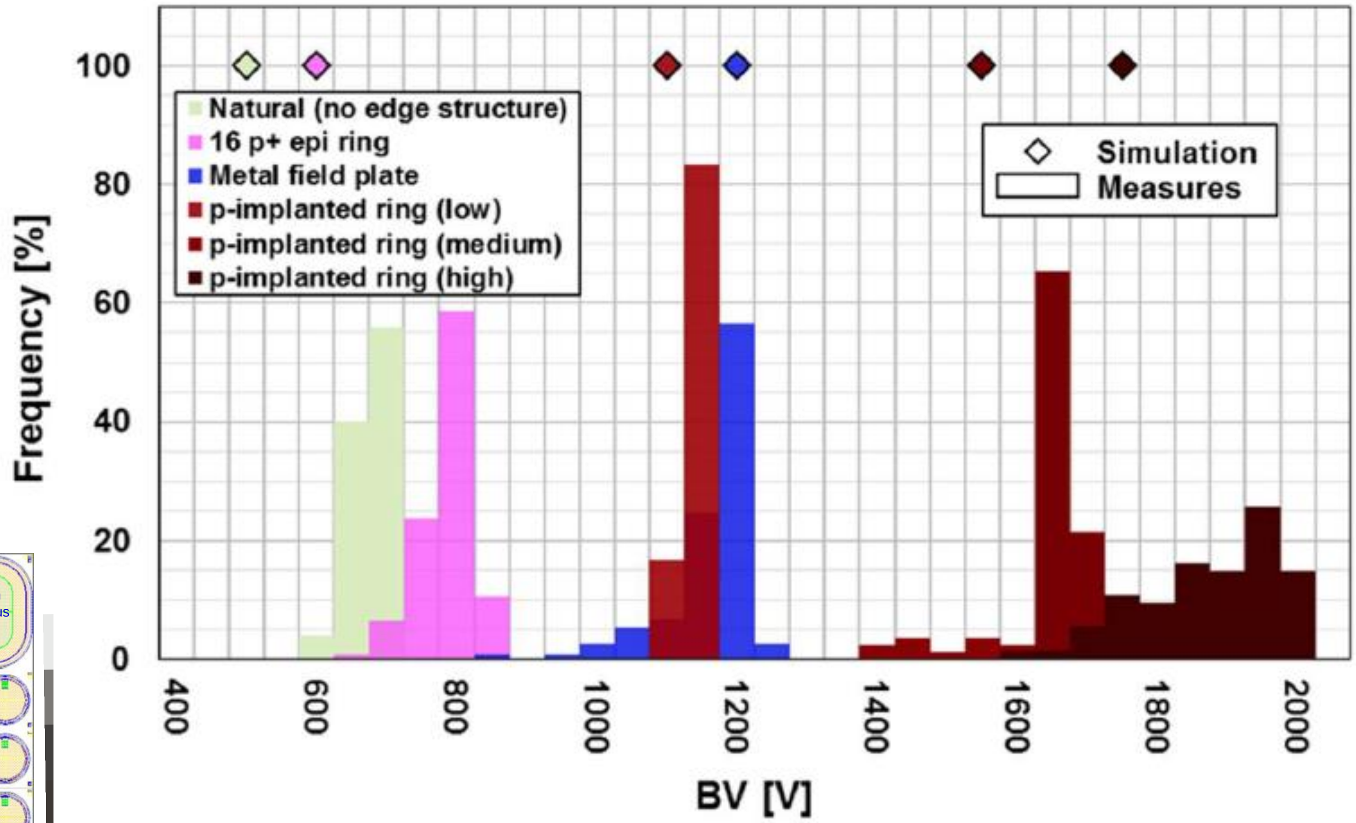
V_{BD} > 750 V

S. Tudisco, F. La Via et al. Sensors 2018, 18, 2289; doi:10.3390/s18072

Edge structure



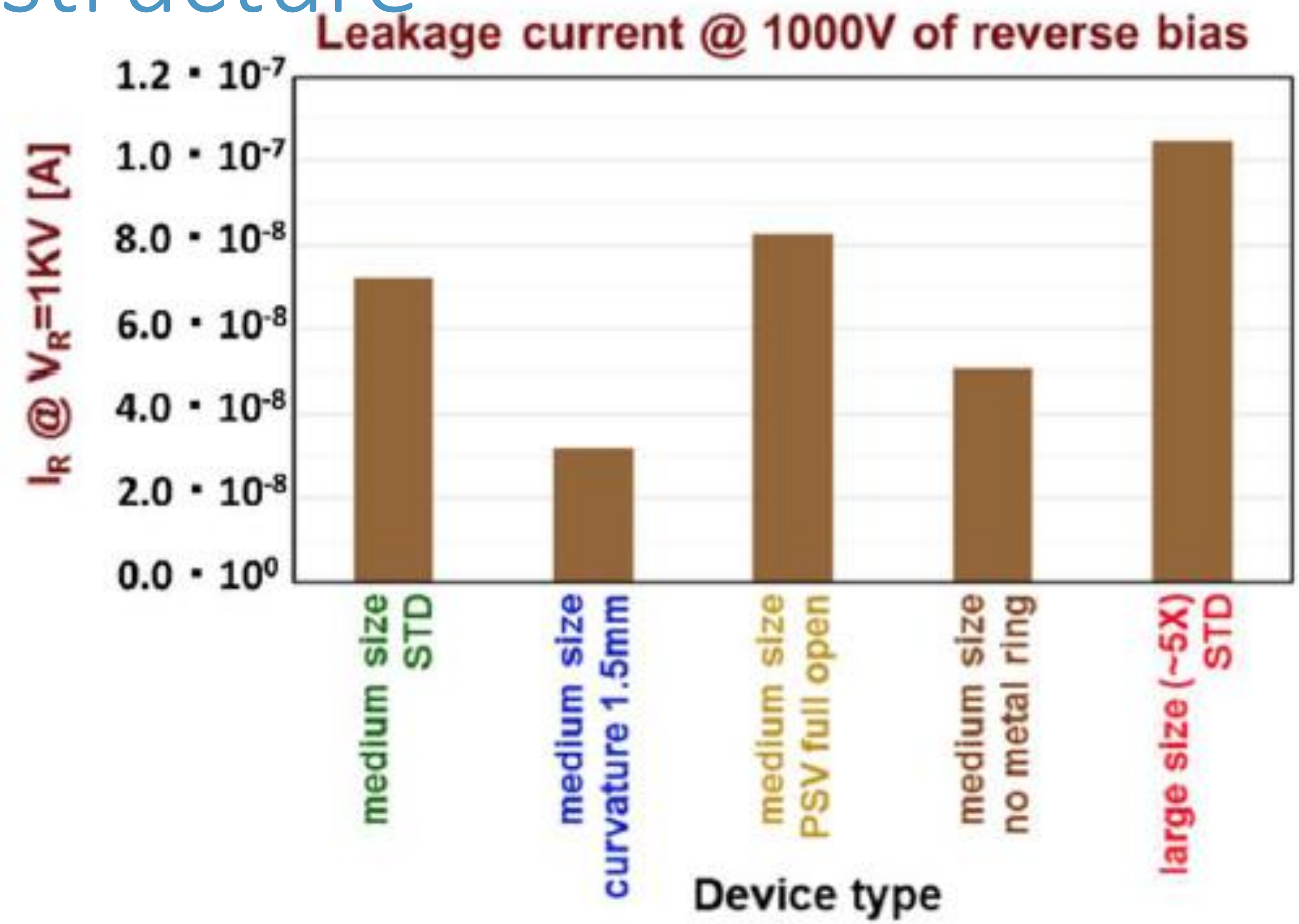
Single step layout view



Several edge structures have been simulated and tested

S. Tudisco, F. La Via et al. Sensors 2018, 18, 2289; doi:10.3390/s18072

Leakage current vs. edge structure

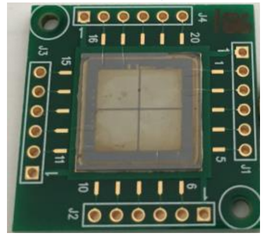


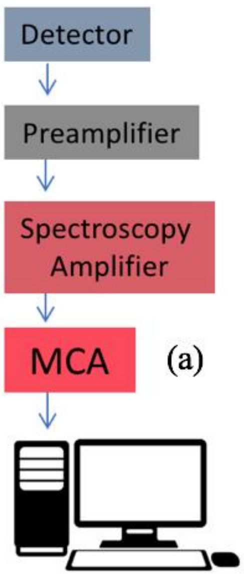
The leakage current has not dependence on the edge structure but only on the dimension of the detector

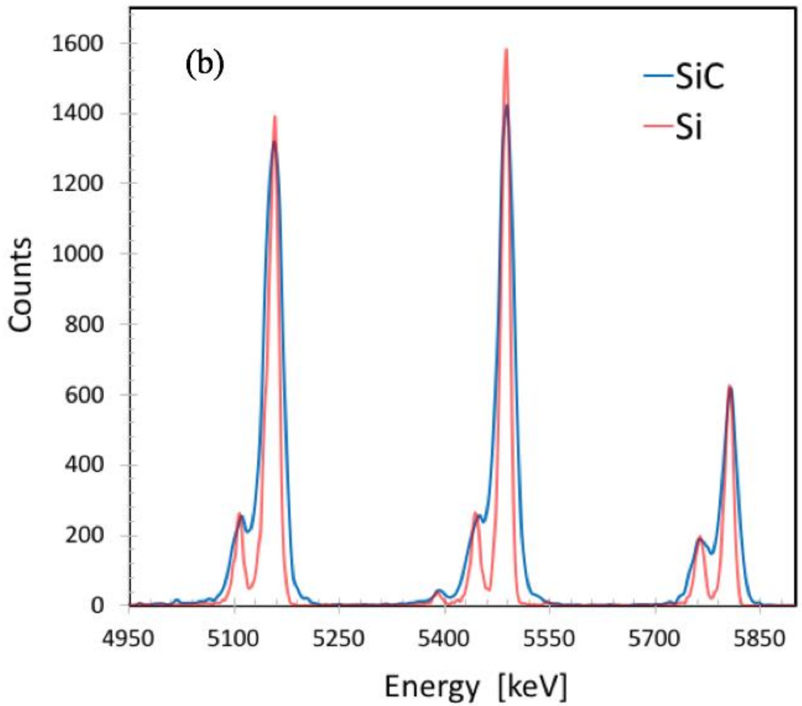
S. Tudisco, F. La Via et al. Sensors 2018, 18, 2289; doi:10.3390/s18072289

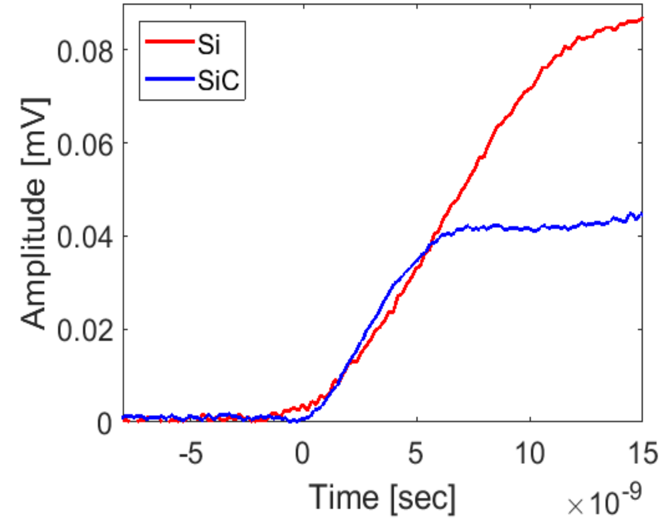
ΔE stage 100 μm

Energy measure









The amplitude of the signal is lower in SiC with respect to silicon

^{241}Am alpha Radioactive Source

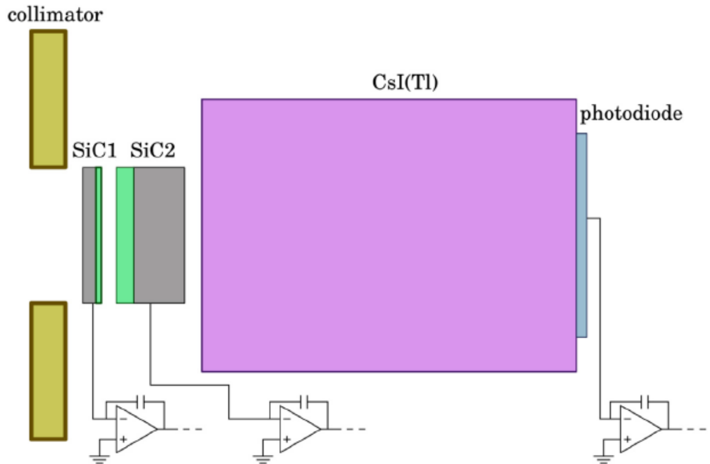
SiC = ➢ 42.8 keV FWHM (37.9 keV)
Si = ➢ 21.4 keV FWHM (17.1 keV)

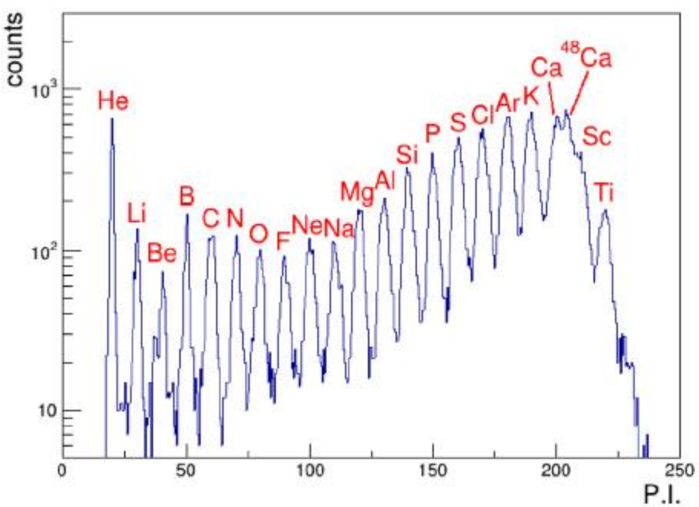
Electronic Noise

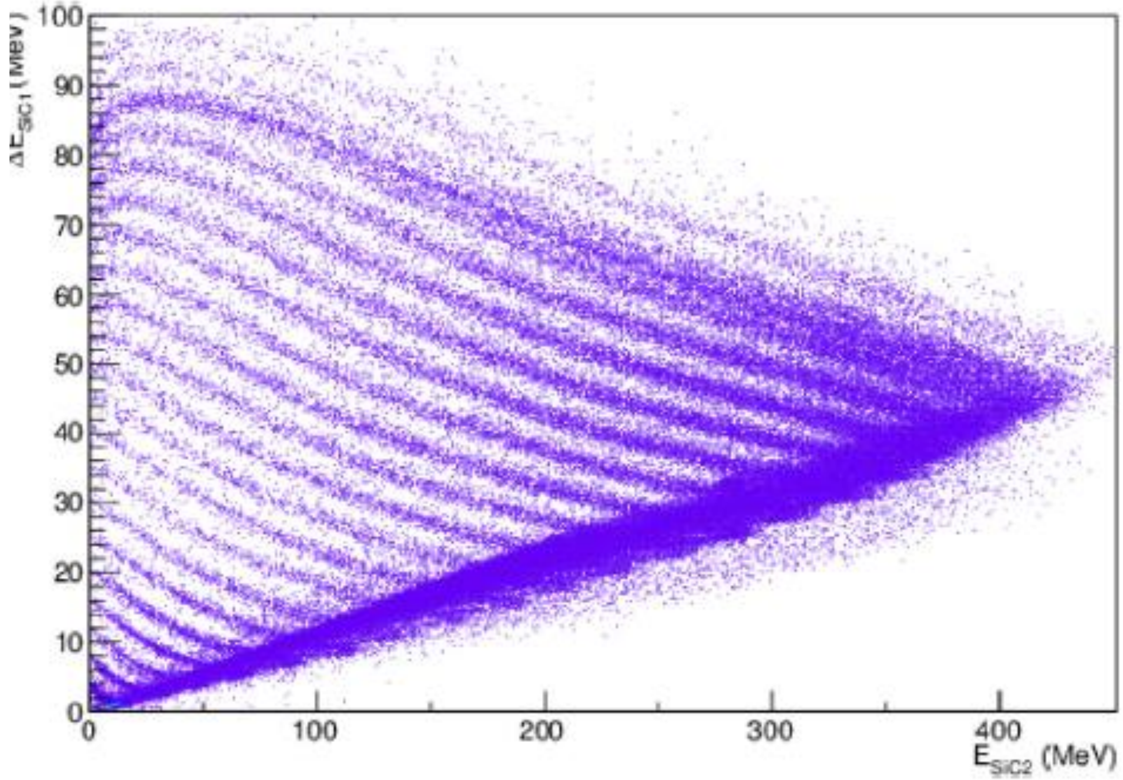
The resolution is worse in SiC but taking into account the electronic noise it becomes similar.

S. Tudisco, F. La Via et al. Sensors 2018, 18, 2289; doi:10.3390/s18072289

ΔE-E telescope







Good particles and isotopes identification has been obtained.

C. Ciampi, G. Pasquali, Nuclear Inst. and Methods in Physics Research, A 925 (2019) 60–69

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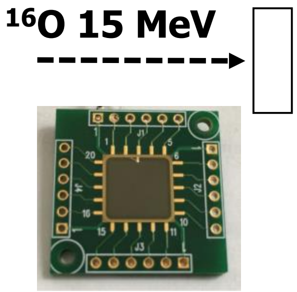
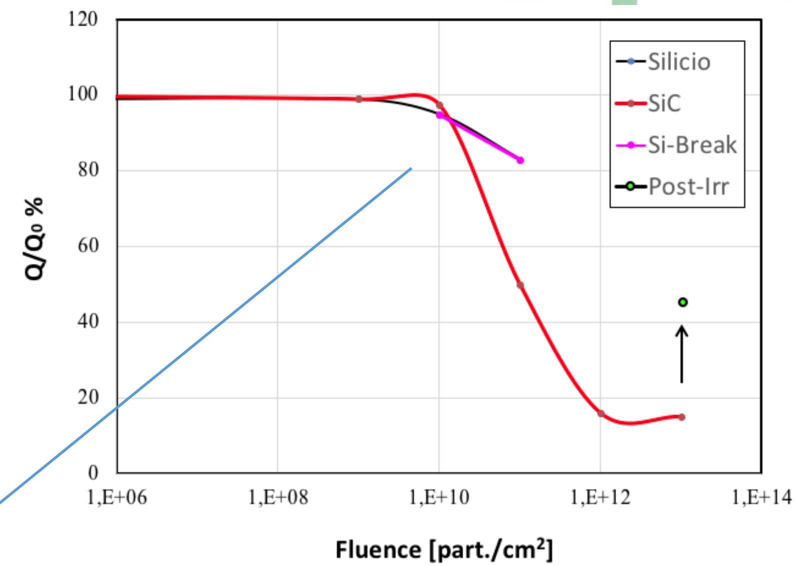
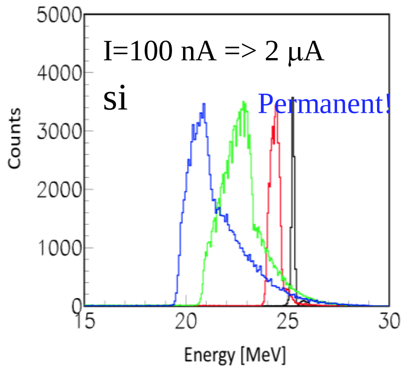
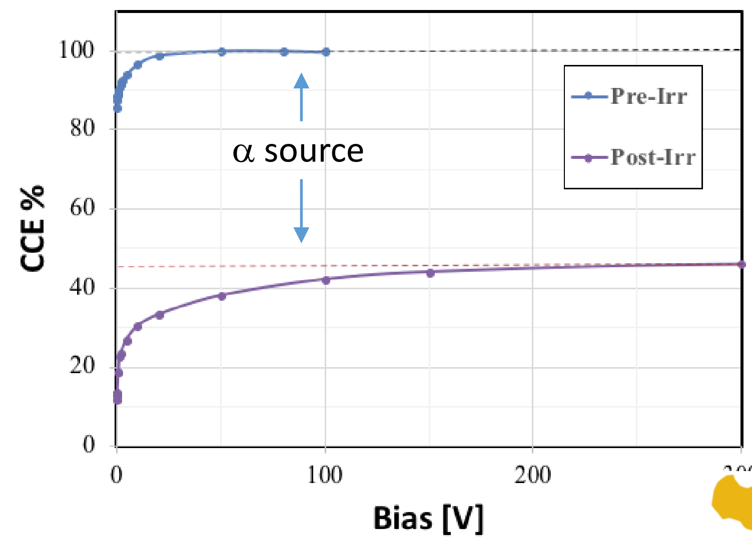
Radiation hardness





10^{13} Ions/cm^2





While Si detectors deteriorate permanently after 10^{11} ions/cm^2, SiC detectors are working even after 10^{13} ions/cm^2 and after a break a considerable improvement is observed.

S. Tudisco, F. La Via et al. (in press)

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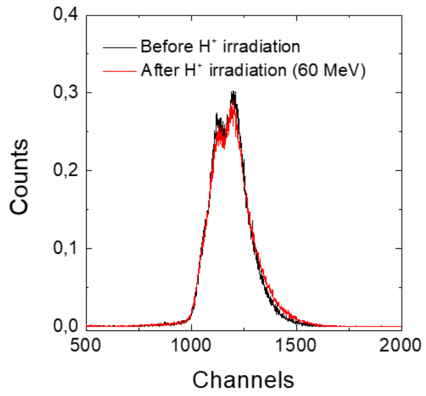
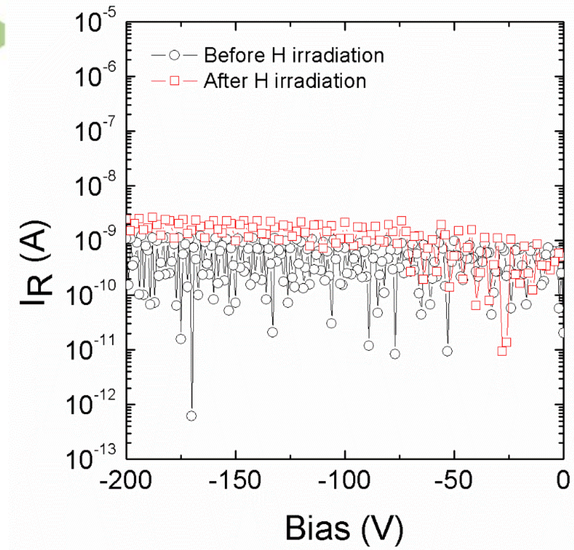
Dosimetry

LNS Catana line

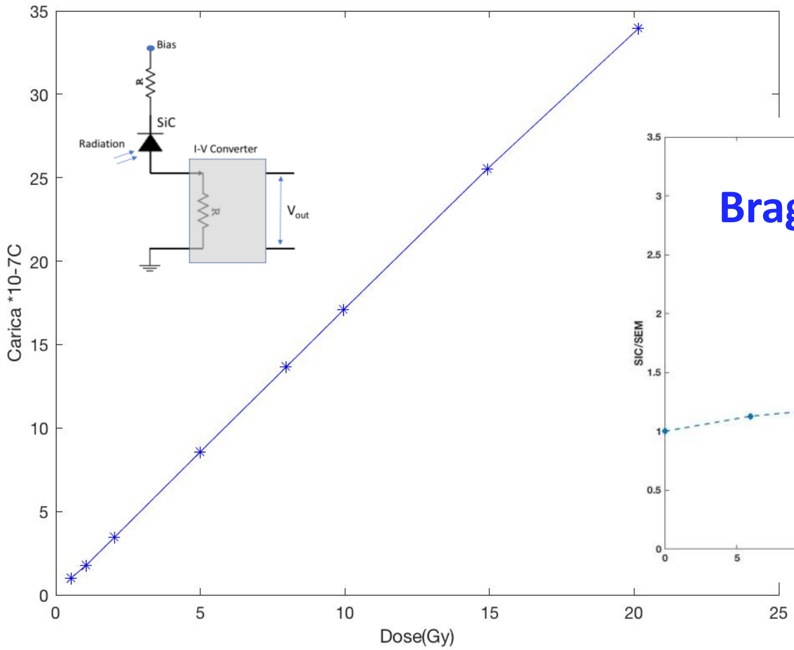
60 MeV H^+ → SiC 10µm 1x1 cm^2

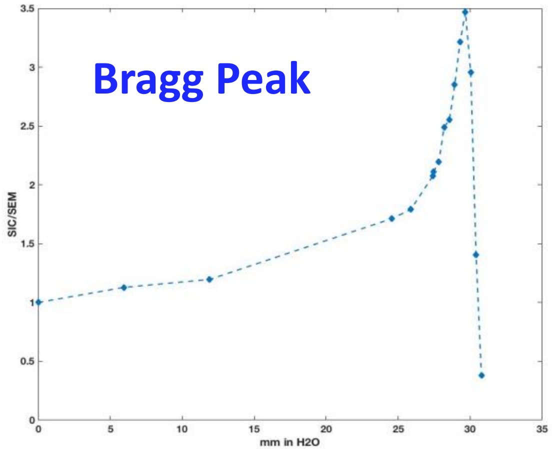
2KGy (2.5×10^{12} H^+/cm^2)

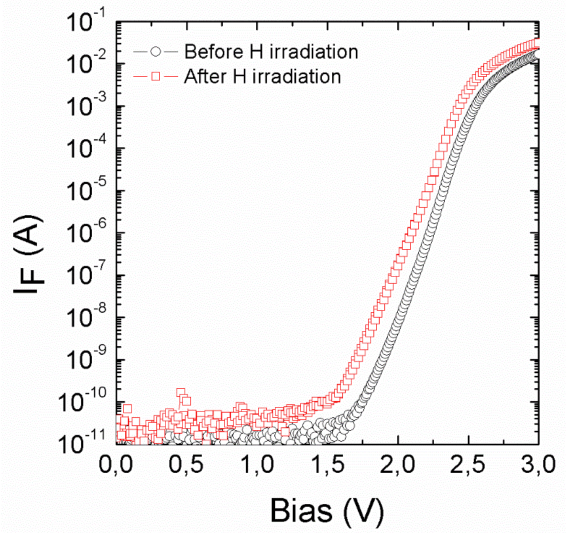




Dose Measure







Good radiation hardness

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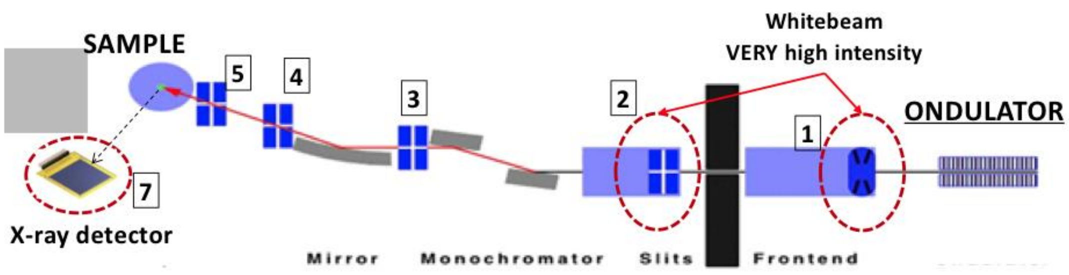
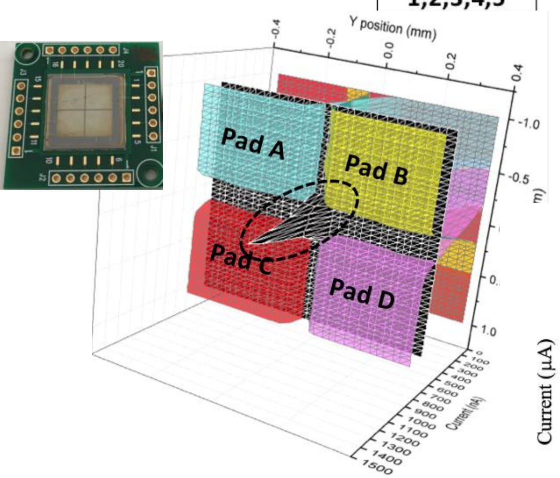
Application of SiC for X-Ray detection in synchrotrons

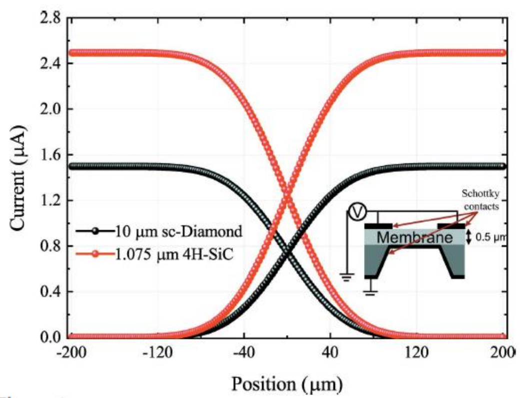
PAUL SCHERRER INSTITUT

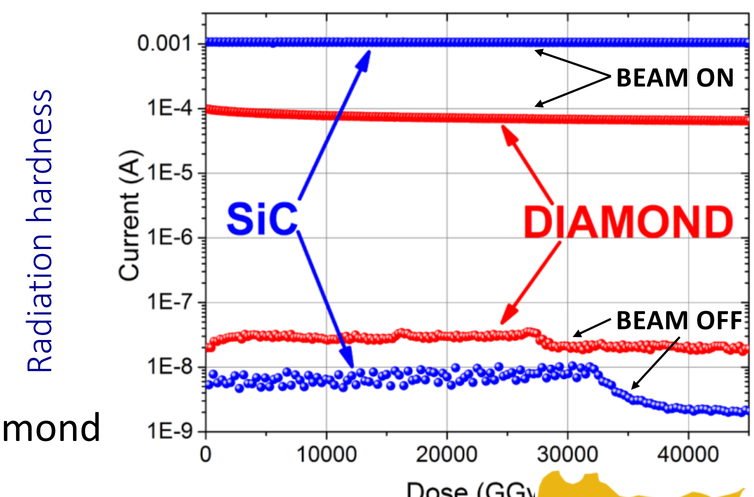


Beam Position Monitor (XBPM) 1,2,3,4,5
- Transparency
- Extreme radiation hardness
- Fast response



X-ray beam 10x10 µm², 5E10 ph/sec @ 12.4keV





SiC has higher signal to noise ratio and it is faster than diamond

M. Camarda et al. J. Synchrotron Rad. (2019). 26, 28–35

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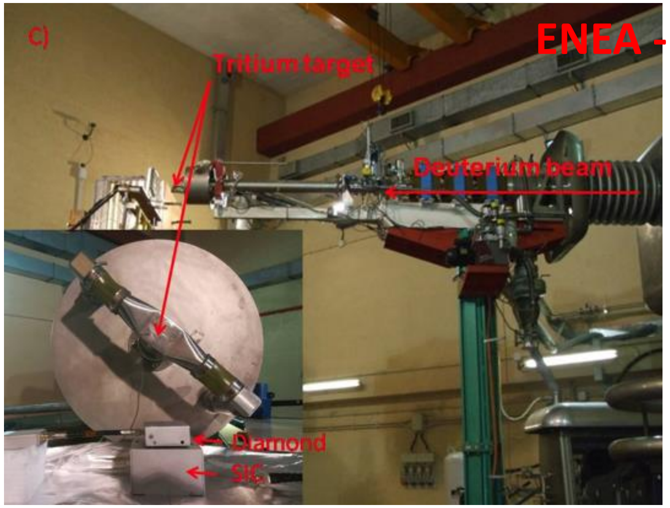
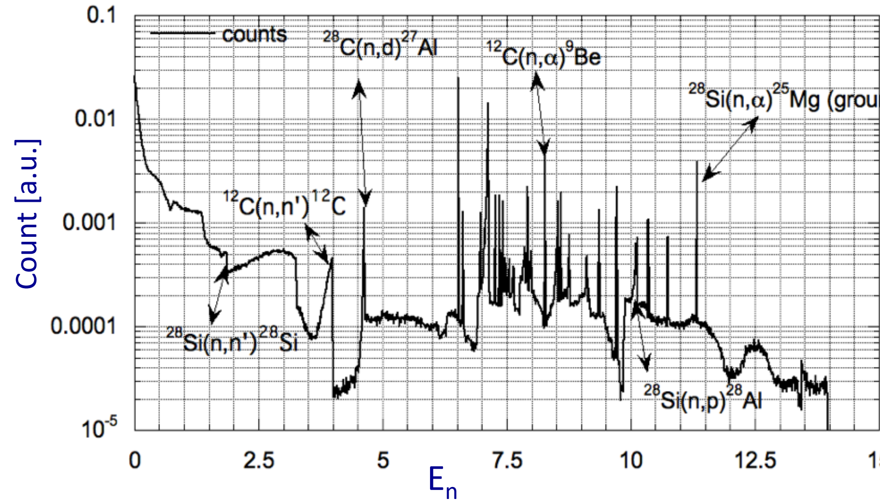
Neutron detection

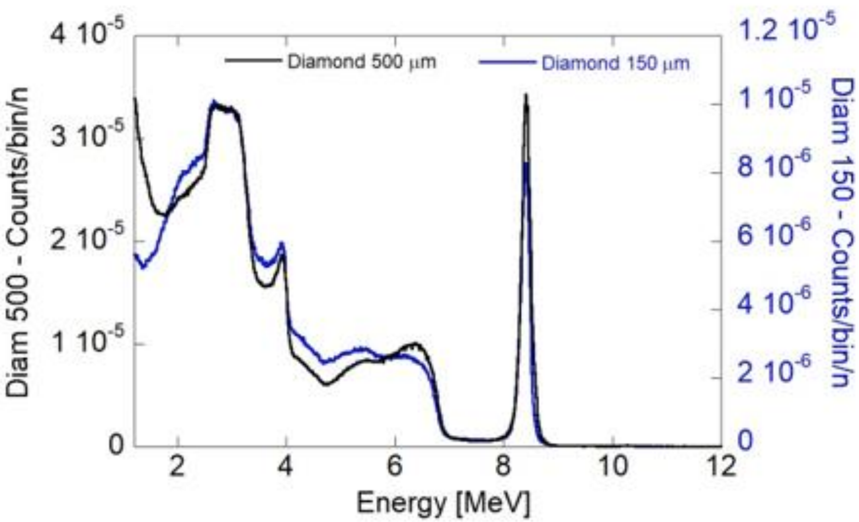
FNG
ENEA - Frascati

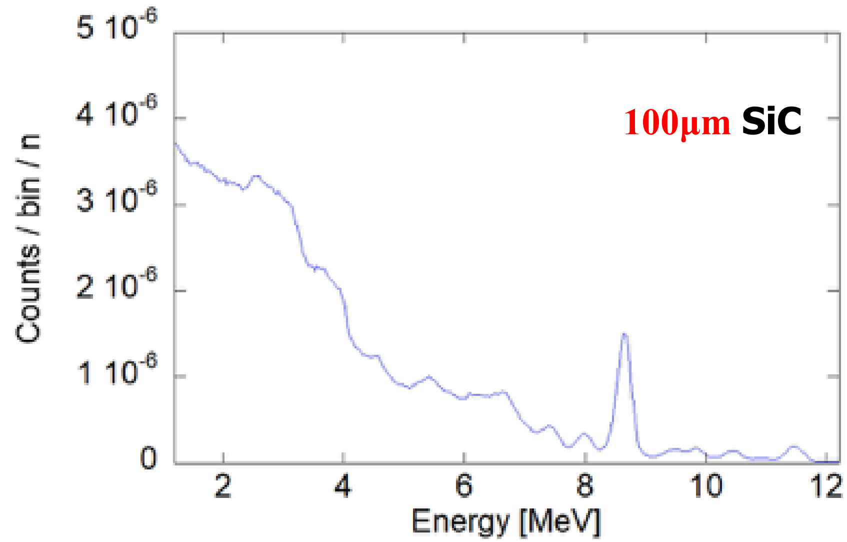


Simulation MCNPX deposited energy in SiC by14 MeV neutrons



Ed<4 MeV contribution of the elastic recoils on ^{12}C e ^{28}Si.
Ed>5 MeV contribution of the anelastic recoils on ^{28}Si e ^{12}C.





Similar resolution between diamond and SiC detectors can be observed

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Summary

- In SiCilia new SiC detectors for high energy particles with good resolution and good radiation hardness have been obtained.
- Several applications have been tested (X-Ray detectors in synchrotrons, dosimetry, neutron detectors) where the high radiation hardness of these detectors can be interesting.

OUTLOOK

- The E detector structure will be optimized in the next months.
- The ΔE detector process will be optimized.