Challenges of SiC technology for high radiation hardness detectors

F. La Via,
S. Privitera, G. Litrico
CNR-IMM, Catania, Italy
S. Tudisco, C. Agodi
LNS, INFN, Catania, Italy
L. Calcagno, F. Capuzzello
Dipartimento di Fisica, Catania, Italy
N. Piluso, P. Badalà,S. Cascino, G. Longo, A. Santangelo
STMicroelectronics, Catania, Italy
M. Mauceri
ETC, Catania, Italy

Outline

- Introduction
- The SiCilia detectors
- Challenge for SiC detectors production
  - Epitaxy
  - Defects and Yield
  - Edge structure
  - Carrier lifetime
  - Thin substrate and back metallization
  - Thick detectors on intrinsic wafers
- Summary and Outlook

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	$4\cdot10^6$	$2.2\cdot10^6$	$3\cdot10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2\cdot10^7$	-	$2\cdot10^7$	$0.8\cdot10^7$
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)

Þ lower leakage current than silicon

- Signal (**for MIP !**):

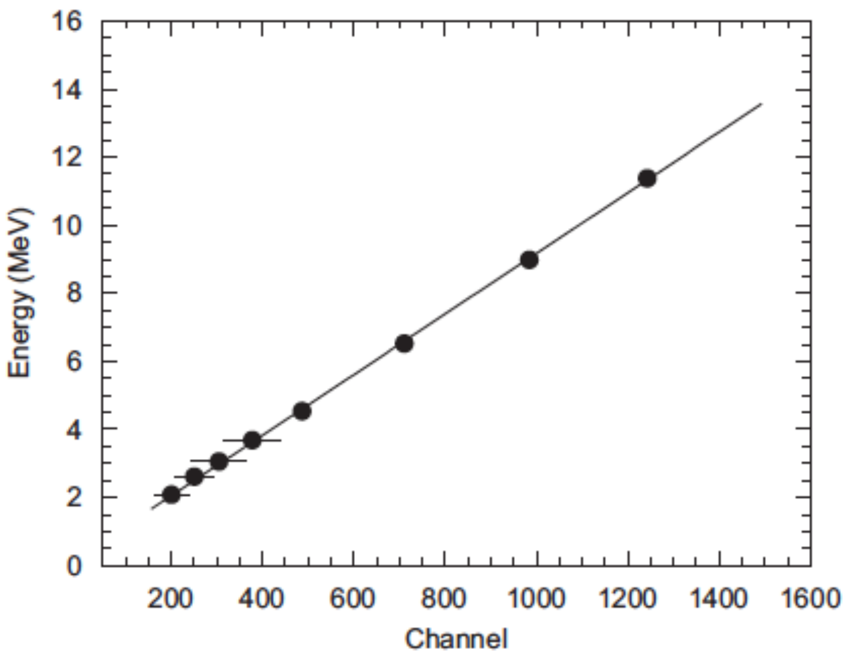
Diamond	36 e/mm
SiC	51 e/mm
Si	89 e/mm

Þ more charge than diamond Si/SiC≈2

- Higher displacement threshold than silicon

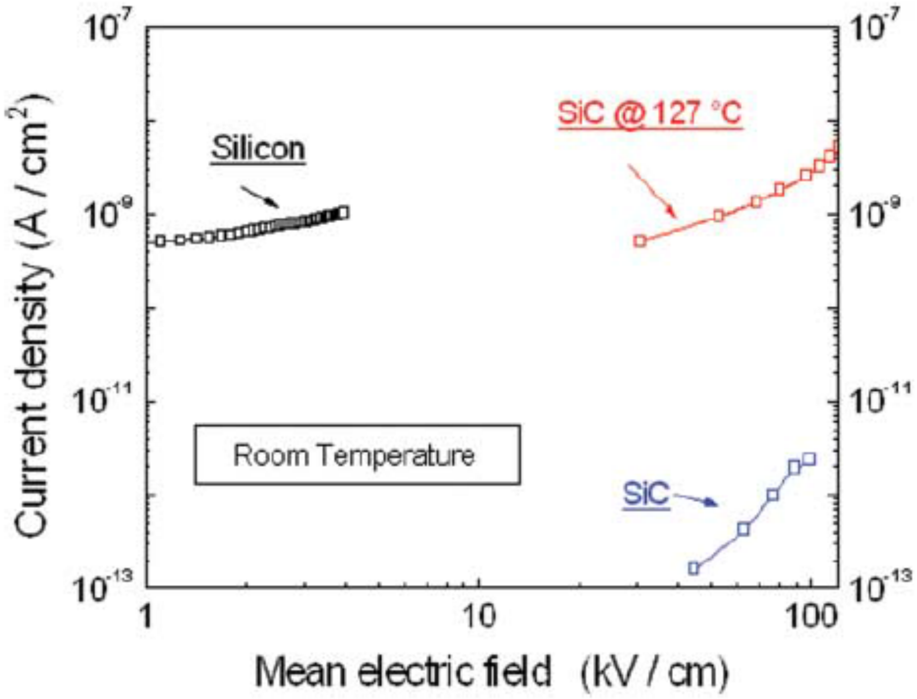
Þ radiation harder than silicon

SiC detectors



De Napoli et al. NIM A, 572 (2007), 831

CNR-IMM detector



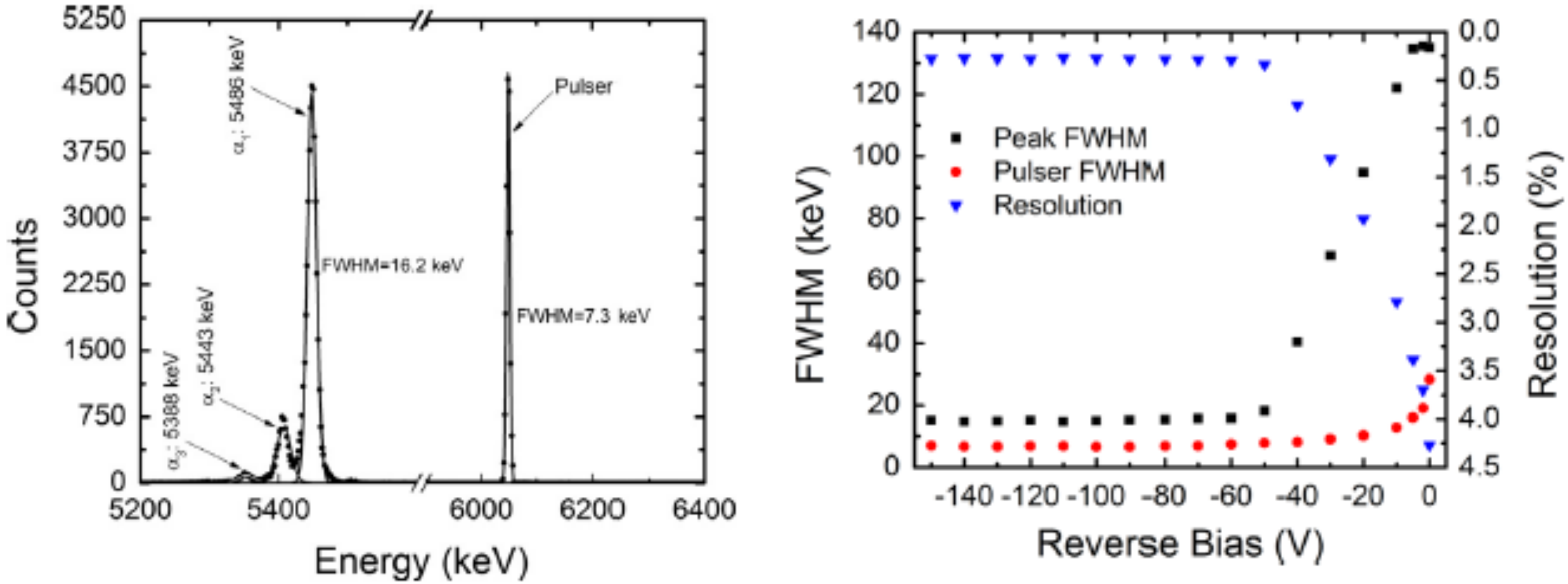
L. Calcagno et al. Radiation Effect & Defects in Solid, 170(4), (2015) 303

CNR-IMM detector

High linearity

Low noise

SiC detectors

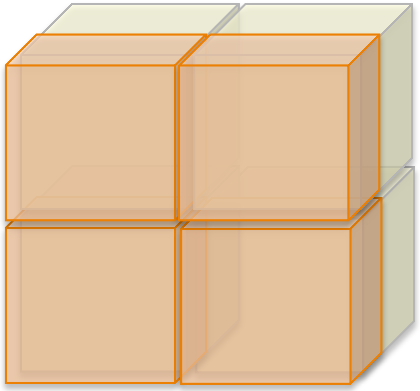


S.K. Chaudhuri et al. / Nuclear Instruments and Methods in Physics Research A 728 (2013) 97–101

Intrinsic detector resolution 14.5 KeV (0.2%)

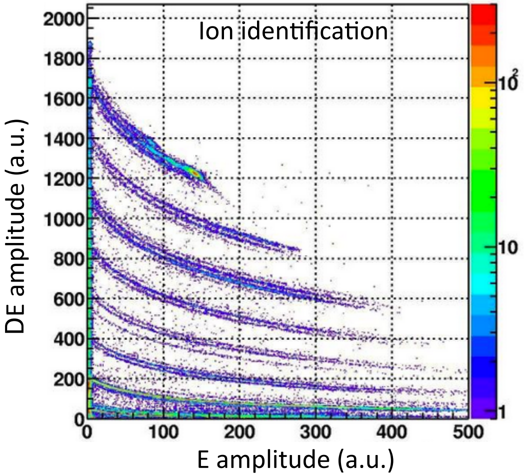
SiCilia detectors

Radiation Hard detectors for Nuclear Physics experiments and Nuclear applications



SiC *DE-E* telescopes

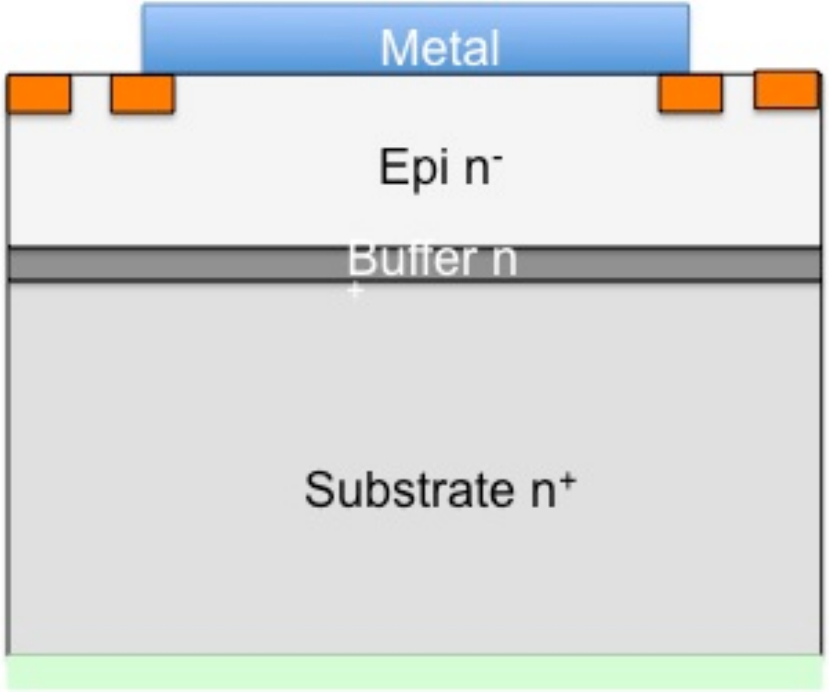
- ✓ Active area 1 cm^2
- ✓ *DE* stage thickness ≥ 100 mm
- ✓ *E* stage thickness 500 ÷ 1000 mm

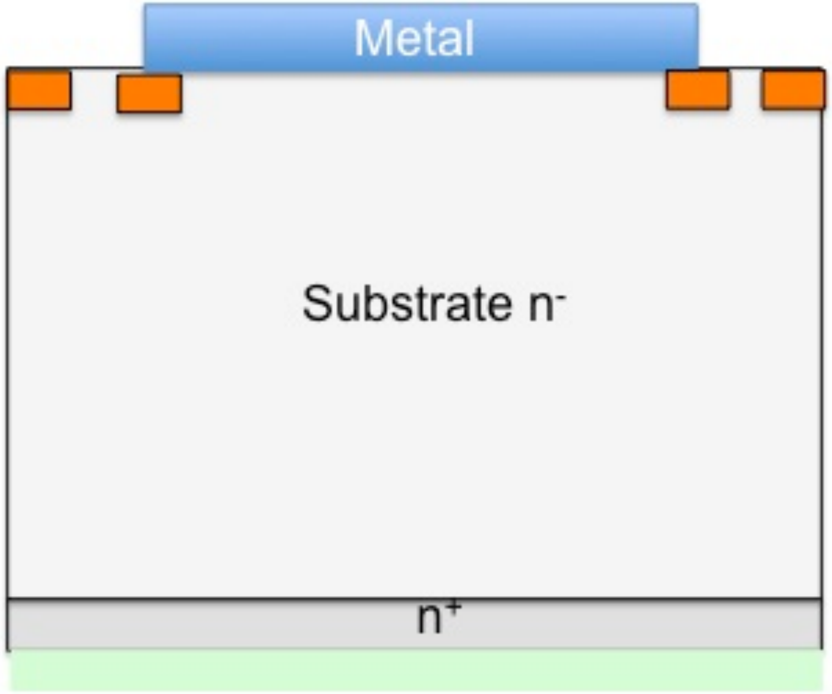


R. H. → 10^{14} ions/cm^2 in ten years of activity

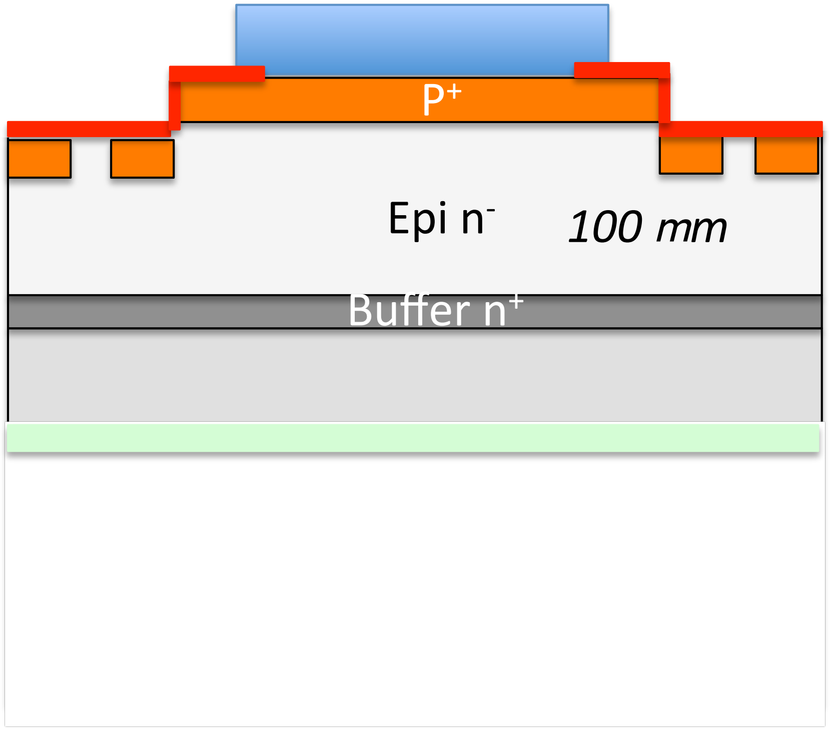
(Si detector dead @ 10^9 implanted ions/cm^2)

Schottky diode detectors

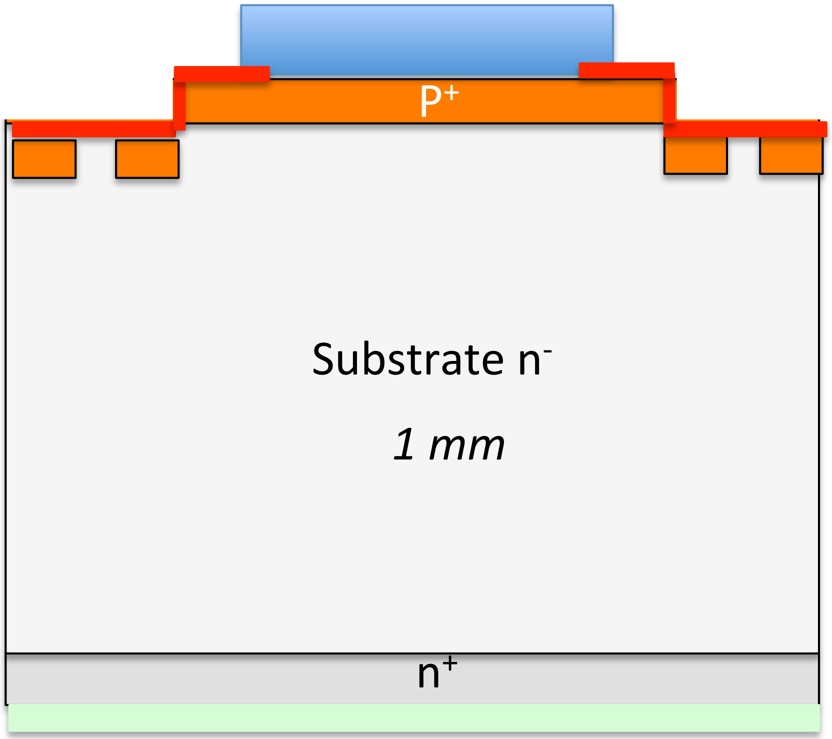




P^+/N detectors

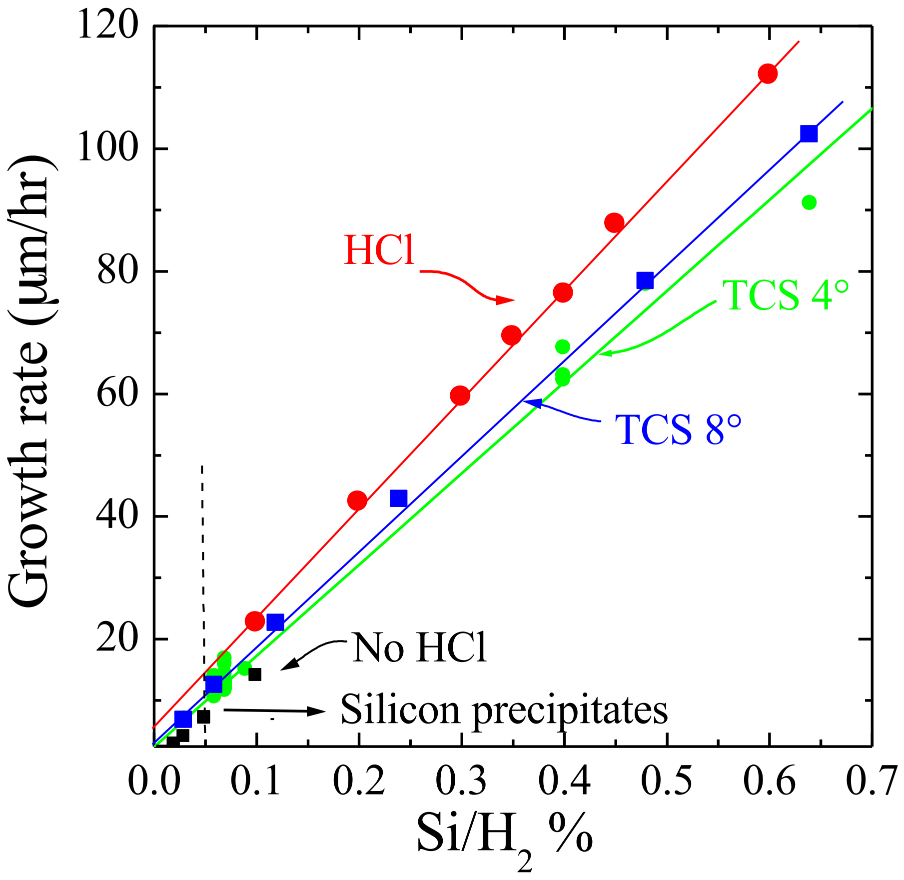


DE detector



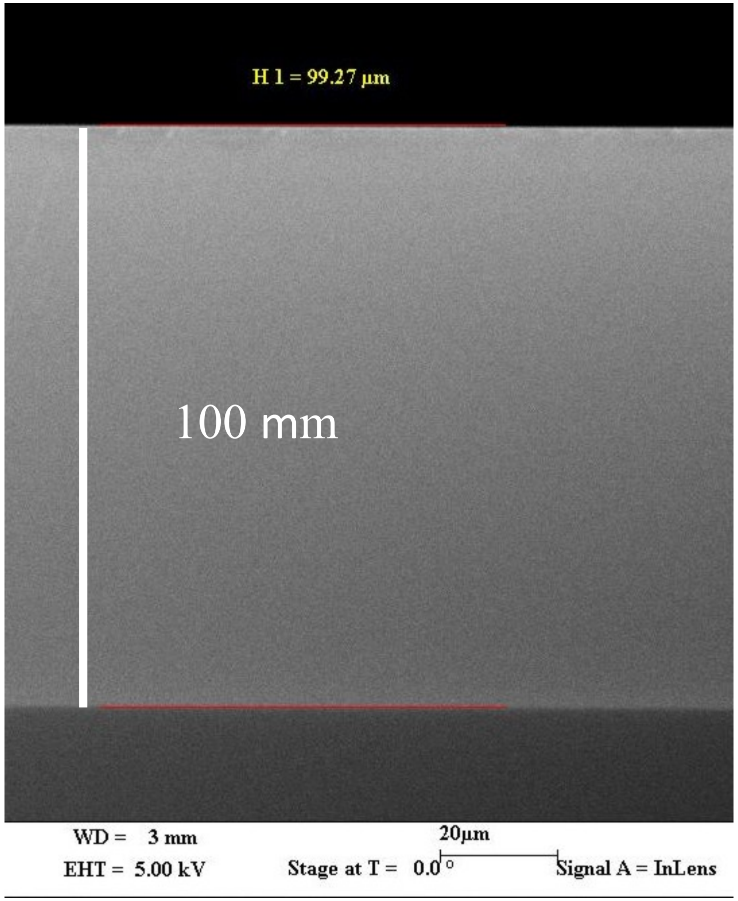
E detector

High growth rate epitaxy

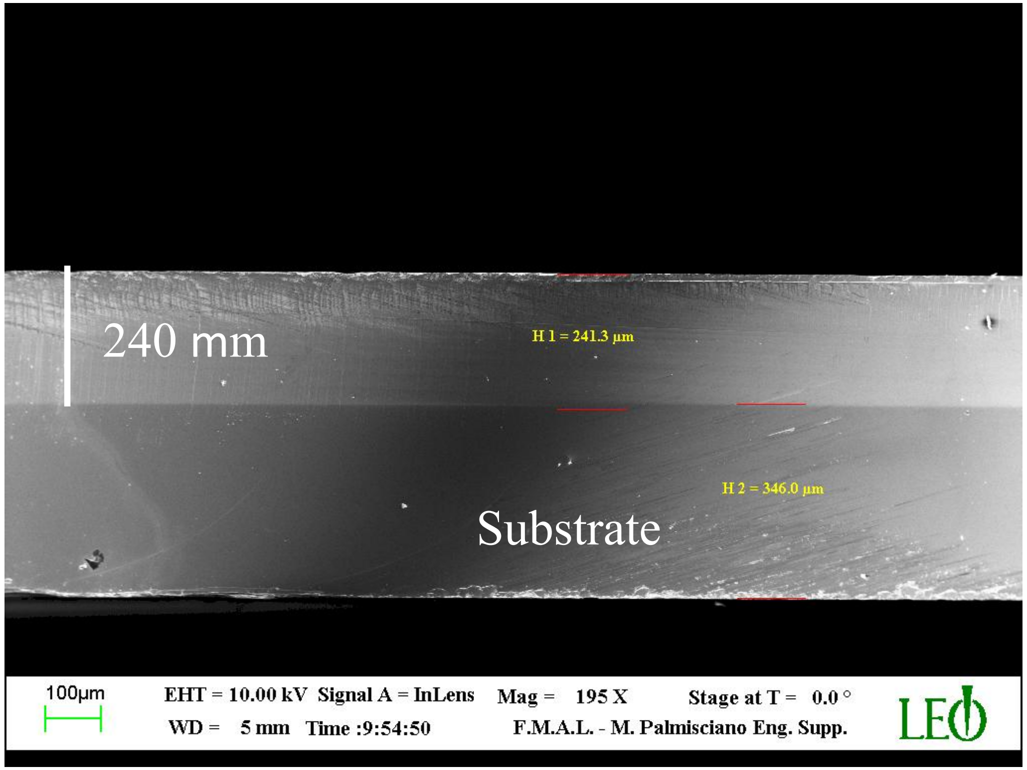


Thick epitaxy

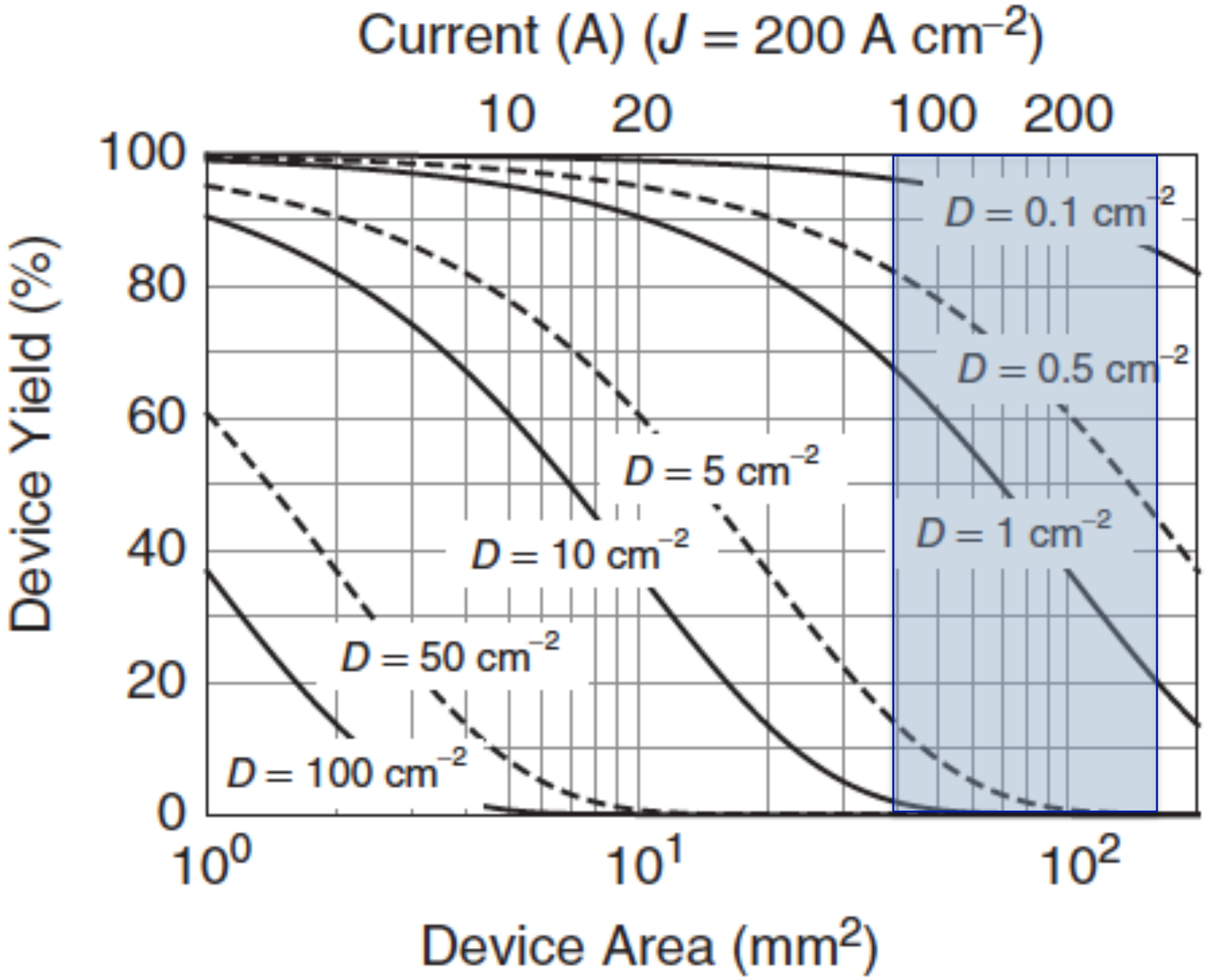
100 mm



240 mm

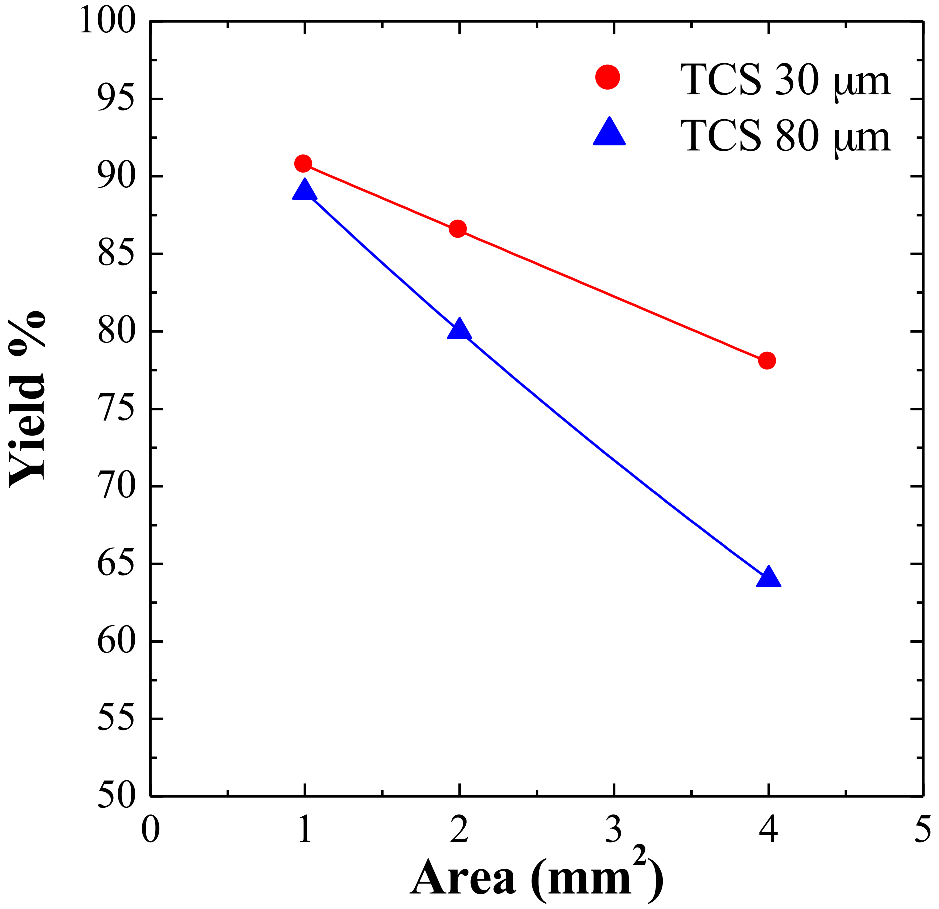


Challenge for SiC detectors production: device area



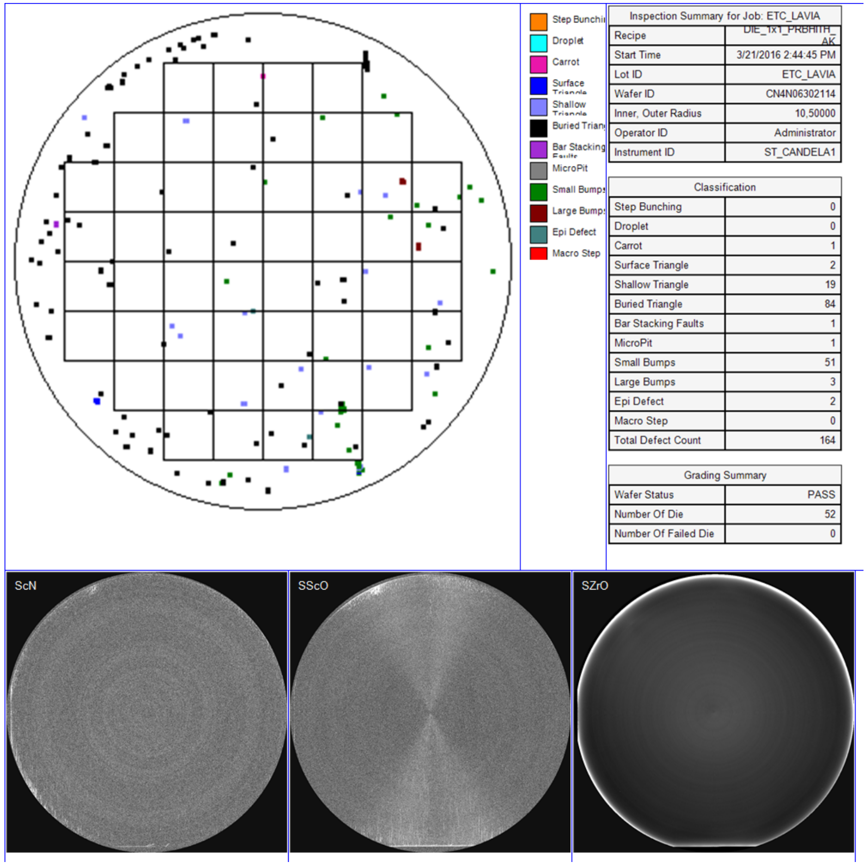
For large area detectors a very low defects density D is needed

Experimental device Yield (2008)



Maximum device yield from optical measurements (2016)

Best wafer

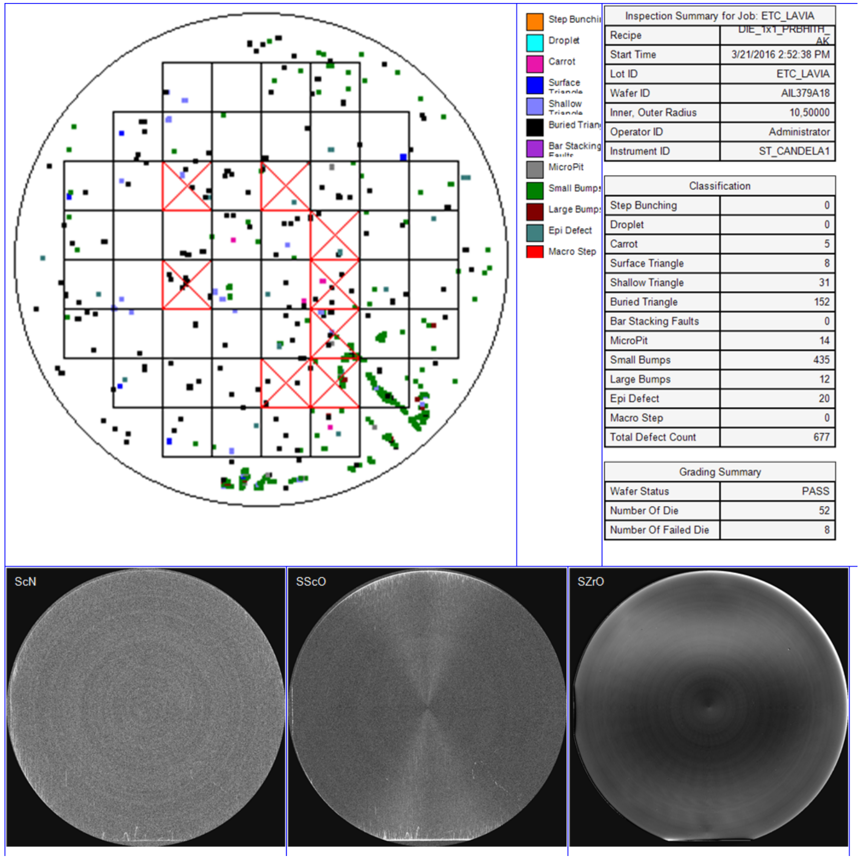


Inspection Summary for Job: ETC_LAVIA	
Recipe	DIE_1x1_PRBHITH_AK
Start Time	3/21/2016 2:44:45 PM
Lot ID	ETC_LAVIA
Wafer ID	CN4N06302114
Inner, Outer Radius	10,50000
Operator ID	Administrator
Instrument ID	ST_CANDELA1

Classification	
Step Bunching	0
Droplet	0
Carrot	1
Surface Triangle	2
Shallow Triangle	19
Buried Triangle	84
Bar Stacking Faults	1
MicroPit	1
Small Bumps	51
Large Bumps	3
Epi Defect	2
Macro Step	0
Total Defect Count	164

Grading Summary	
Wafer Status	PASS
Number Of Die	52
Number Of Failed Die	0

Worse wafer



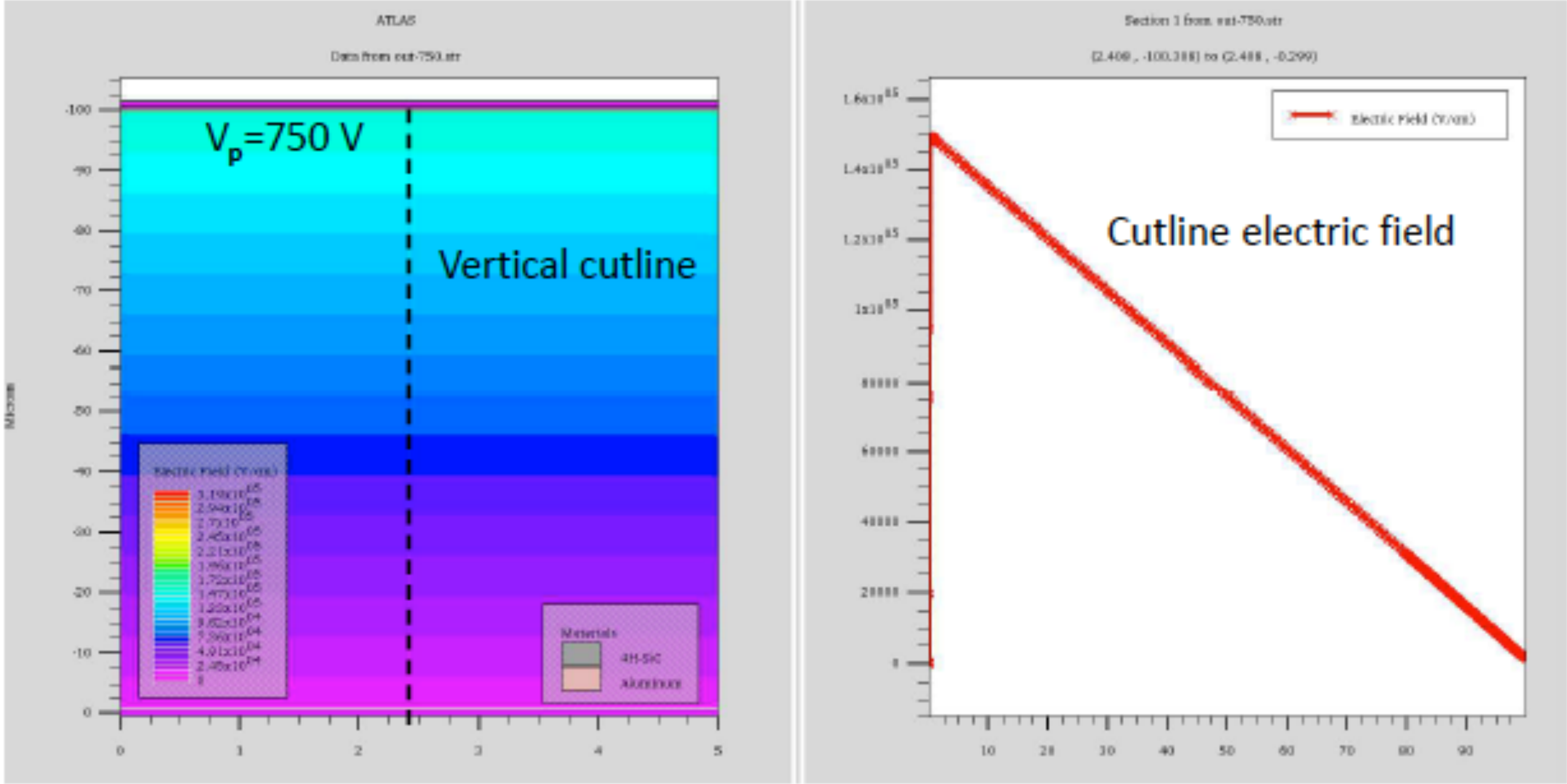
Inspection Summary for Job: ETC_LAVIA	
Recipe	DIE_1x1_PRBHITH_AK
Start Time	3/21/2016 2:52:38 PM
Lot ID	ETC_LAVIA
Wafer ID	AIL379A18
Inner, Outer Radius	10,50000
Operator ID	Administrator
Instrument ID	ST_CANDELA1

Classification	
Step Bunching	0
Droplet	0
Carrot	5
Surface Triangle	8
Shallow Triangle	31
Buried Triangle	152
Bar Stacking Faults	0
MicroPit	14
Small Bumps	435
Large Bumps	12
Epi Defect	20
Macro Step	0
Total Defect Count	677

Grading Summary	
Wafer Status	PASS
Number Of Die	52
Number Of Failed Die	8

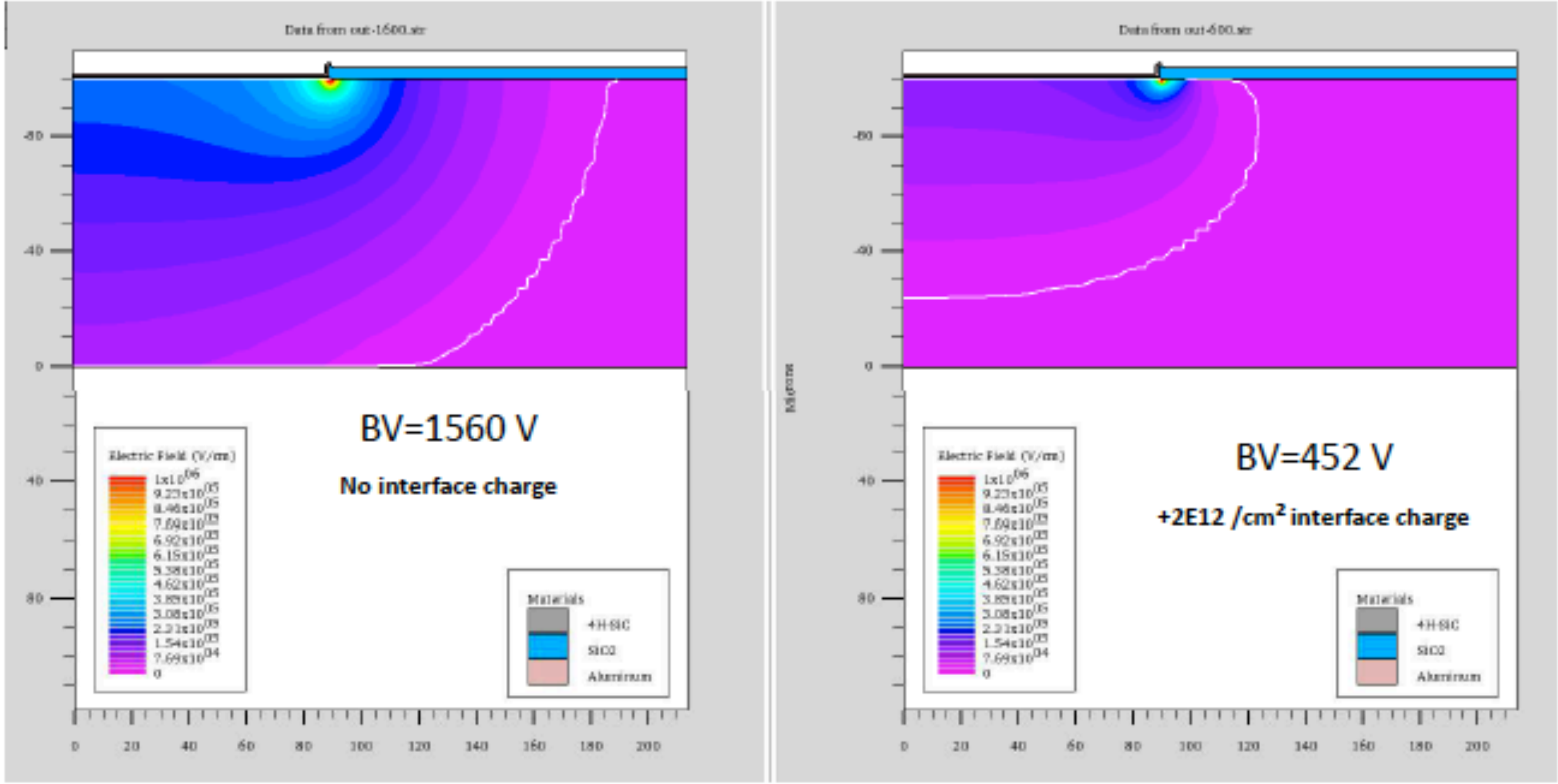
10 mm epitaxial layer

Planar junction



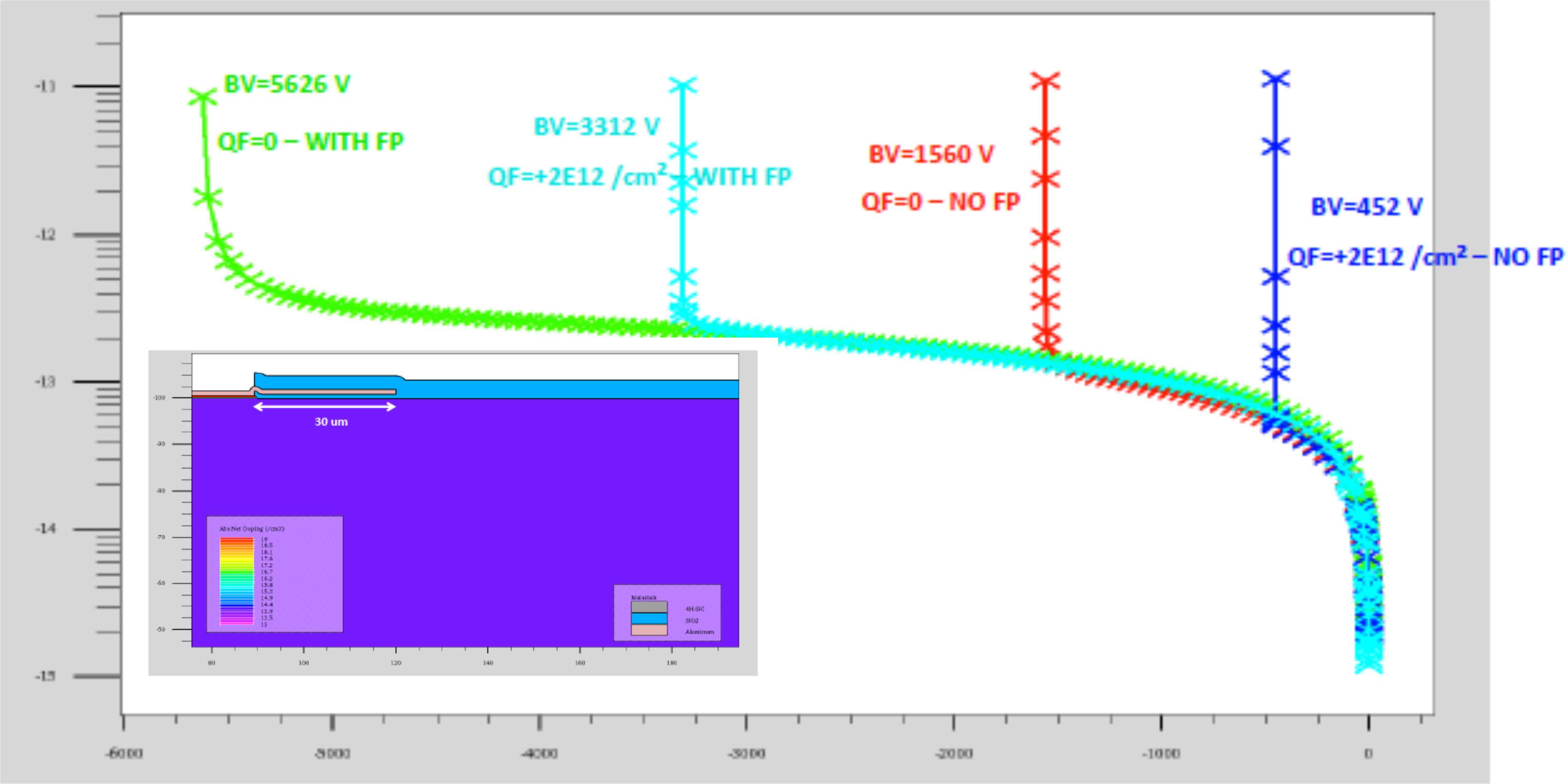
The reverse voltage necessary to deplete the 100 mm epilayer is 750 V.
The breakdown voltage of the planar junction is > 10kV

Interface charge

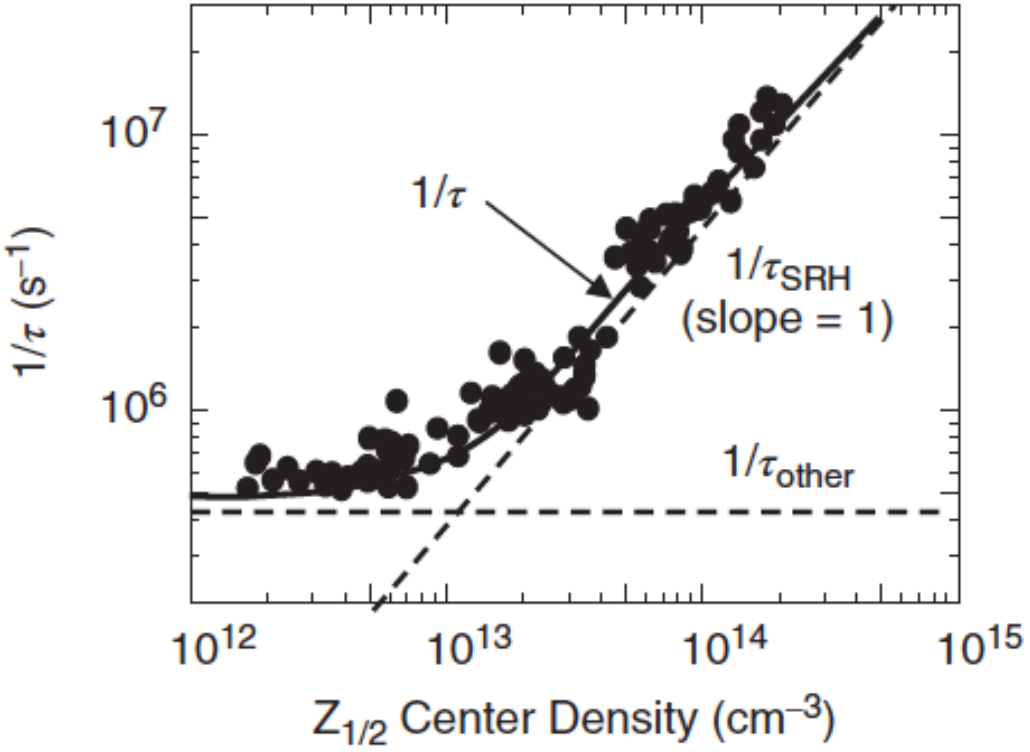


The presence of an interface charge can decrease considerably the breakdown voltage. Then a edge structure is necessary.

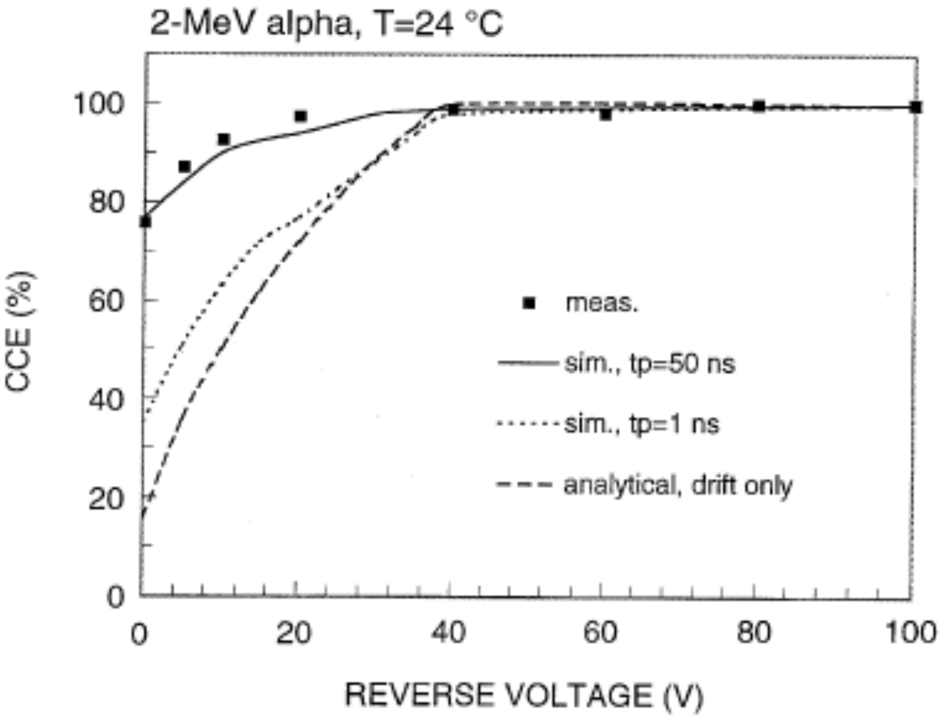
Edge structure



Challenge for SiC detectors production: carrier lifetime



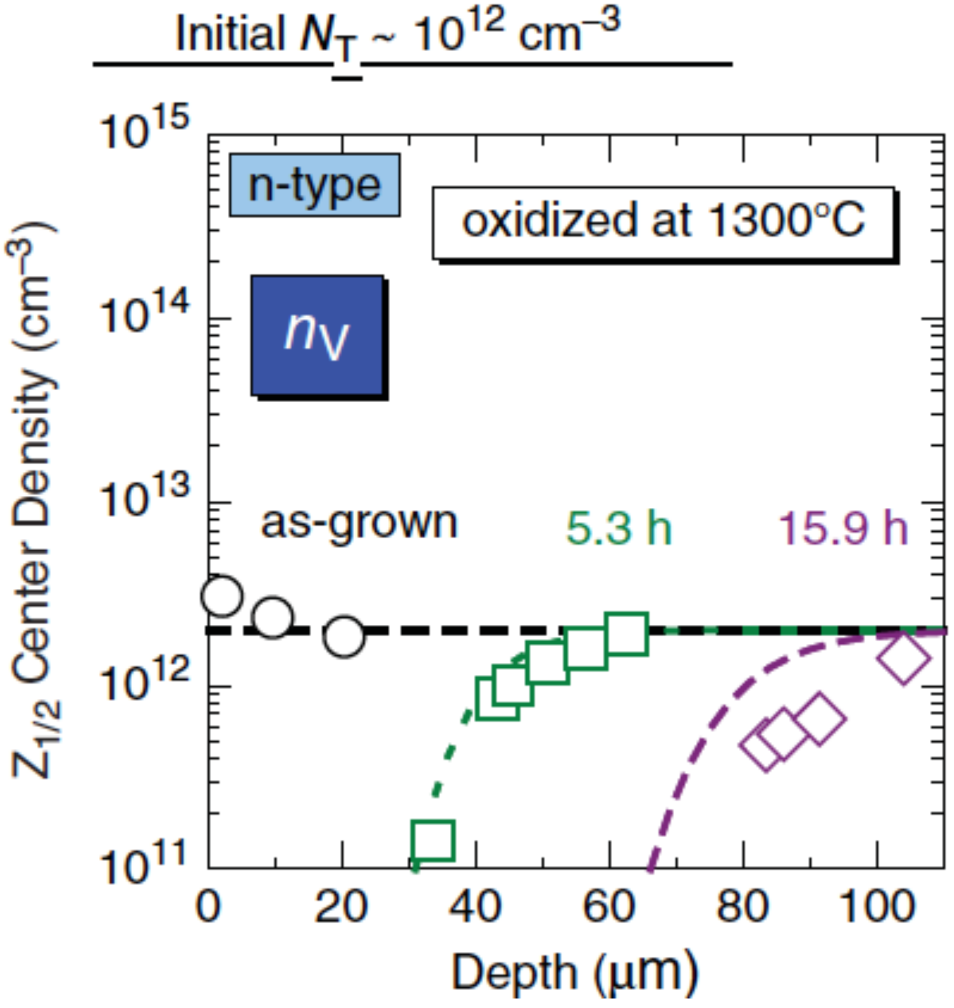
T. Kimoto et al. in *"Silicon carbide epitaxy" (Ed. F. La Via, Research Signapost)*



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.

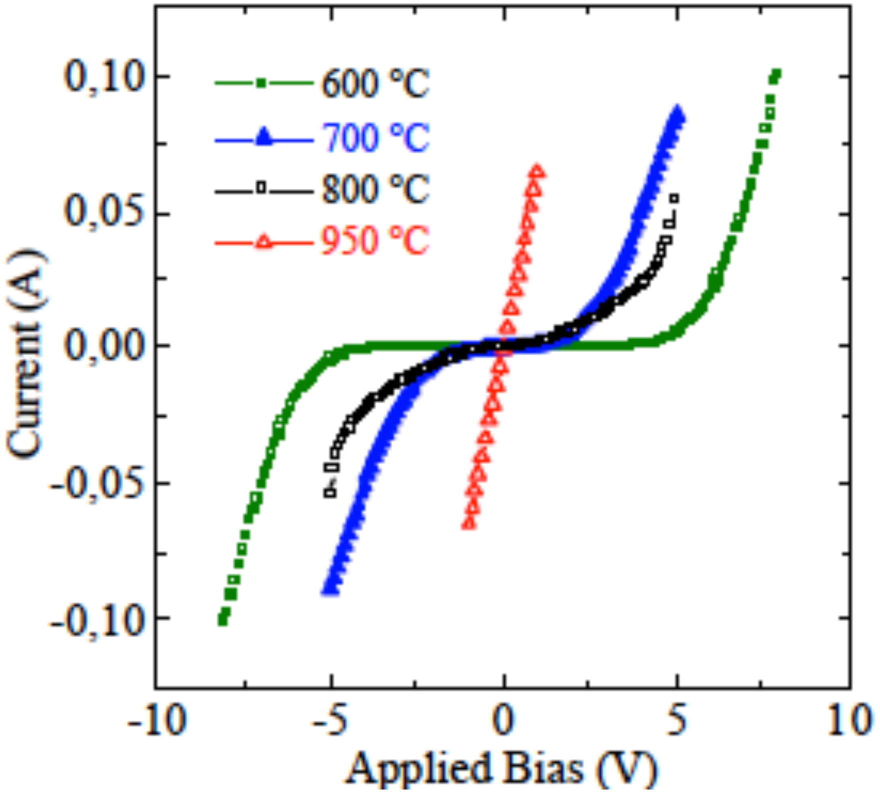
Challenge for SiC detectors production: carrier lifetime

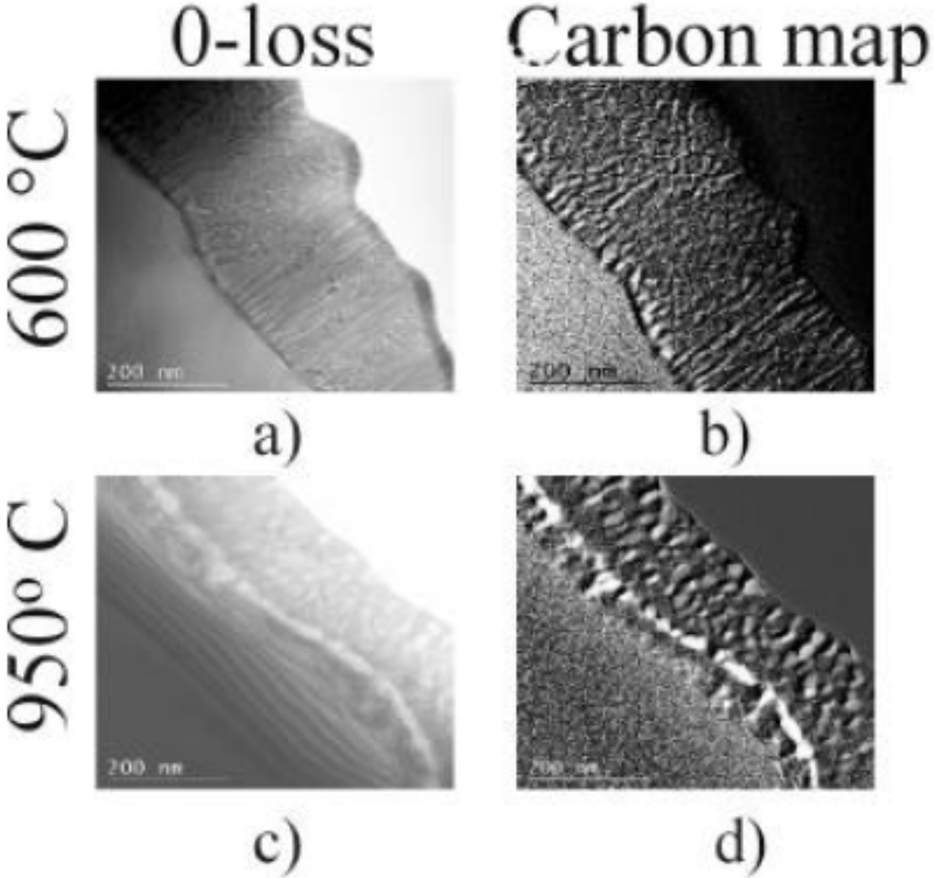


To reduce the carbon vacancies and increase the minority carrier lifetime a high temperature oxidation or an oxidation and a subsequent high temperature annealing should be done

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

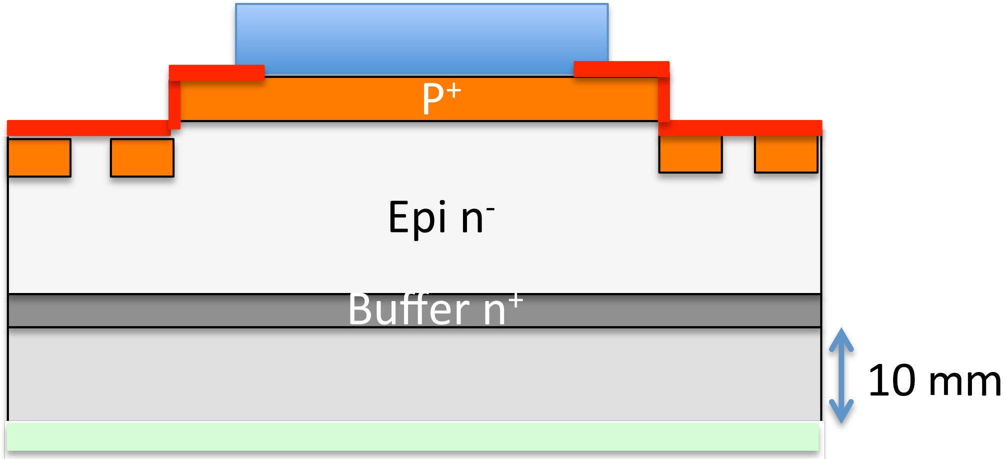
Back contact





High annealing temperature are needed to have a good ohmic contact on the backside

Thinning of the substrate



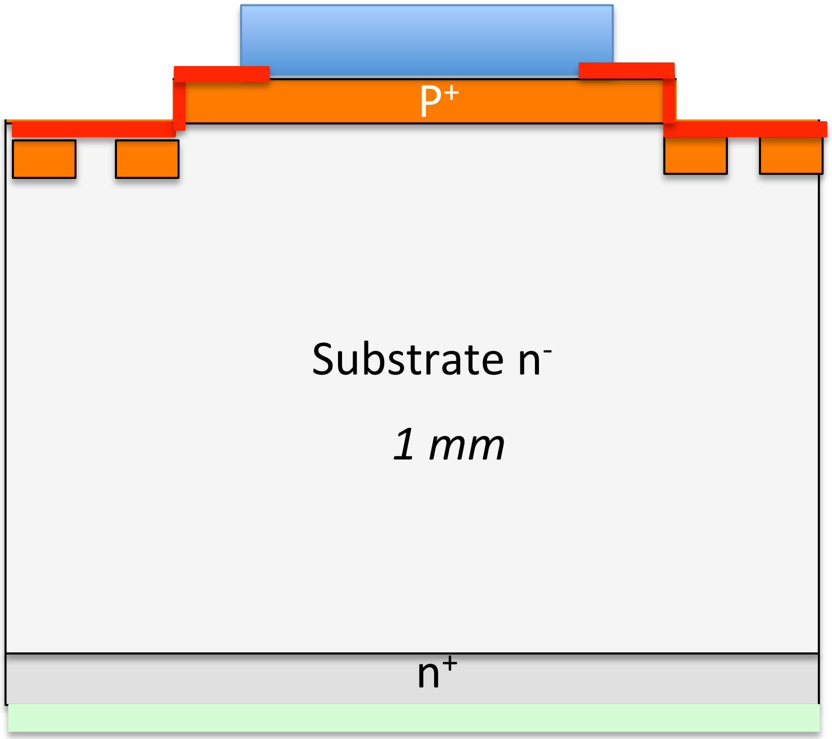
To realize a thin substrate and a good ohmic contact on the backside, a laser annealing process of the backside metallization is needed.

Yb:YAG laser
l = 515 nm
Scan speed = 30 mm/s
Frequency = 10kHz

6.5 J/cm^2
T=1.2 ms
2 sweeps

Good silicide formation

Thick detectors on intrinsic wafers



E detector

- Carrier lifetime?
- Defects?
- Signal/noise ratio?
- Resolution?

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.

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