Challenges of SiC technology for high radiation hardness detectors

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Outline

- Introduction
- Defects production by ion irradiation
    - Low fluence regime
    - High fluence regime
- Efficiency of point defects production
- SiC vs. Si radiation hardness
- Challenge for SiC detectors production
- Conclusions

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Introduction

M.Moll , NIM in Physics Research A 511 (2003) 97–105

Property	Diamond	GaN	4H SiC	Si
E_g [eV]	**5.5**	**3.39**	**3.26**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4 \cdot 10^6$	$2.2 \cdot 10^6$	$3 \cdot 10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2 \cdot 10^7$	-	$2 \cdot 10^7$	$0.8 \cdot 10^7$
Z	6	31/7	14/6	14
ε_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**	**≥15**	**25**	**13-20**

- Wide bandgap (3.3eV)

⇒ lower leakage current than silicon

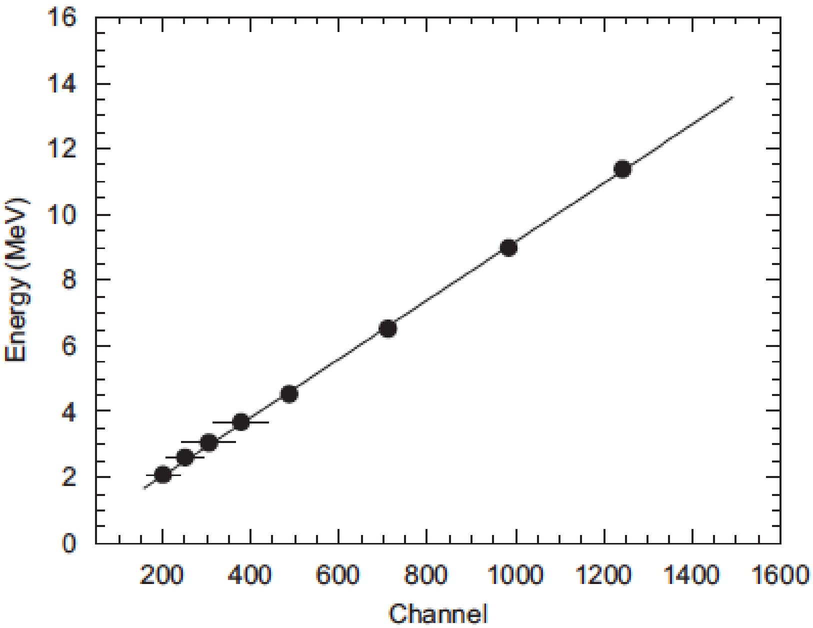
- Signal (**for MIP !**):
  Diamond 36 e/μm
  SiC 51 e/μm
  Si 89 e/μm

⇒ more charge than diamond Si/SiC≈2

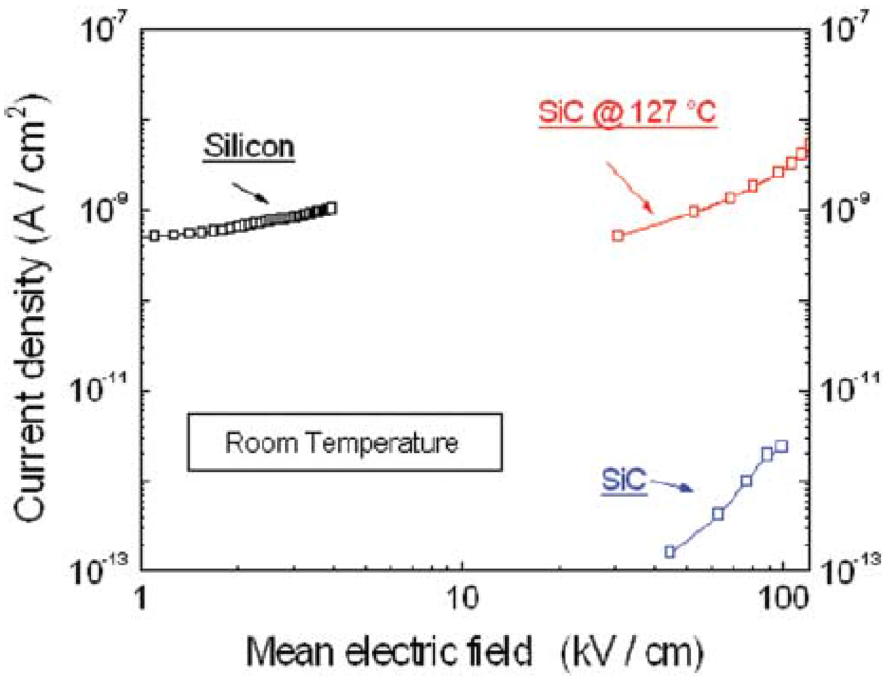
- Higher displacement threshold than silicon

⇒ radiation harder than silicon

SiC detectors



De Napoli et al. NIM A, 572 (2007), 831
CNR-IMM detector



L. Calcagno et al. Radiation Effect & Defects in Solid, 170(4), (2015) 303
CNR-IMM detector

High linearity

Low noise

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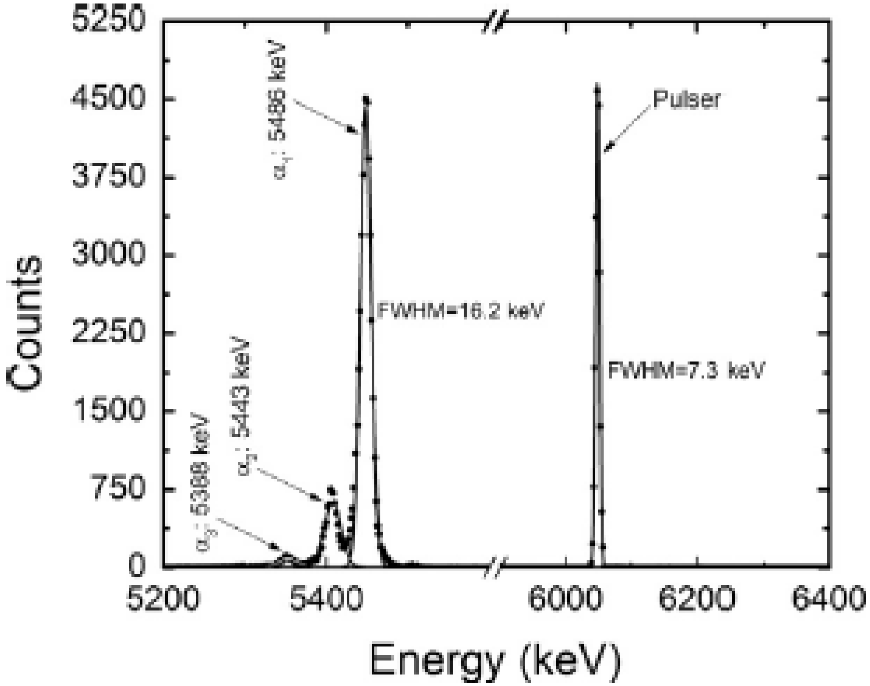
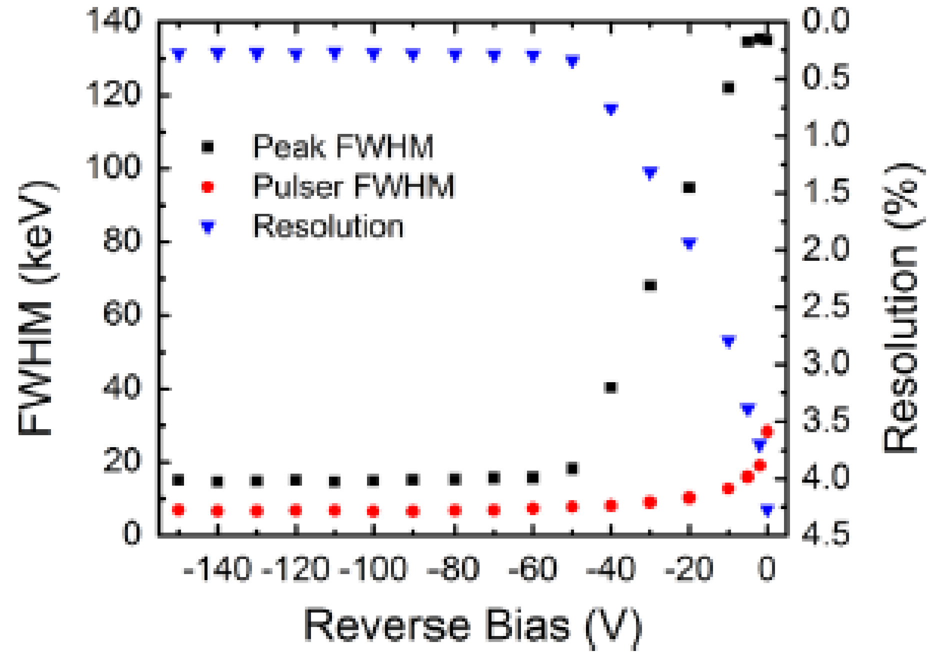
SiC detectors



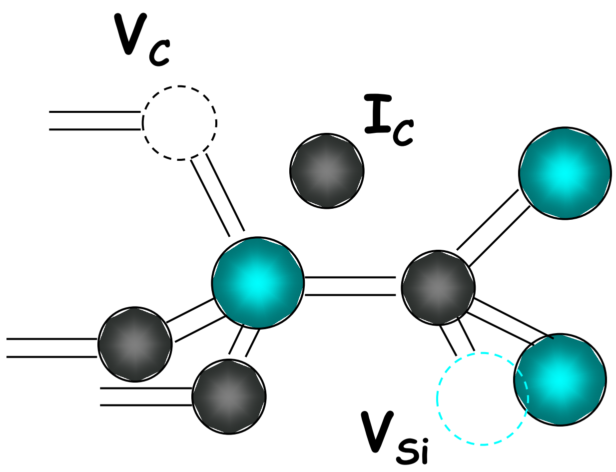


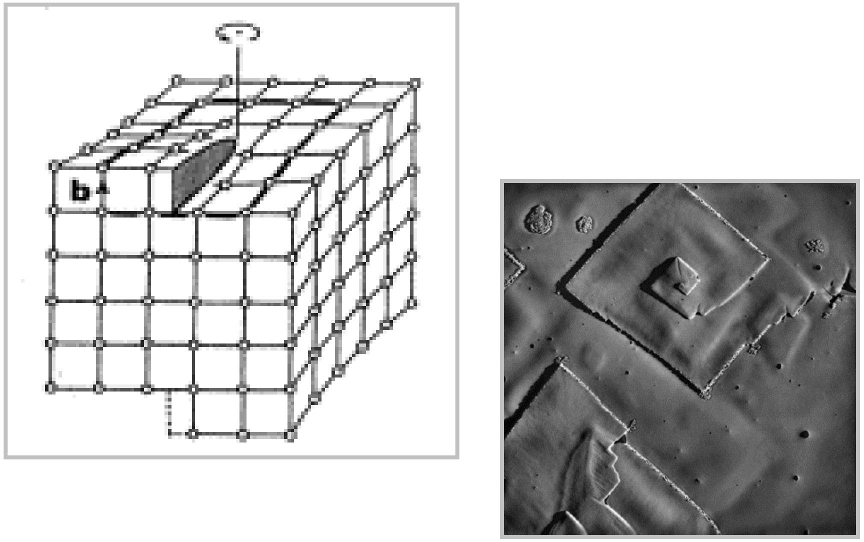
S.K. Chaudhuri et al. / Nuclear Instruments and Methods in Physics Research A 728 (2013) 97–101

Intrinsic detector resolution 14.5 KeV (0.2%)

Effects of ion irradiation

Ion irradiation can produce defects in the crystal lattice of the semiconductor



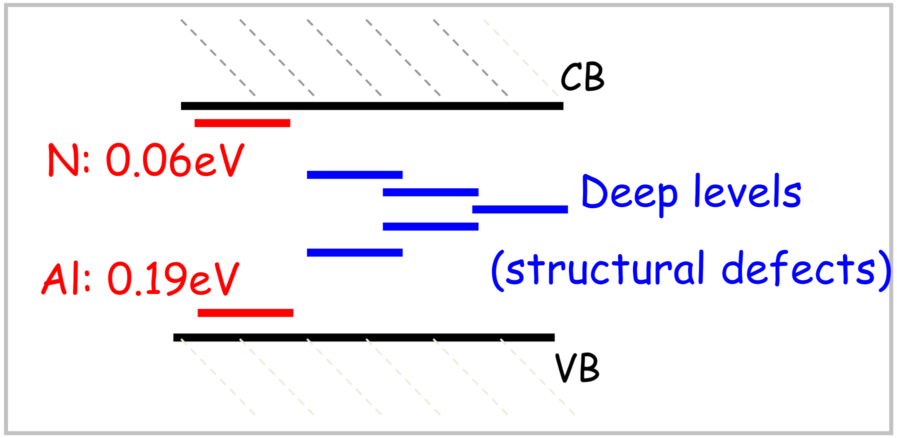


Point defects
(vacancies, interstitial, antisites, etc…)

Extended defects
(dislocations, etc…)

Effect of defects on the detectors

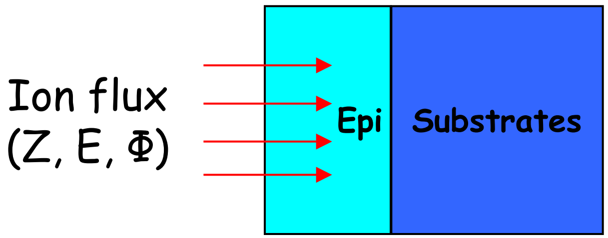
The defects in the lattice produce some levels in the band-gap



Increasing the density of these levels with the increasing of the ion dose, the characteristics of the detectors deteriorate

- Charge Collection Efficiency (CCE)
- Resolution (FWHM)

Radiation induced defects



4H-SiC homo-epitaxial layers:
- Point defects < 10^{11} cm^{-3}
- Extended defects < 10^{5} - 10^{7} cm^{-2}

Low Fluence Regime:

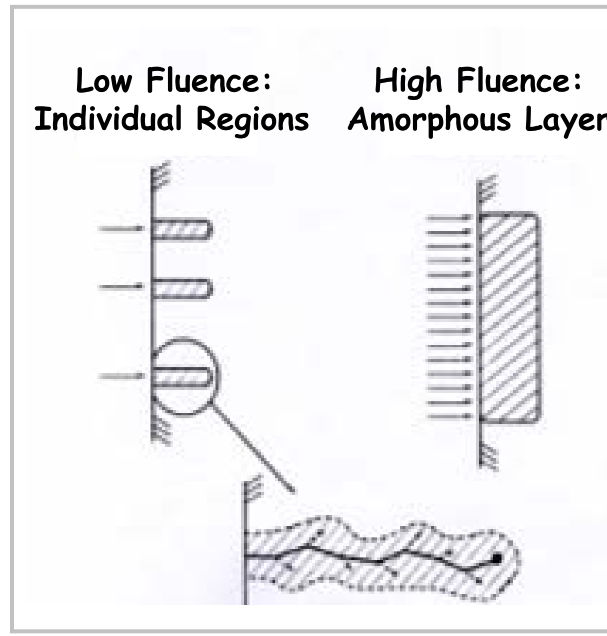
$10^{9} < \Phi < 10^{13}$ ions/cm^2

↓

point defects & defects cluster

< 10^{18} defects/cm^3

(DLTS, LTPL …)



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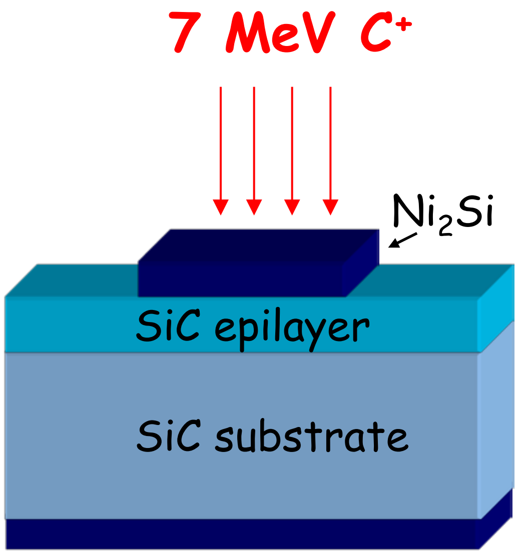
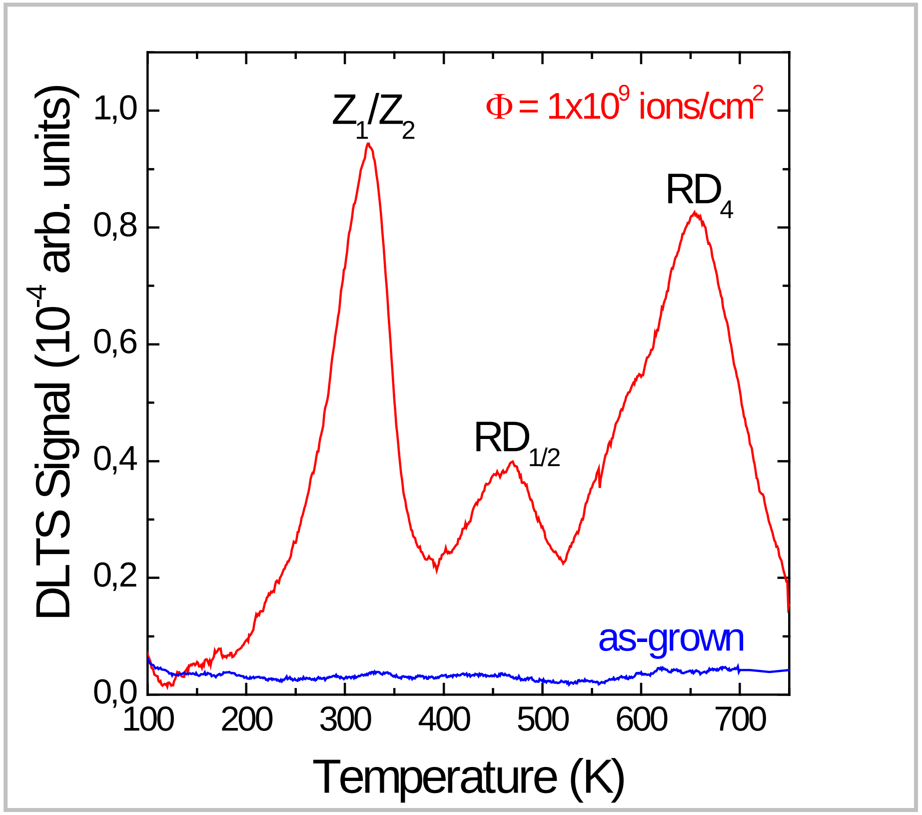
Analisys of the radiation induced defects by DLTS



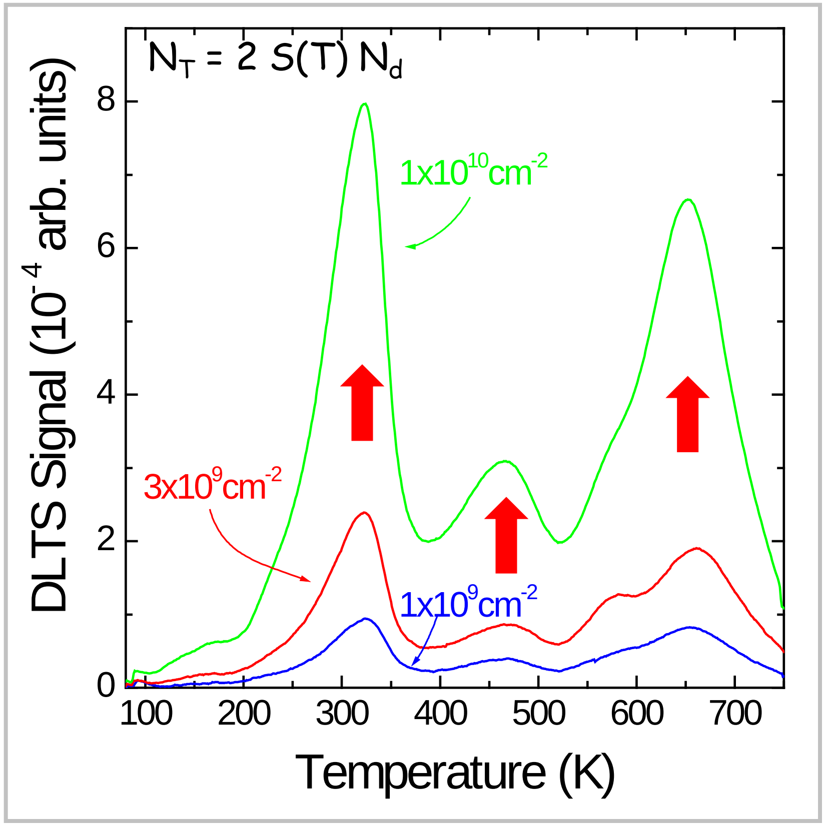
Schottky Diode

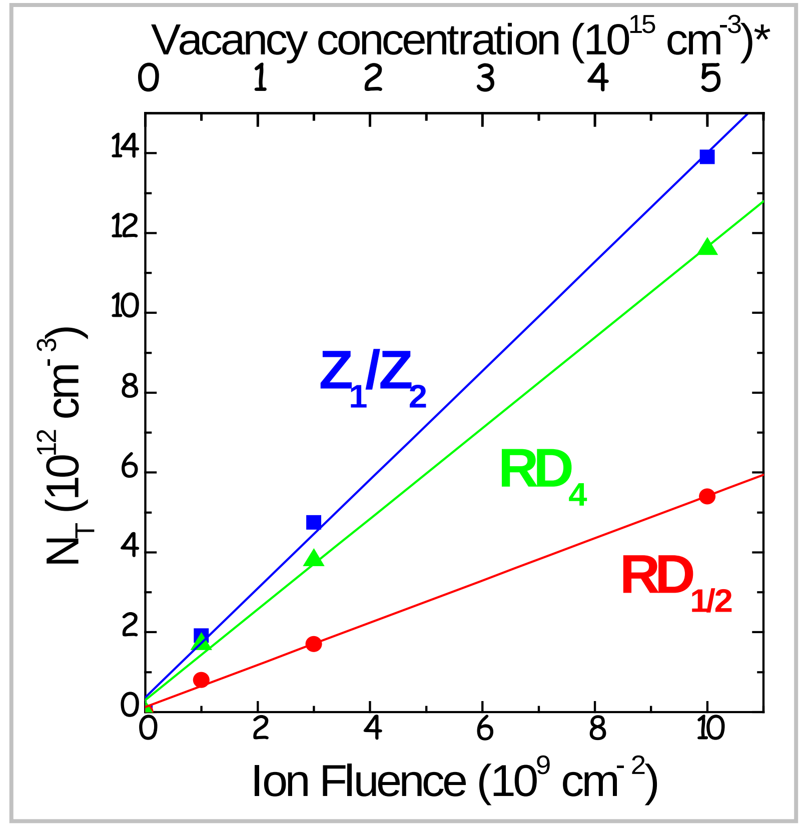
$\Phi = 1 \times 10^9 - 5 \times 10^{13}$ ions/cm^2

$[V]^* = 10^{14} – 10^{19}$ vacancies/cm^3



Defects vs. ion dose





POINT DEFECTS

- *Z_1/Z_2: ($V_{Si/C}$, Si_C, C_{Si}, C_i)***
- *$RD_{1/2}$: (V_c+V_{Si})***
- *RD_4: (V_C)***

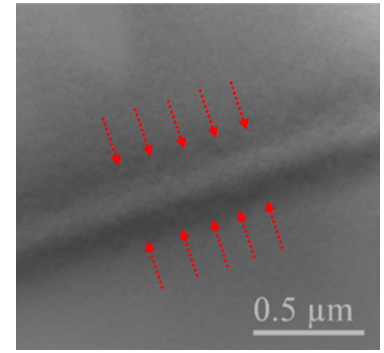
** From literature

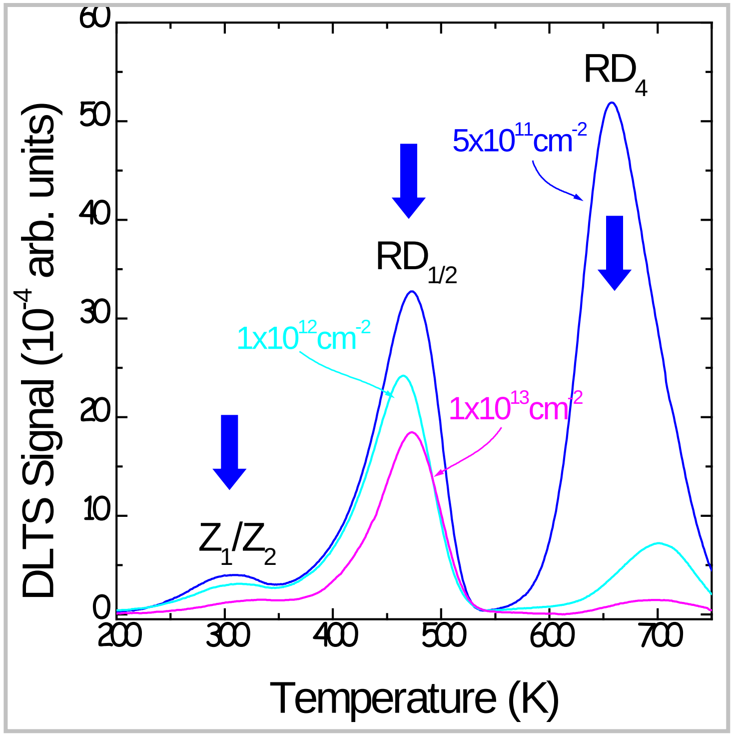
Increasing ion dose the point defects increase linearly

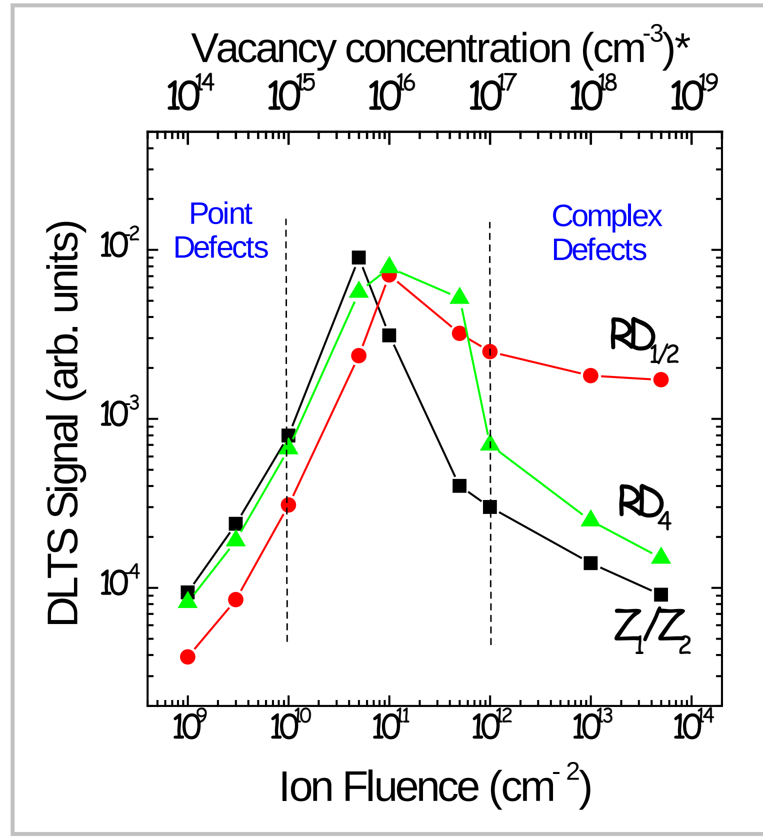
High fluence regime

$\Phi = 5 \times 10^{10} - 5 \times 10^{13}$ ions/cm^2

TEM







POINT DEFECTS CLUSTERS

G. Litrico et al. Mater. Sci. For. Vols. 615-617, (2009), pp. 397-400

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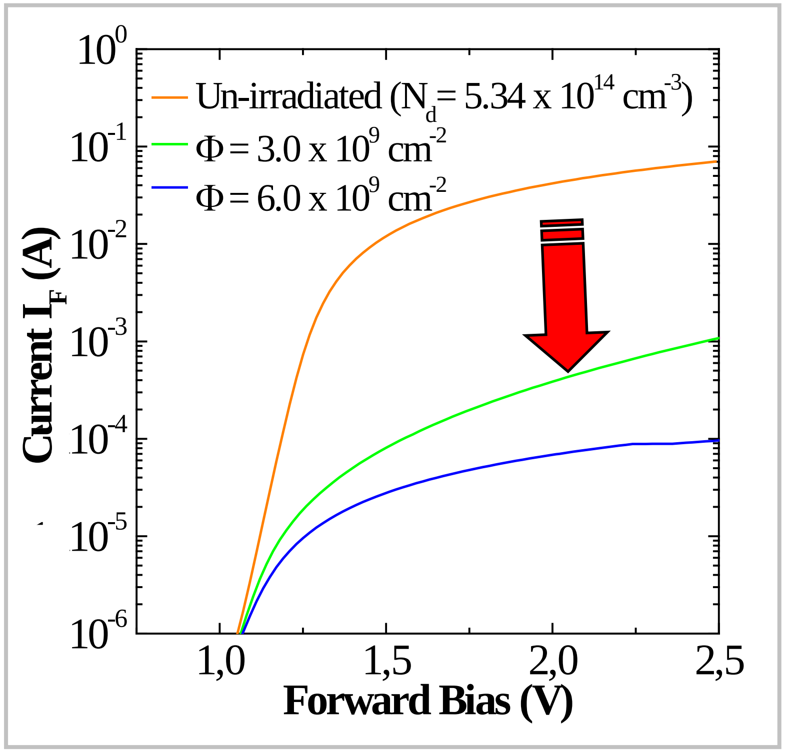
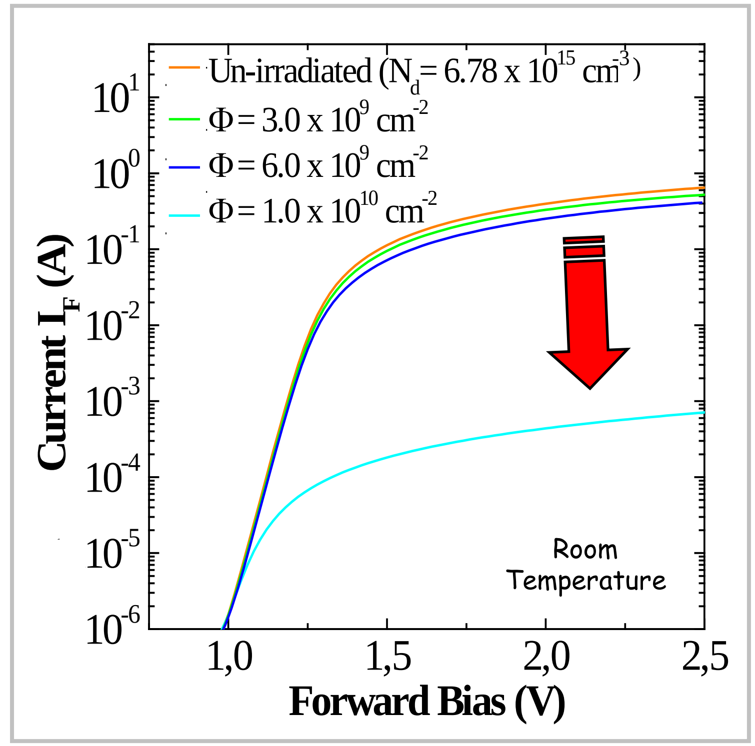
Effect of radiation induced defect on I-V characteristics

7 MeV C^+





Increasing the doping of the epitaxial layer the effect on the doping compensation decreases.

G. Litrico et al. J. Appl. Phys. Vol. 104 (2008) p. 093711

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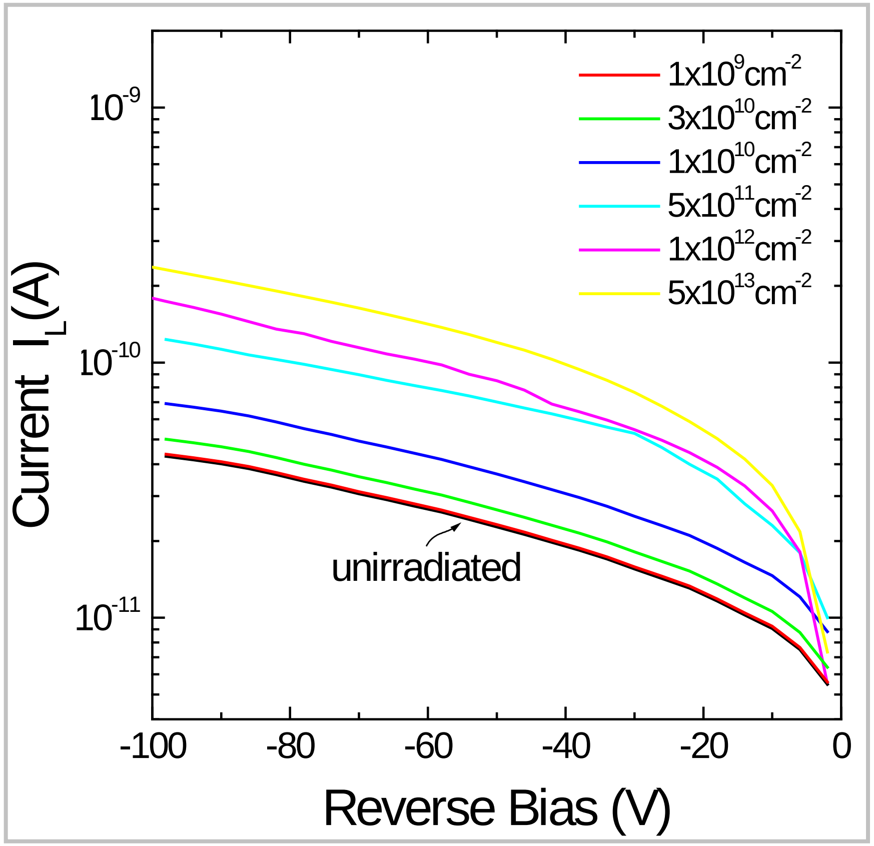
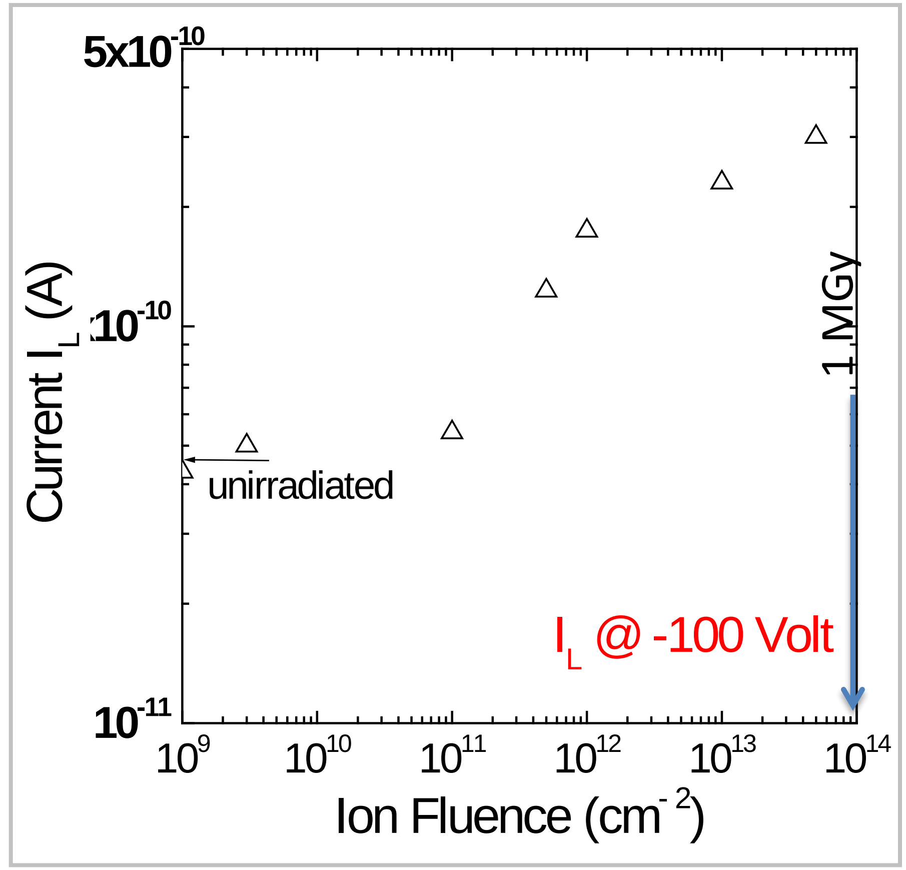
Effect of radiation induced defect on I-V characteristics





A fluence of 10^{14}/cm^2 is needed to have an increase of the leakage current of one order of magnitude

Efficiency of point defects production

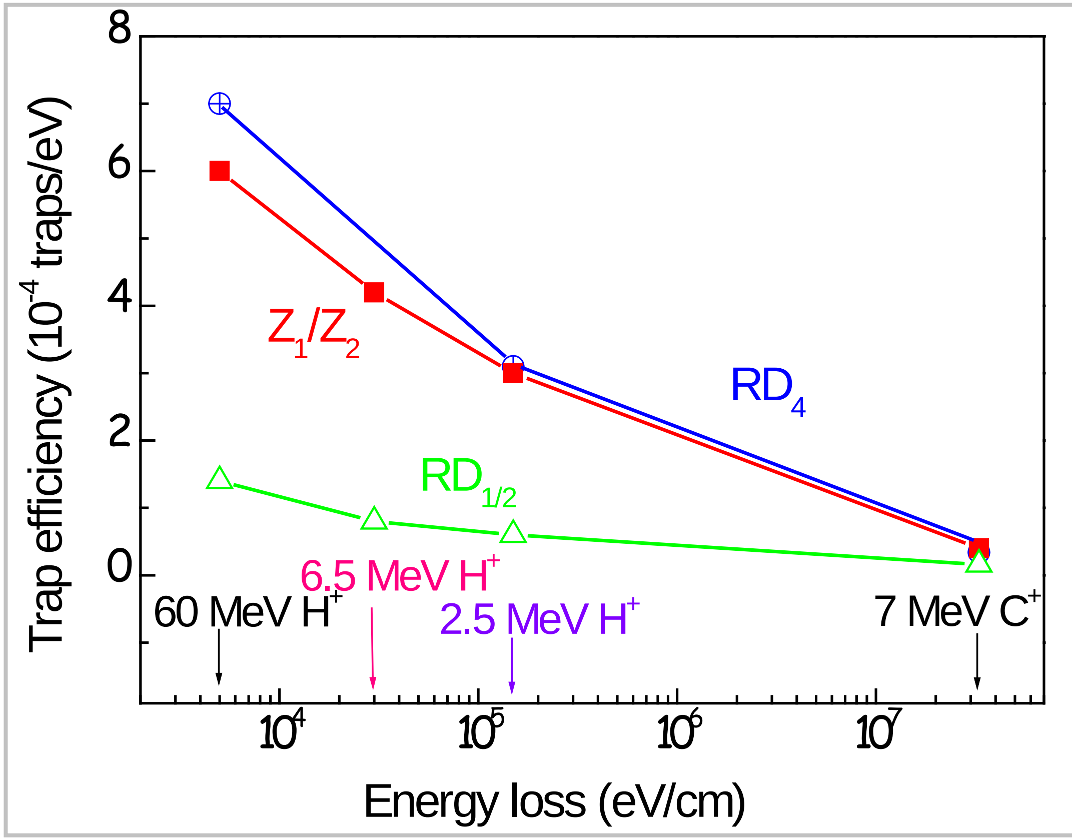
INTRODUCTION RATE $\eta = \dfrac{N_T}{\Phi}$ [traps/cm]

- ion mass
- energy

$\eta\ (Z_1/Z_2)$ { 1363 traps/cm 7 MeV C^+ ; 3 traps/cm 60 MeV H^+ }

TRAPS PRODUCTION EFFICIENCY

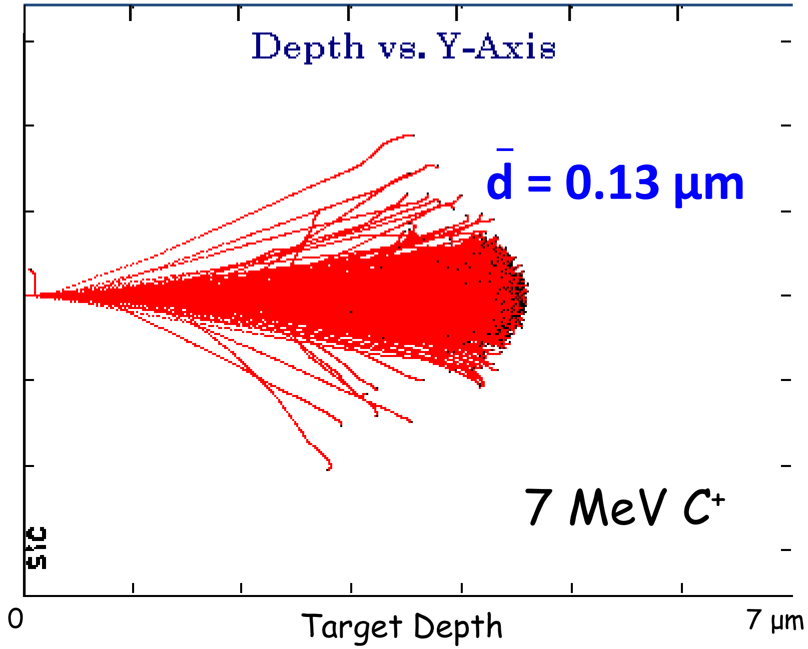
$$\varepsilon = \frac{\eta}{S_n} \quad \text{[traps/eV]}$$

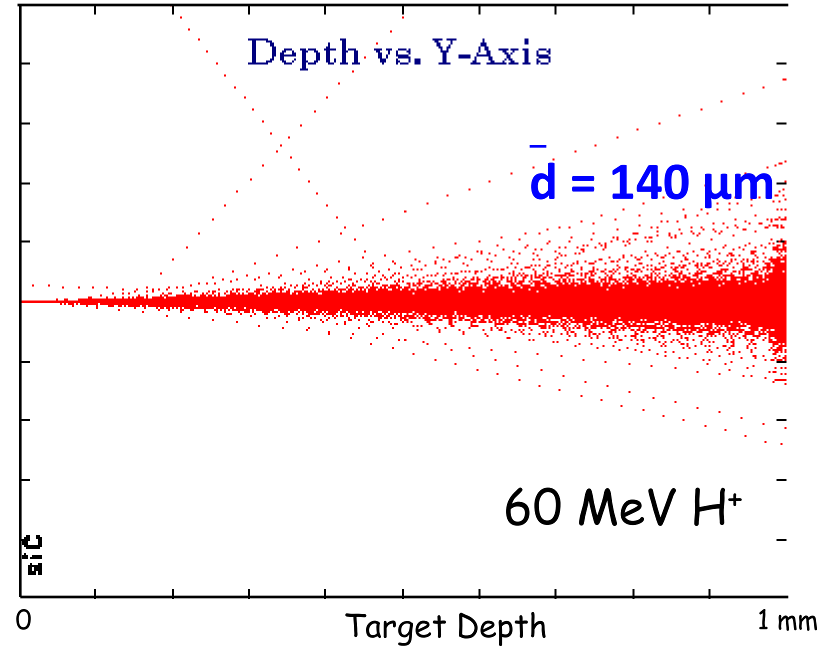


L. Calcagno et al. / Nucl. Instr. and Meth. in Phys. Res. B 257 (2007) 279–282

Efficiency of point defects production

Ion track effect





low distance between primary defects

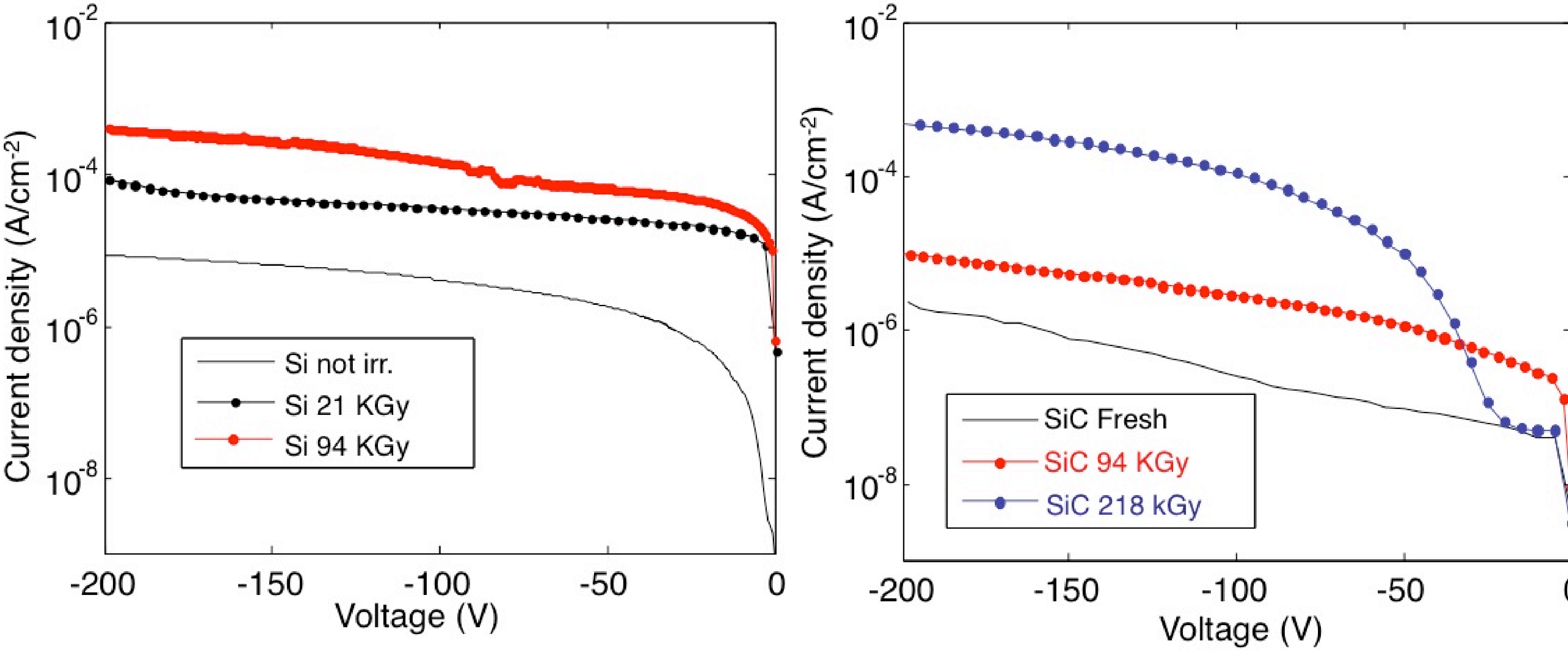
defects recombination
(LOW ε)

high distance between primary defects

no defects recombination
(HIGH ε)

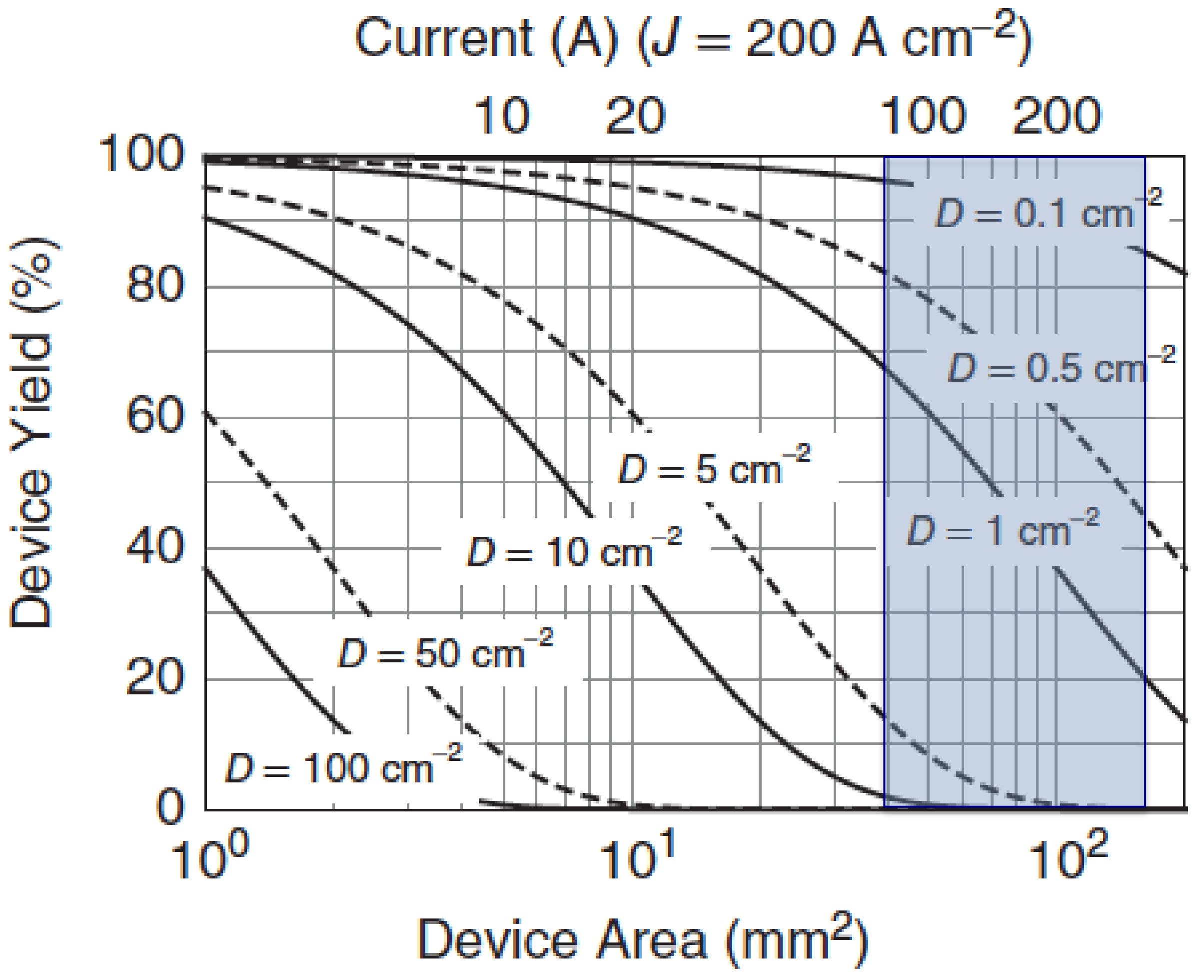
SiC vs. Si radiation hardness

740 MeV C^+



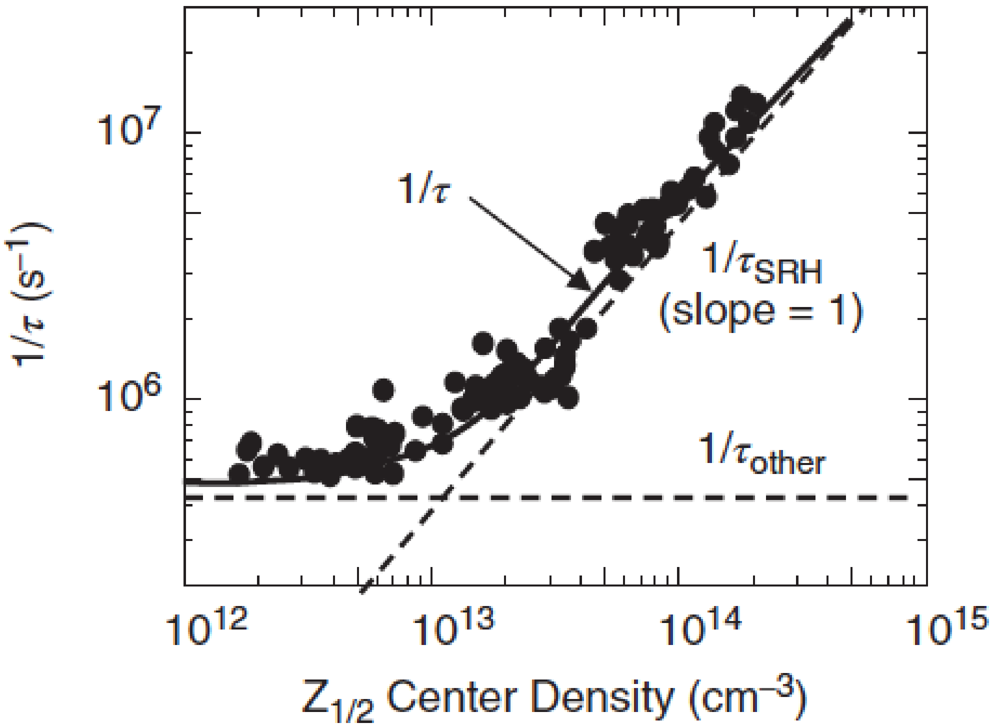
S. Privitera et al. Material Science Forum (2016) in press.

Challenge for SiC detectors production: device area

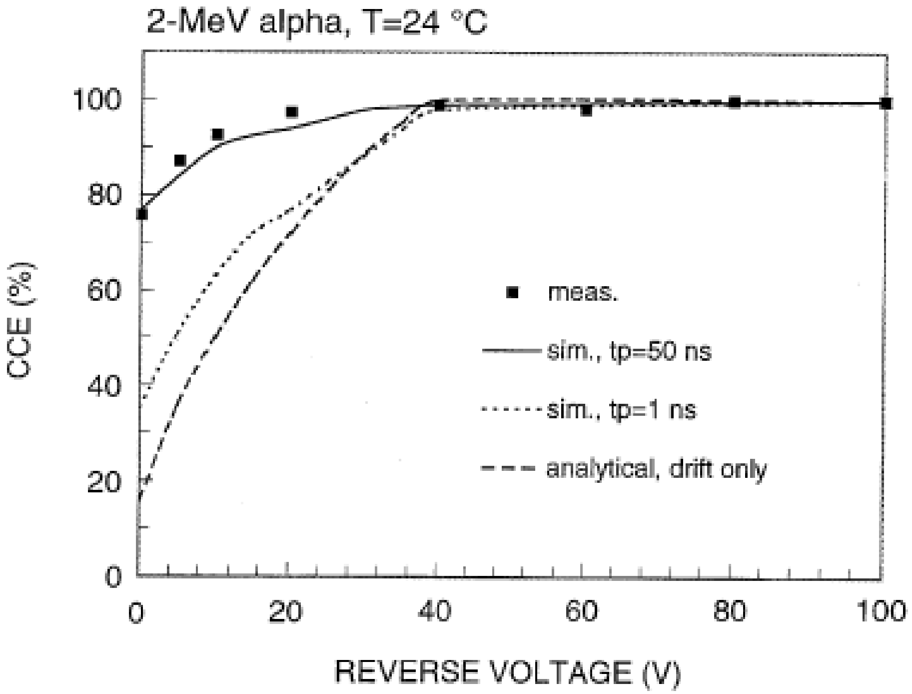


For large area detectors a very low defects density D is needed

Challenge for SiC detectors production: carrier lifetime



T. Kimoto et al. in "*Silicon carbide epitaxy*" *(Ed. F. La Via, Research Signapost)*



G. Verzellesi et al. / Nuclear Instruments and Methods in Physics Research A 476 (2002) 717–721

The carrier lifetime can have an influence on CCE at low reverse bias.

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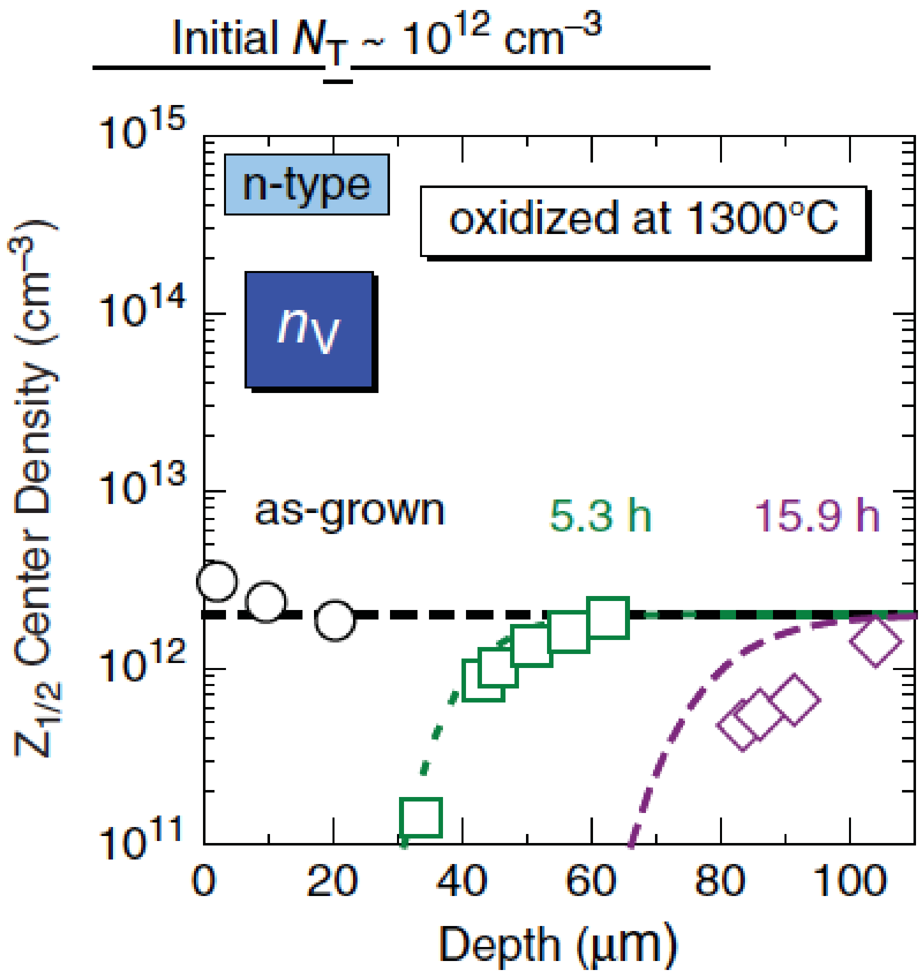
Challenge for SiC detectors production: carrier lifetime



To reduce the carbon vacancies and increase the minority carrier lifetime a high temperature oxidation or an oxidation and a subsequent high temperature annealing should be done

T. Kimoto et al. in *"Silicon carbide epitaxy" (Ed. F. La Via, Research Signapost)*

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Summary

- SiC is extremely interesting for high radiation hardness detectors.
- High linearity and high resolution detectors have been demonstrated.
- The ion irradiation introduces point defects *(low fluence regime)* or cluster of point defects *(high fluence regime).*
    - Deactivation of dopant
    - Increase of the leakage current
- The efficiency in the introduction of point defects strongly depends on the energy.

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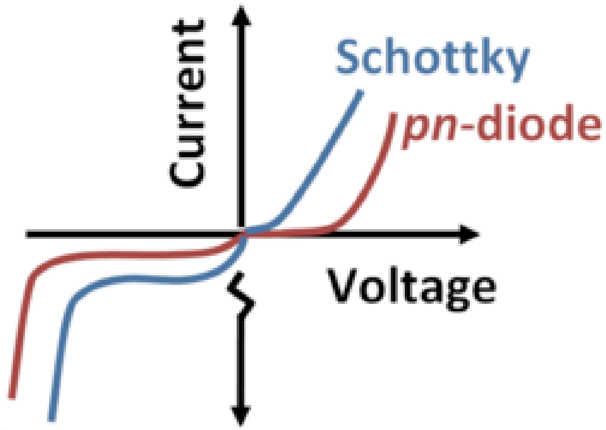
Outlook

- For the realization of high energy ions detectors the main difficulty is reach the low defects density (<1 cm^2) needed to obtain a reasonable yield (>50%).
- Carrier lifetime can have an influence on the CCE at low voltage and then a high temperature oxidation process should be done to reduce the traps.
- The P/N junctions show a lower reverse leakage current with respect to the Schottky diodes at high voltage and then these kind of detectors will be used



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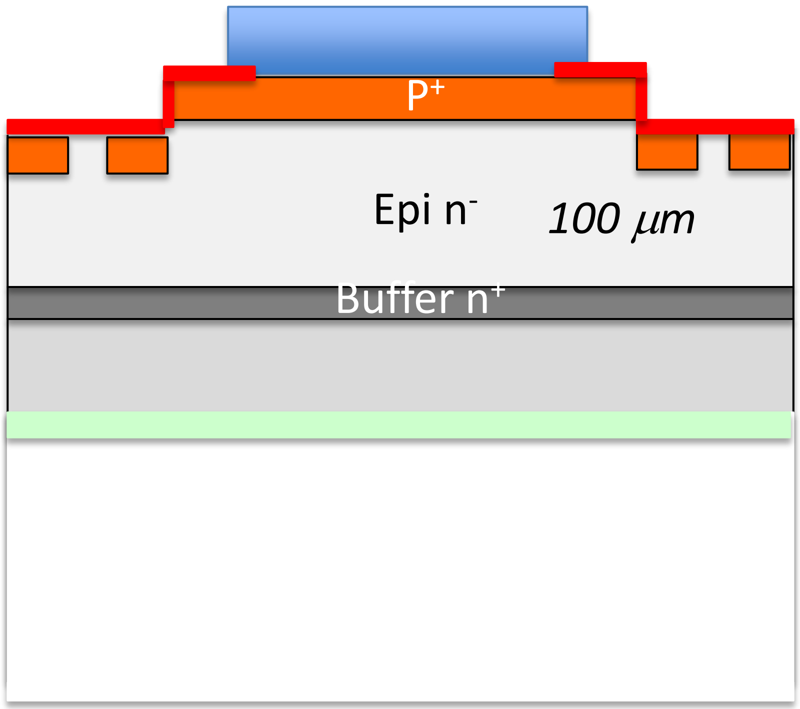
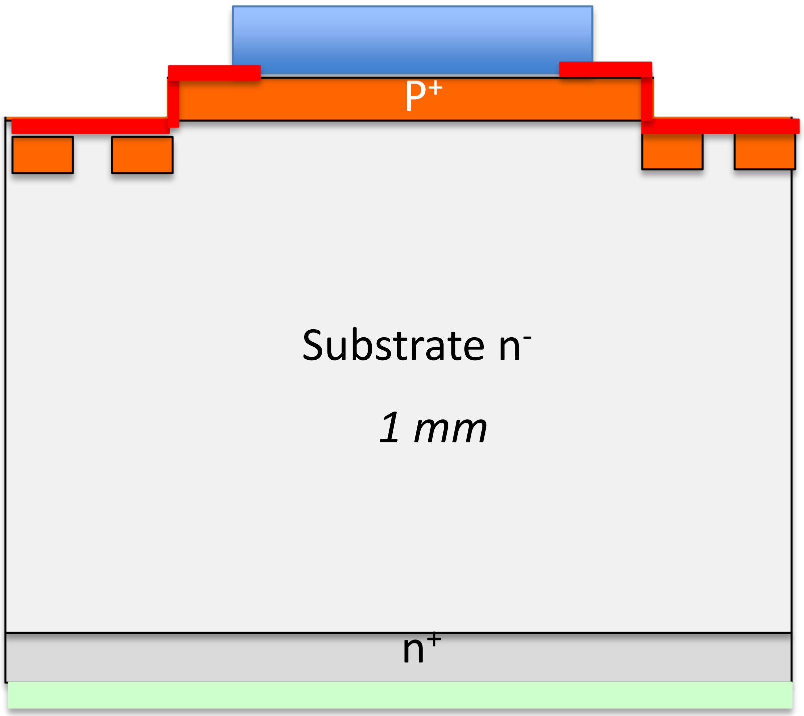
Outlook



ΔE detector



E detector

Thank you for the attention

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