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Assessment of the radiation hardness of 4H-SiC Schottky diodes by IBIC

Ettore Vittone, Paolo Olivero

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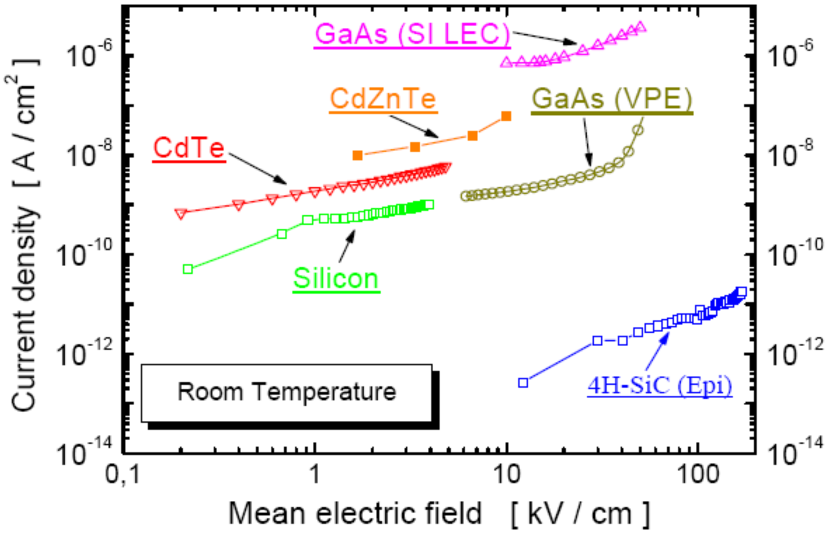
Centre for Accelerator Science, Australian Nuclear Science and Technology Organisation

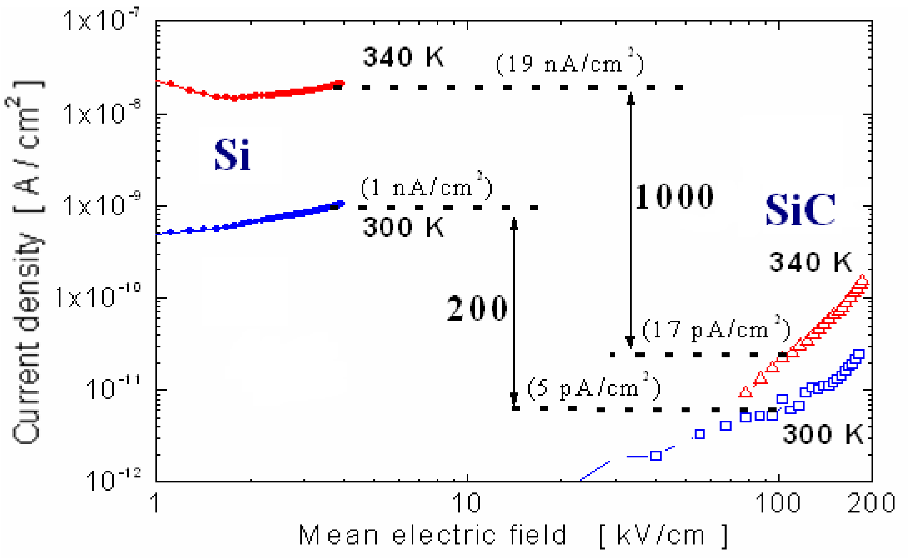
ICNMTa 2022

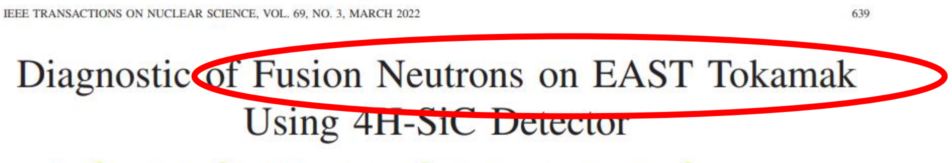
4H-SiC

Property	D	Si	Ge	GaAs	CdTe	4H–SiC
Bandgap (eV)	5.5	1.12	0.67	1.42	1.49	3.27
Relative dielectric constant	5.7	11.9	16	13.1	10	9.7
Breakdown field (MV cm^{-1})	10	0.3	0.1	0.4	0.5	3.0
Density (g cm^{-3})	3.5	2.3	5.33	5.3	5.9	3.2
Atomic number Z	6	14	32	31–33	48–52	14–6
e–h creation energy (eV)	13	3.6	2.95	4.3	4.42	7.78
Saturated electron velocity (10^7 cm s^{-1}) at 300 K	2.2	1.0	0.6	1.2	1.0	2
Electron mobility (cm^2 V^{-1} s^{-1}) at 300 K	1800	1300	3900	8500	1100	800
Hole mobility (cm^2 V^{-1} s^{-1}) at 300 K	1200	460	1900	400	100	115
Threshold displacement energy (eV)	40–50	13–20	16–20	8–20	6–8	22–35
Minimum ionizing energy loss (MeV cm^{-1})	4.7	2.7	6	5.6		4.4

F. Nava, A. Cavallini, G. Bertuccio, E. Vittone, Measurement Science and Technology, 19 (2008)







IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 69, NO. 3, MARCH 2022 639

Diagnostic of Fusion Neutrons on EAST Tokamak Using 4H-SiC Detector

B. Hong, G. Q. Zhong, L. Q. Hu, R. X. Zhang, R. J. Zhou, K. Li, L. S. Huang, and

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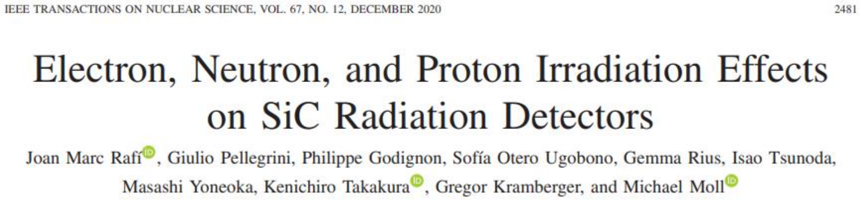

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 67, NO. 12, DECEMBER 2020 2481

Electron, Neutron, and Proton Irradiation Effects on SiC Radiation Detectors

Joan Marc Rafí, Giulio Pellegrini, Philippe Godignon, Sofía Otero Ugobono, Gemma Rius, Isao Tsunoda, Masashi Yoneoka, Kenichiro Takakura, Gregor Kramberger, and Michael Moll

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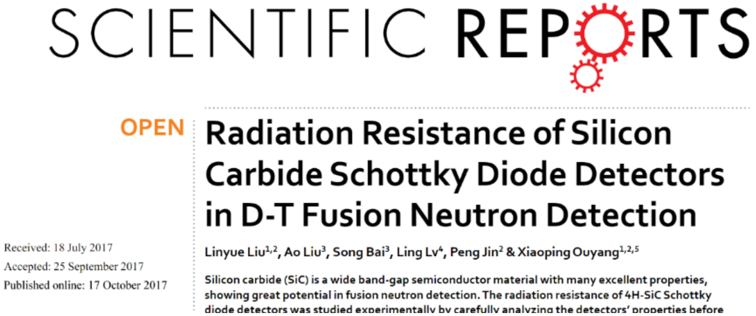

SCIENTIFIC REPORTS

OPEN

Radiation Resistance of Silicon Carbide Schottky Diode Detectors in D-T Fusion Neutron Detection

Received: 18 July 2017
Accepted: 25 September 2017

Linyue Liu[1,2], Ao Liu[3], Song Bai[3], Ling Lv[4], Peng Jin[2] & Xiaoping Ouyang[1,2,5]

Silicon carbide (SiC) is a wide band-gap semiconductor material with many excellent properties, showing great potential in fusion neutron detection. The radiation resistance of 4H-SiC Schottky diode detectors was studied experimentally by carefully analyzing the detectors' properties before

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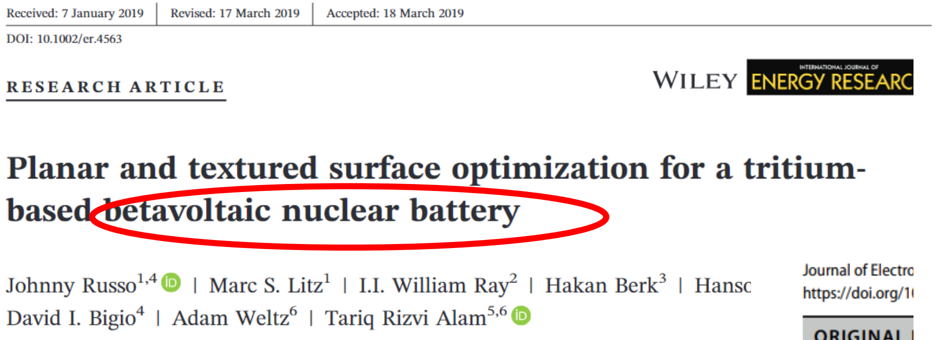


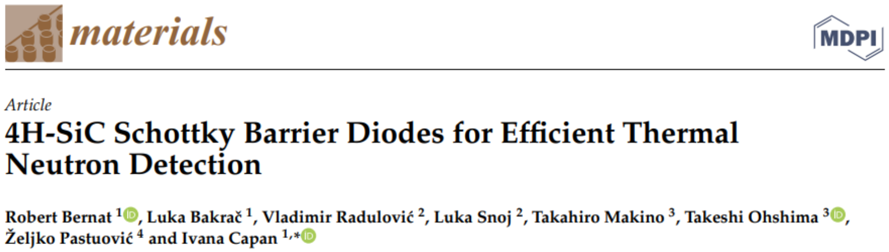
Received: 7 January 2019 | Revised: 17 March 2019 | Accepted: 18 March 2019
DOI: 10.1002/er.4563

RESEARCH ARTICLE

WILEY ENERGY RESEARC

Planar and textured surface optimization for a tritium-based betavoltaic nuclear battery

Johnny Russo[1,4] | Marc S. Litz[1] | I.I. William Ray[2] | Hakan Berk[3] | Hansc
David I. Bigio[4] | Adam Weltz[6] | Tariq Rizvi Alam[5,6]

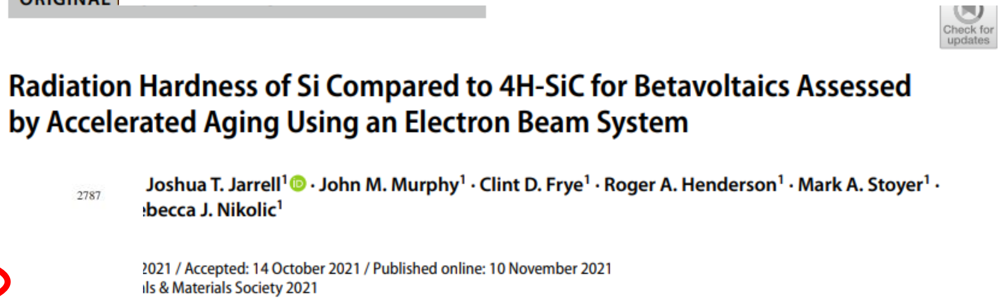


materials MDPI

Article

4H-SiC Schottky Barrier Diodes for Efficient Thermal Neutron Detection

Robert Bernat [1], Luka Bakrač [1], Vladimir Radulović [2], Luka Snoj [2], Takahiro Makino [3], Takeshi Ohshima [3], Željko Pastuović [4] and Ivana Capan [1,*]



Journal of Electro
https://doi.org/1

ORIGINAL

Check for updates

Radiation Hardness of Si Compared to 4H-SiC for Betavoltaics Assessed by Accelerated Aging Using an Electron Beam System

Joshua T. Jarrell[1] · John M. Murphy[1] · Clint D. Frye[1] · Roger A. Henderson[1] · Mark A. Stoyer[1] ·
ebecca J. Nikolic[1]

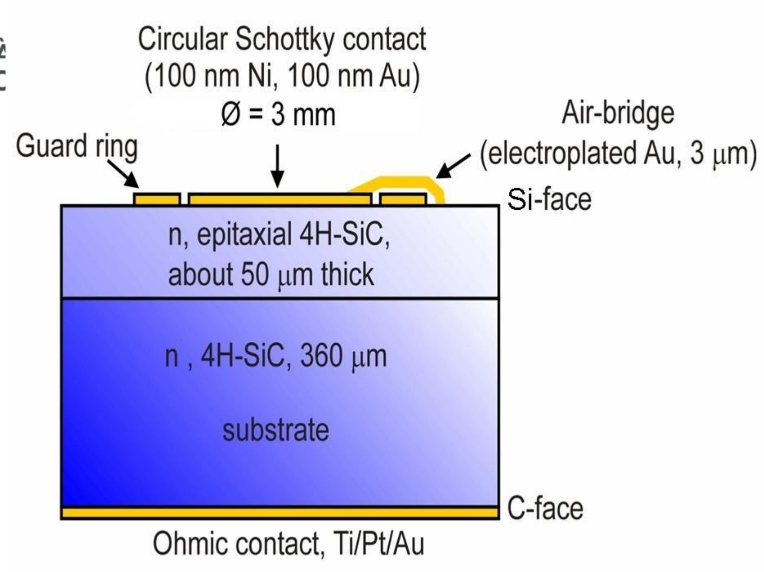
2021 / Accepted: 14 October 2021 / Published online: 10 November 2021
ls & Materials Society 2021

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 68, NO. 12, DECEMBER 2021 2787

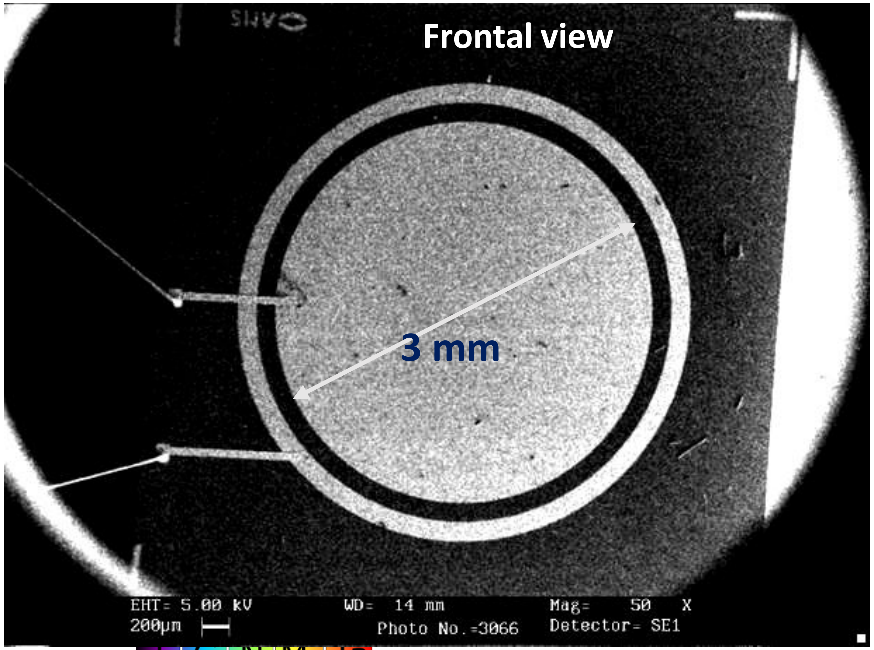
SiC p+n Junction Diodes Toward Beam Monitor Applications

Tetsuichi Kishishita, Ryoji Kosugi, Yowichi Fujita, Yoshinori Fukao, Kazutoshi Kojima, Keiko Masumoto, Hajime Nishiguchi, Manobu M. Tanaka, and Yasunori Tanaka

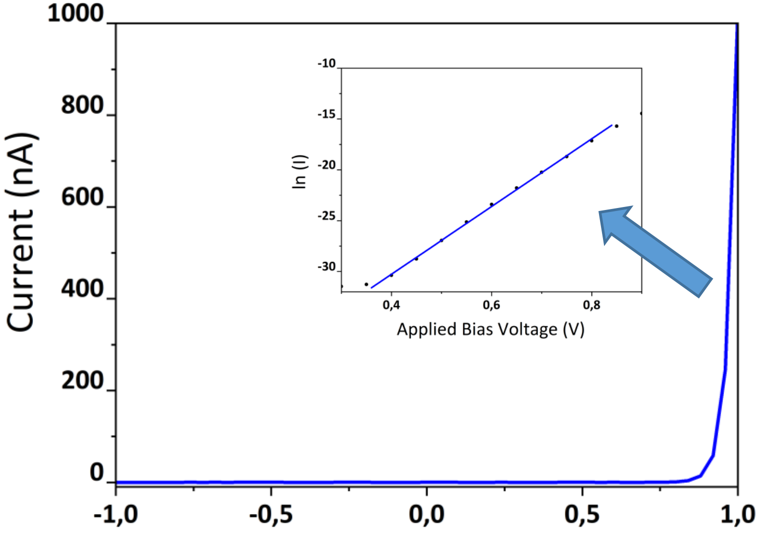
Device under study: 4H-SiC Schottky diode



- ✓ **360 μm - low micropipe density (16–30 cm^{-3}) n+ substrate (CREE Research)**
- ✓ **~50 μm n-type epitaxial layer (Institute of Crystal Growth, IKZ, Berlino)**
- ✓ **Frontal Schottky barrier electrodes Ni (100 nm) / Au (100 nm) (Alenia Marconi)**
- ✓ **Common back ohmic contact in Ti (30 nm) / Pt (30 nm) / Au (100 nm) (Alenia Marconi)**

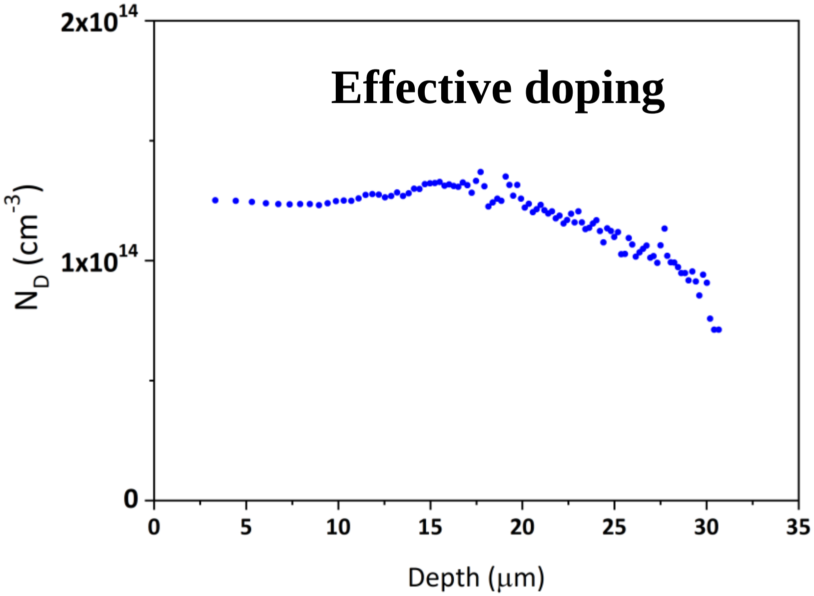


Device under study: 4H-SiC Schottky diode

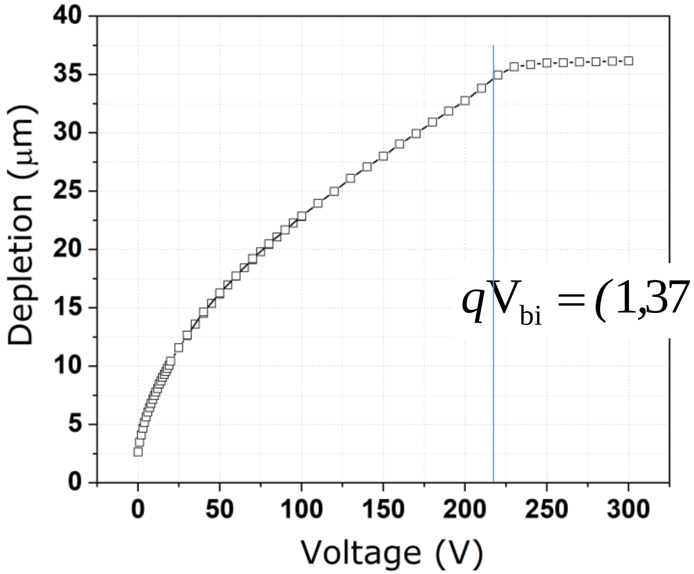


$\eta = (1{,}14 \pm 0{,}03)$ Ideality factor

$q\Phi_{Bn} = (1{,}52 \pm 0{,}01)\,eV$ Barrier Height

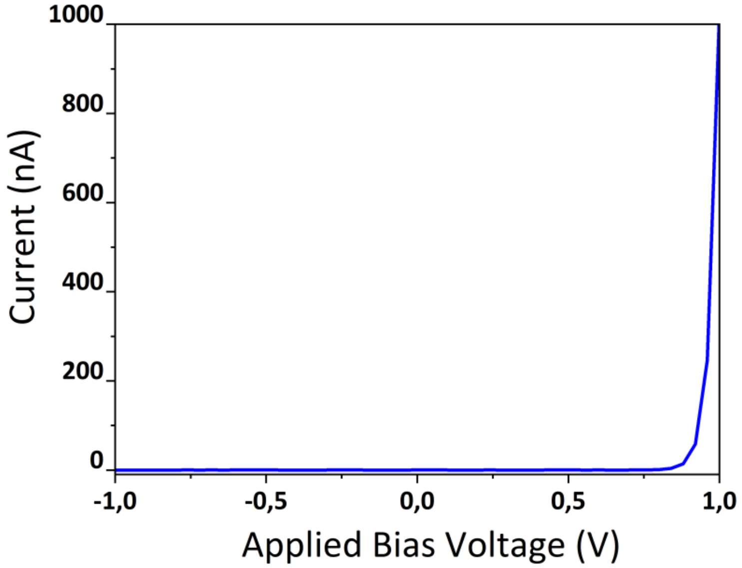


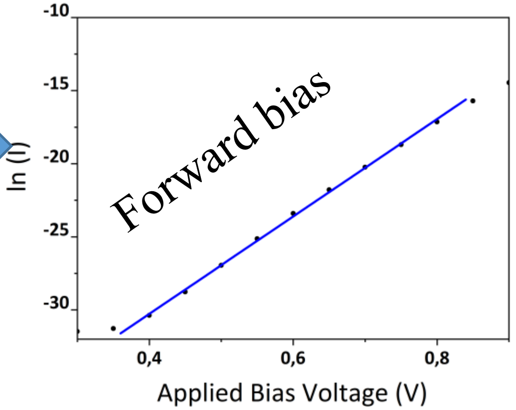
Full depletion @ - 220 V



$qV_{bi} = (1{,}37 \pm 0{,}01)\,eV$

Device under study: 4H-SiC Schottky diode





$\eta = (1{,}14 \pm 0{,}03)$ Ideality factor

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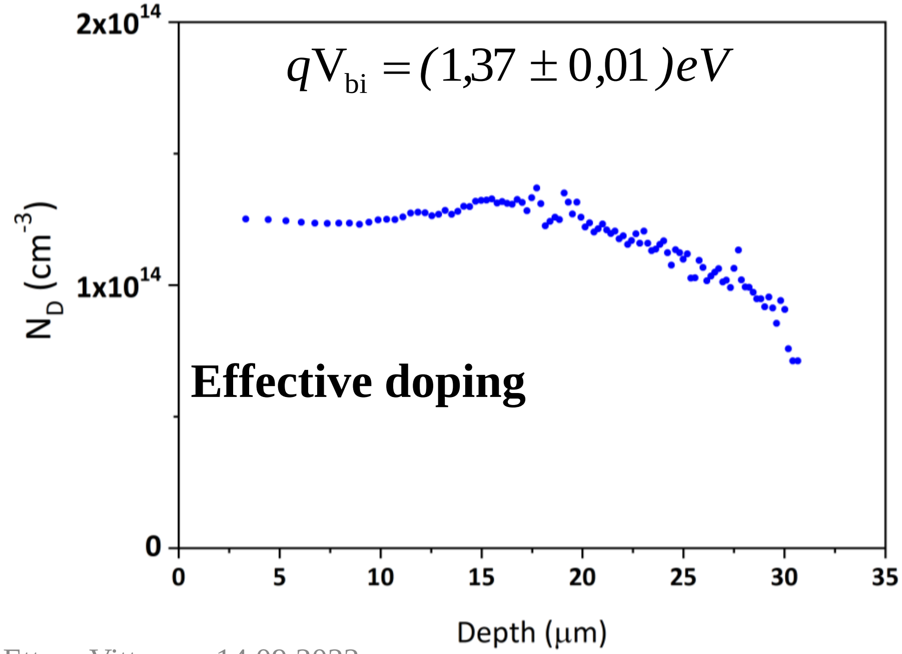
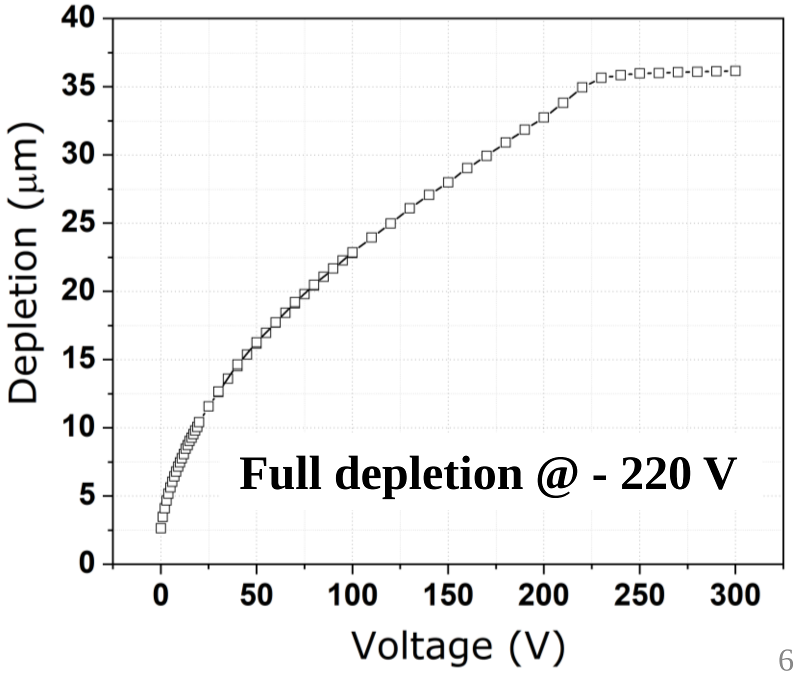


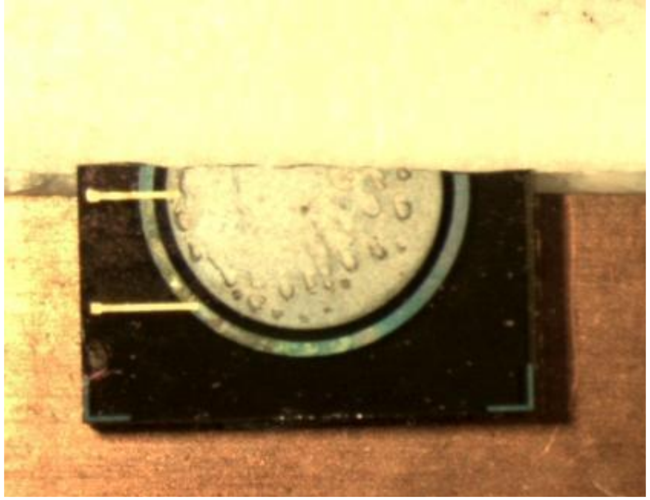
$qV_{bi} = (1{,}37 \pm 0{,}01)eV$

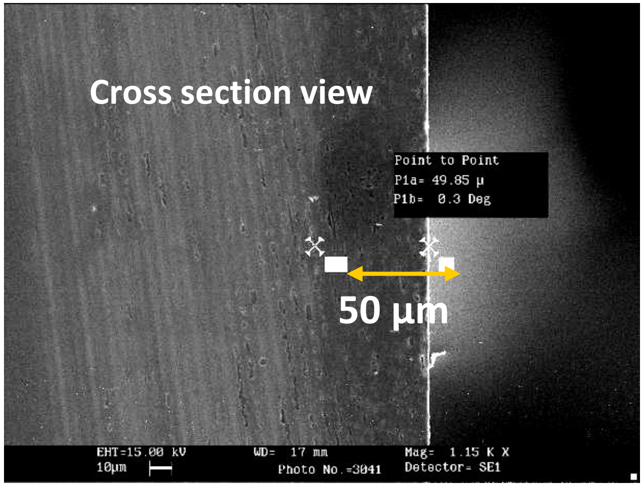
Effective doping

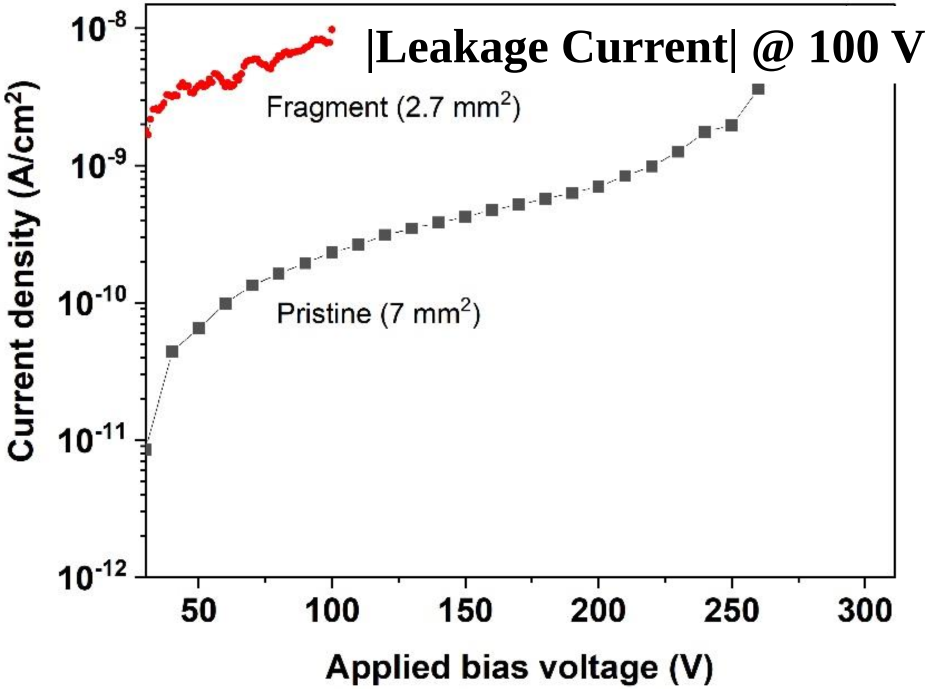


Full depletion @ - 220 V

Device cleavage for lateral IBIC investigation





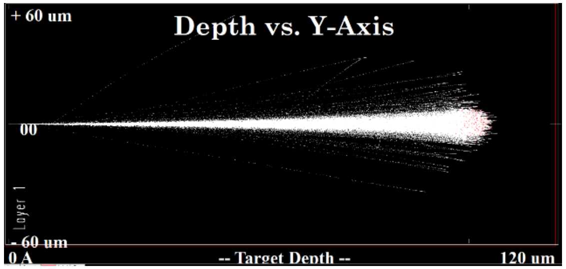


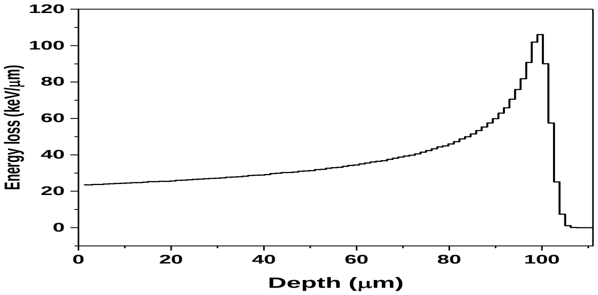
|Leakage Current| @ 100 V < 1 nA

1 - Pristine diode: Lateral IBIC

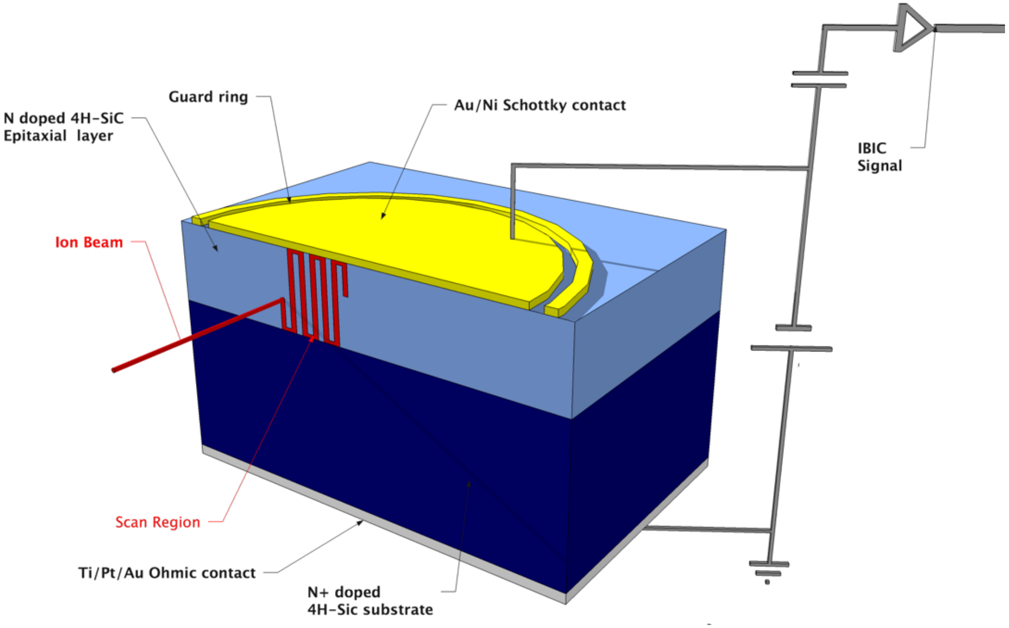
Laboratory for Ion Beam Interactions, Ruder Boškovic Institute, Zagreb, Croatia

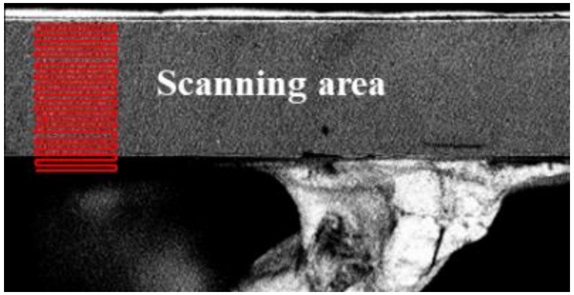
4 MeV protons
2 µm beam spot size (FWHM)
Charge sensitivity 1800 electrons/channel -> 14 keV in SiC
Spectral resolution: 12000 electrons (FWHM) ->94 keV in SiC



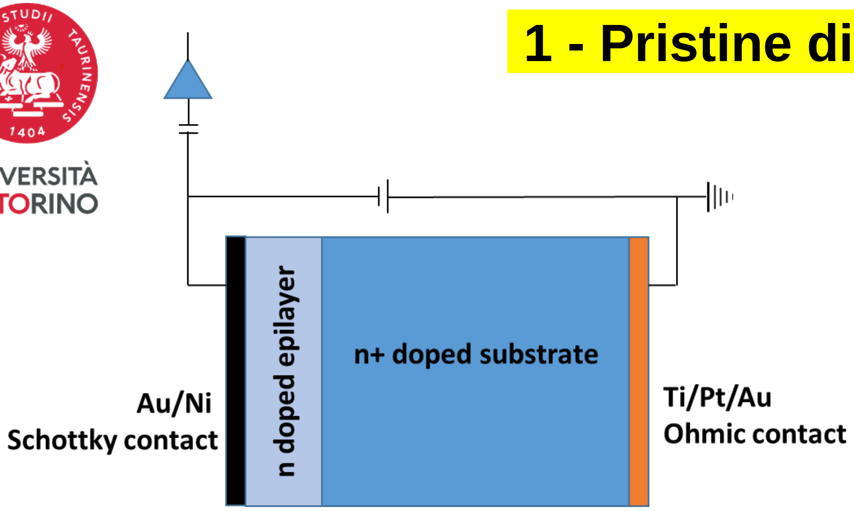


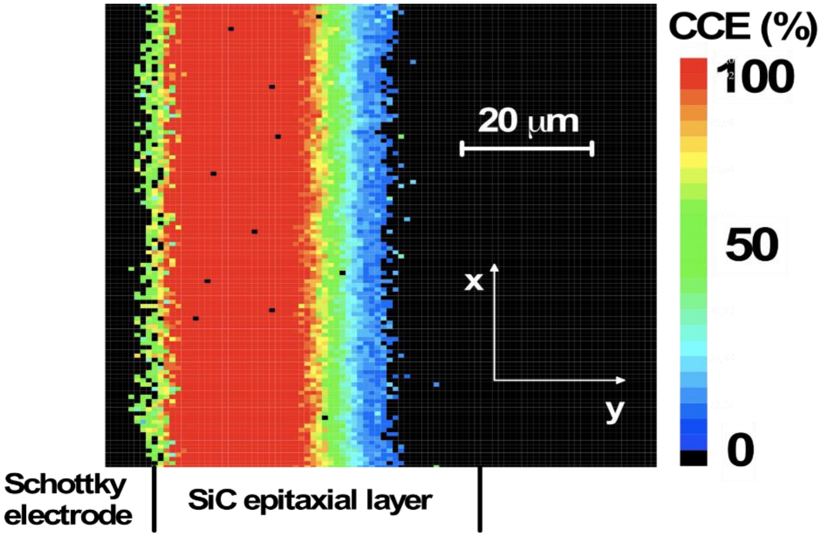
Range
Longitudinal: 100 µm
Lateral: 2.6 µm



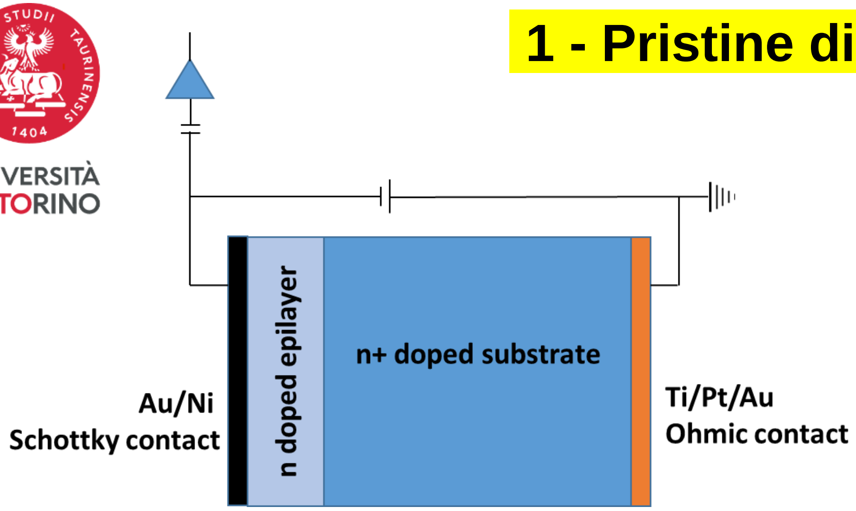


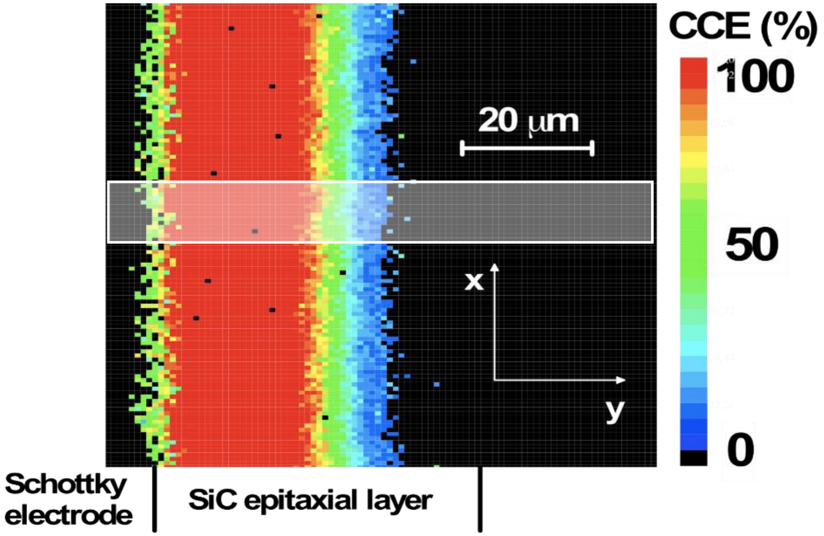
1 - Pristine diode: Lateral IBIC

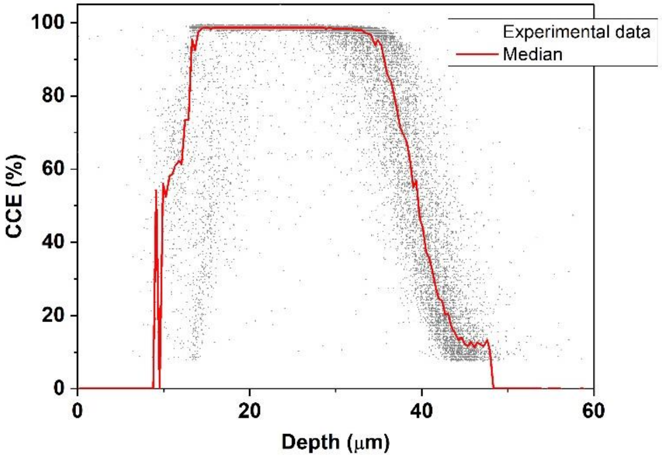




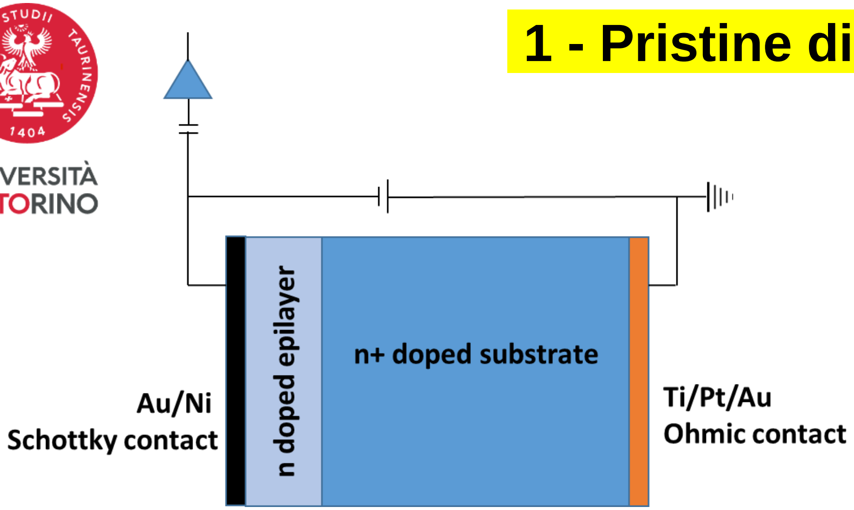
1 - Pristine diode: Lateral IBIC

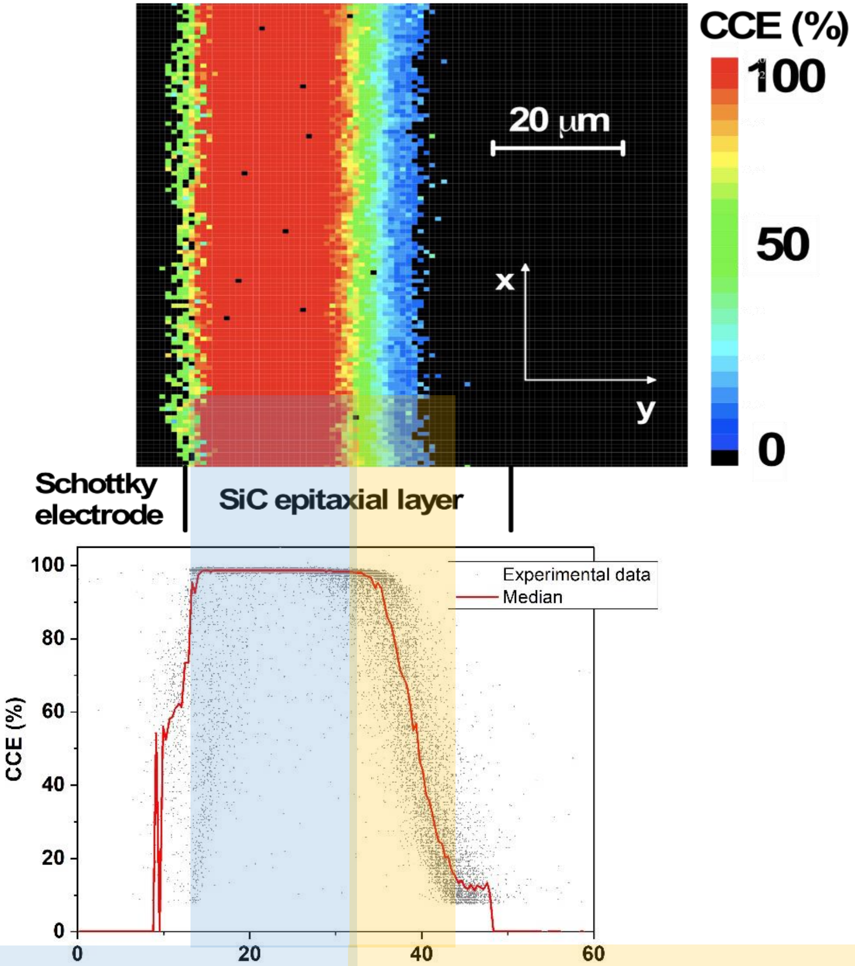






1 - Pristine diode: Lateral IBIC



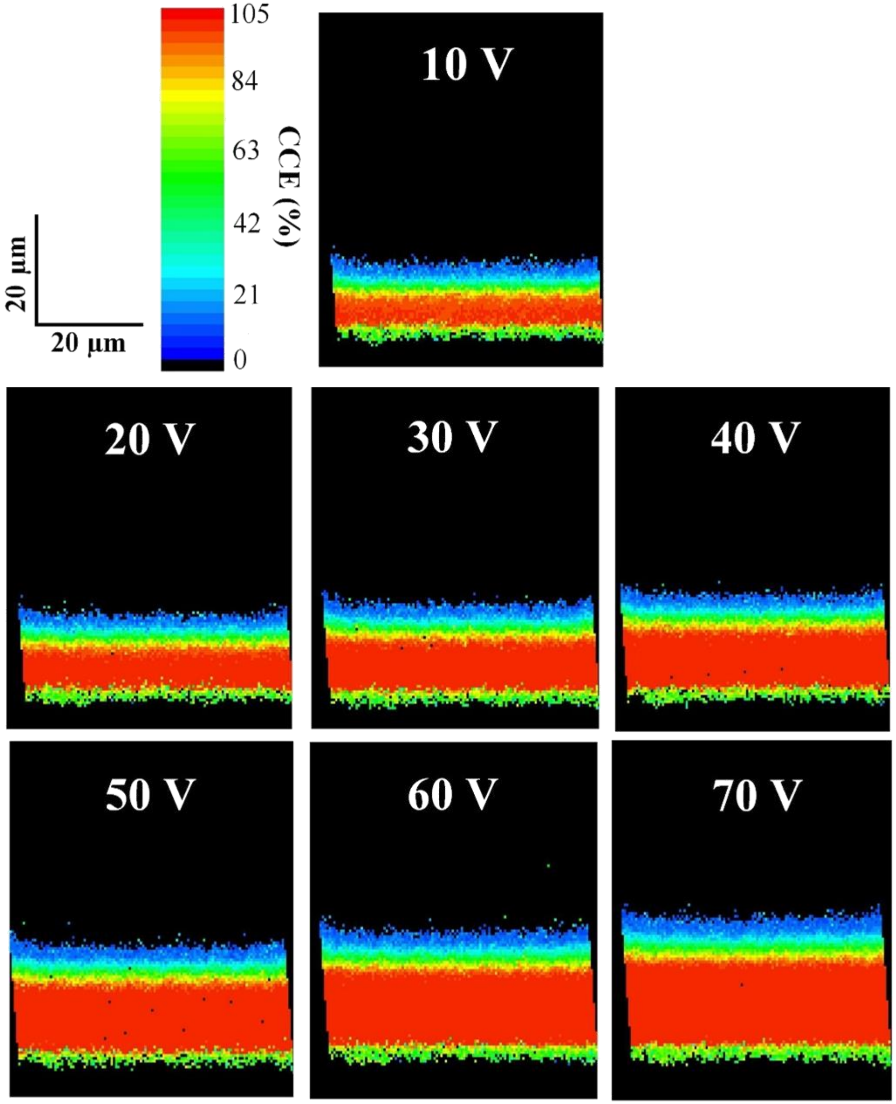


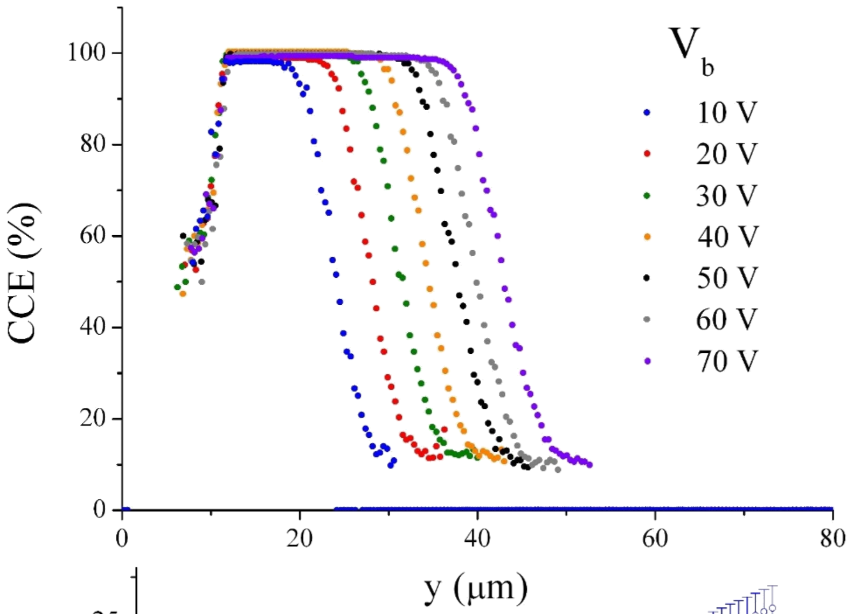
Drift-Diffusion model

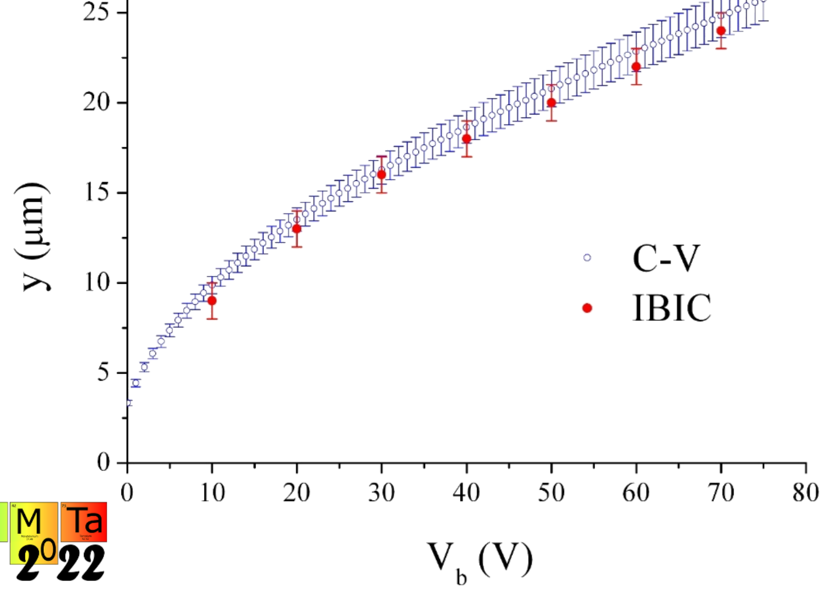
Depletion layer → **high electric field/drift velocity** → **Complete induced charge collection (Ramo theorem)**

Neutral layer → **Minority carrier diffusion** → **CCE exponential decay**

1 - Pristine diode: Lateral IBIC

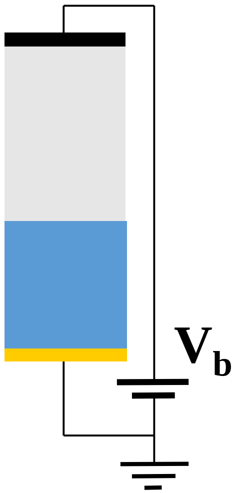


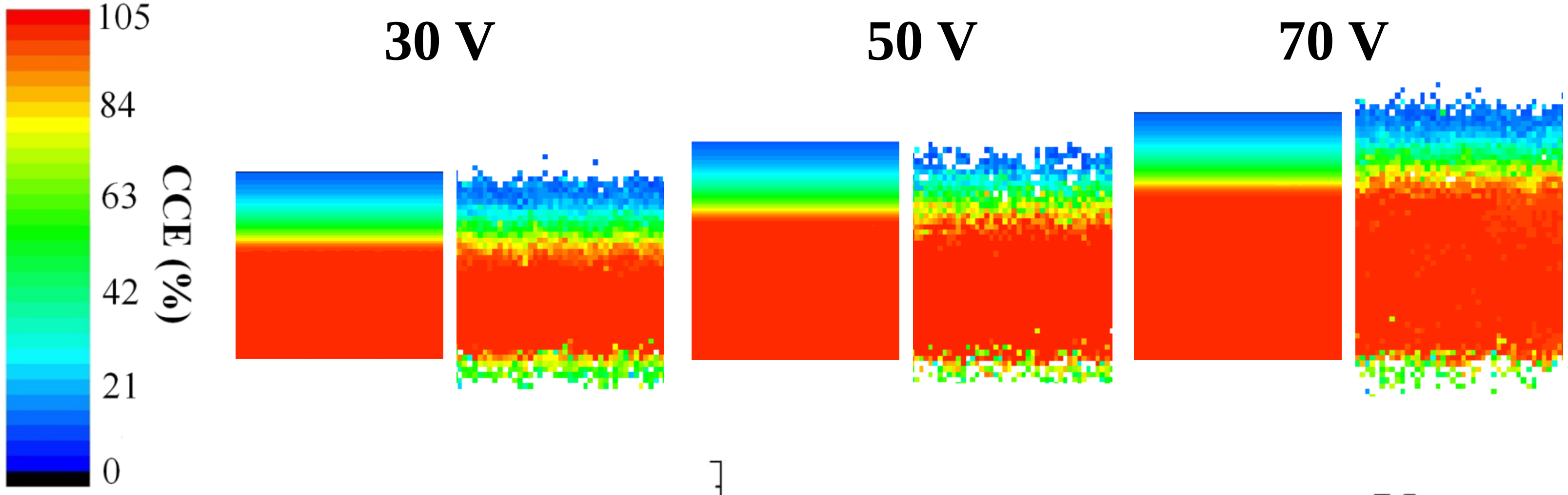




1 - Pristine diode: Lateral IBIC

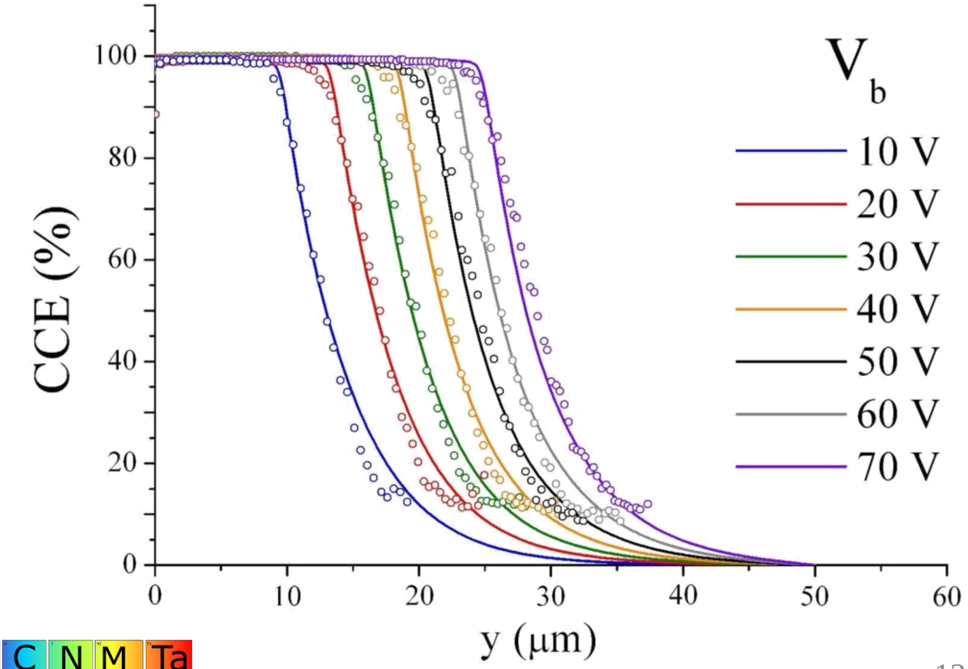
Drift-diffusion model - Simulation



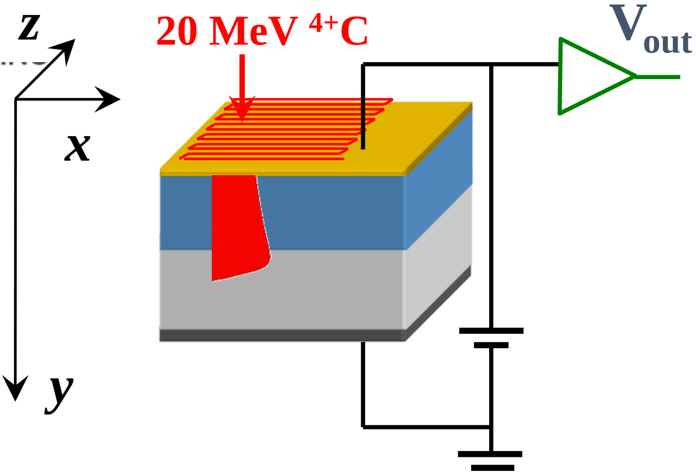


$$L_p = (4{,}9 \pm 0{,}3)\mu m$$

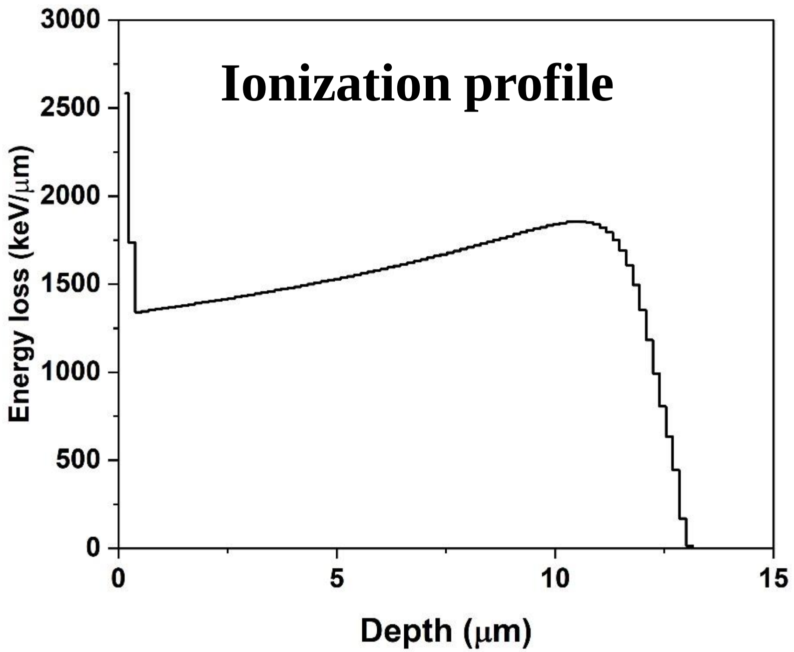
$$\tau_p \approx 80\, ns$$

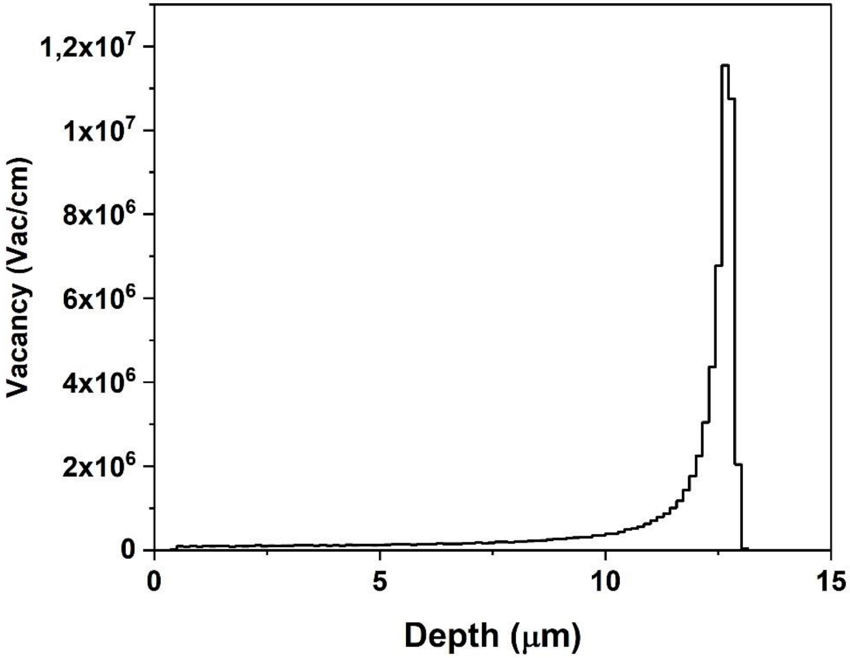


2 – Frontal irradiation



20 MeV C ions in 4H-SiC





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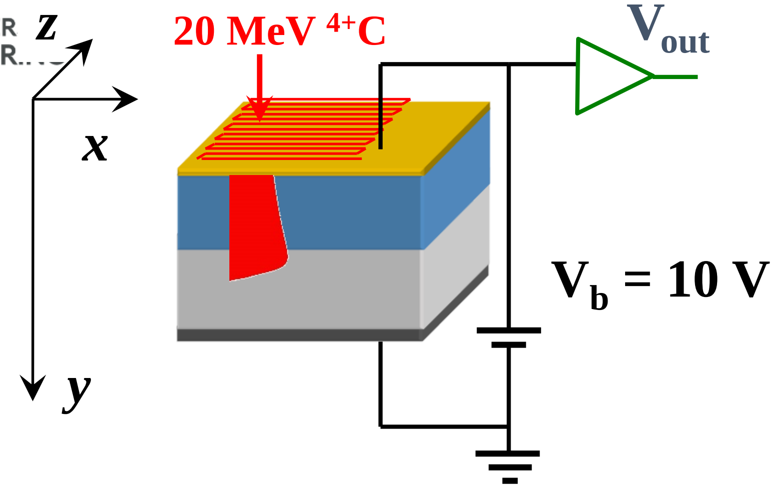

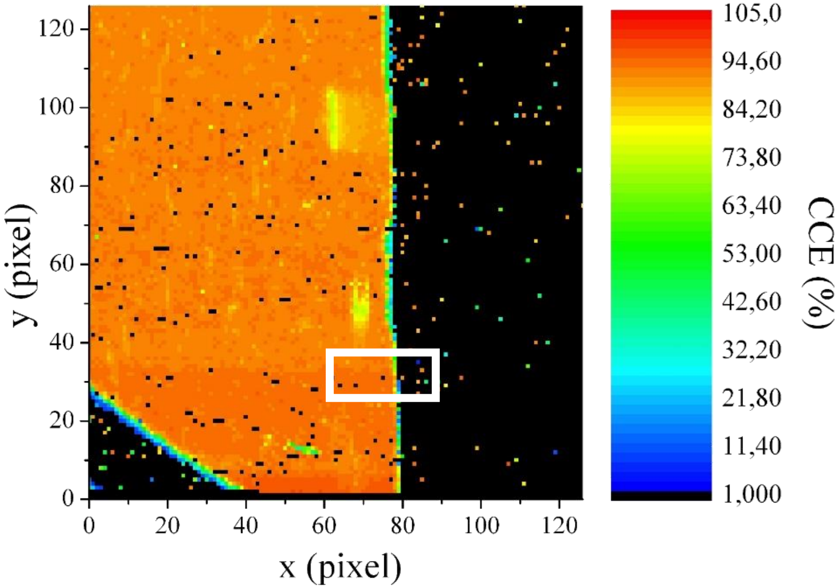

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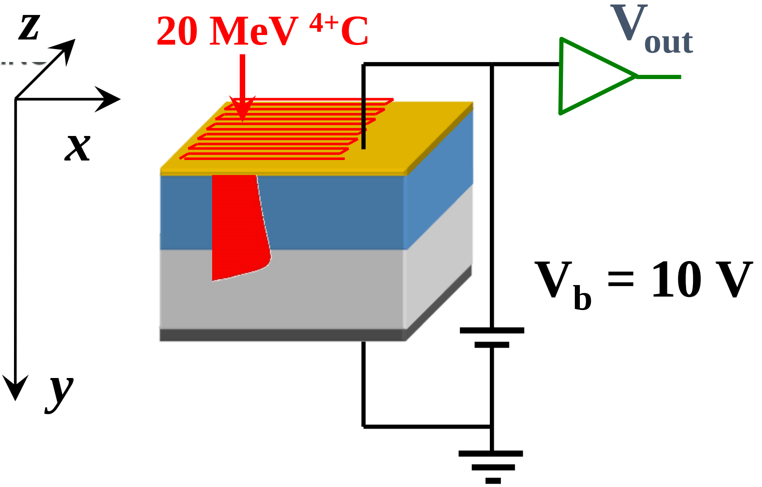

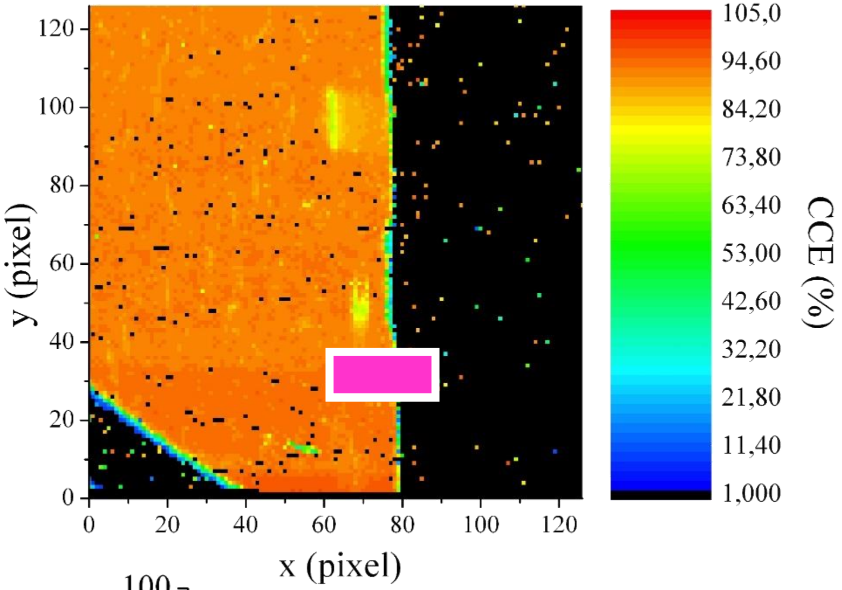

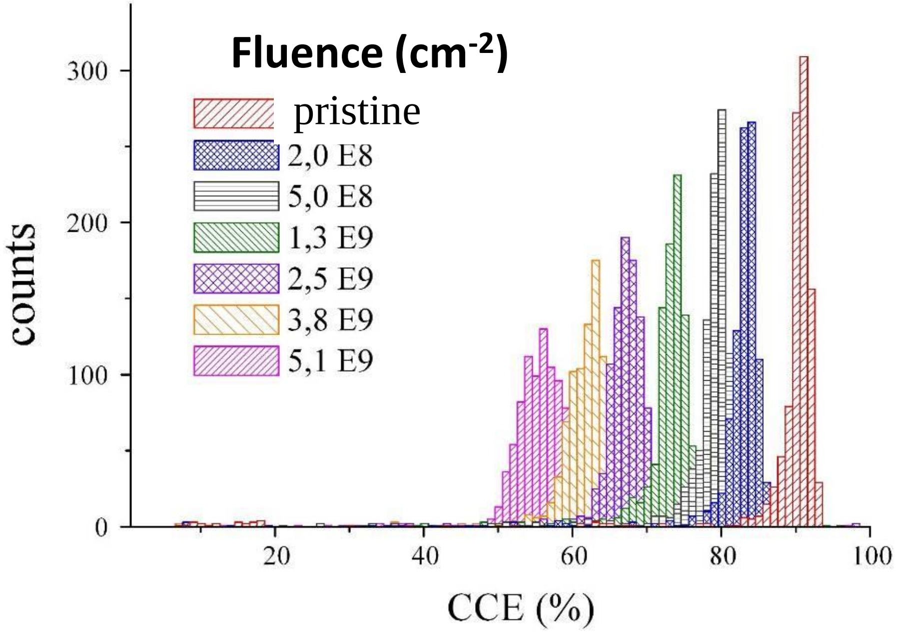

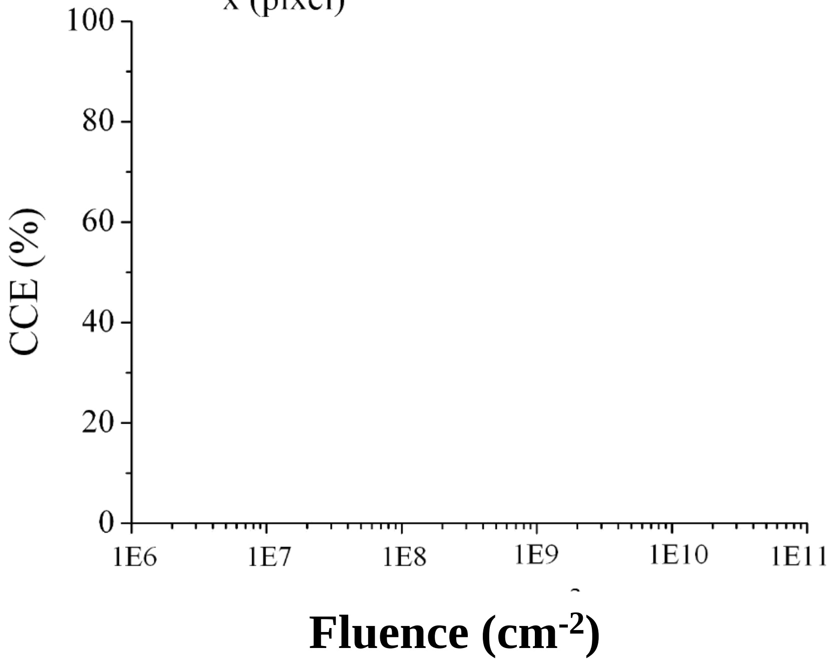

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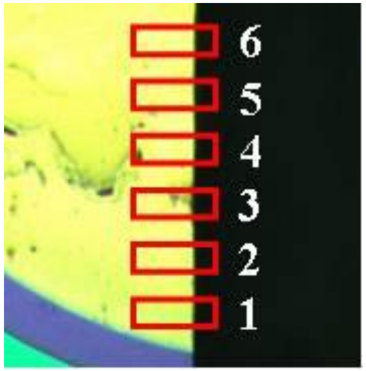
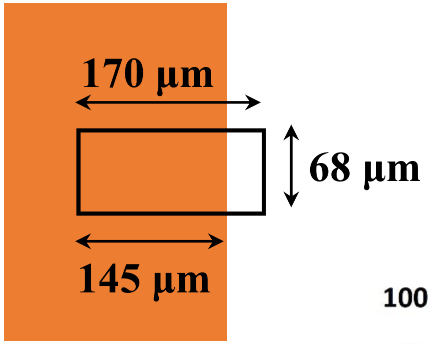




Fluence (cm^{-2})

Area 1 : $200 \cdot 10^8$

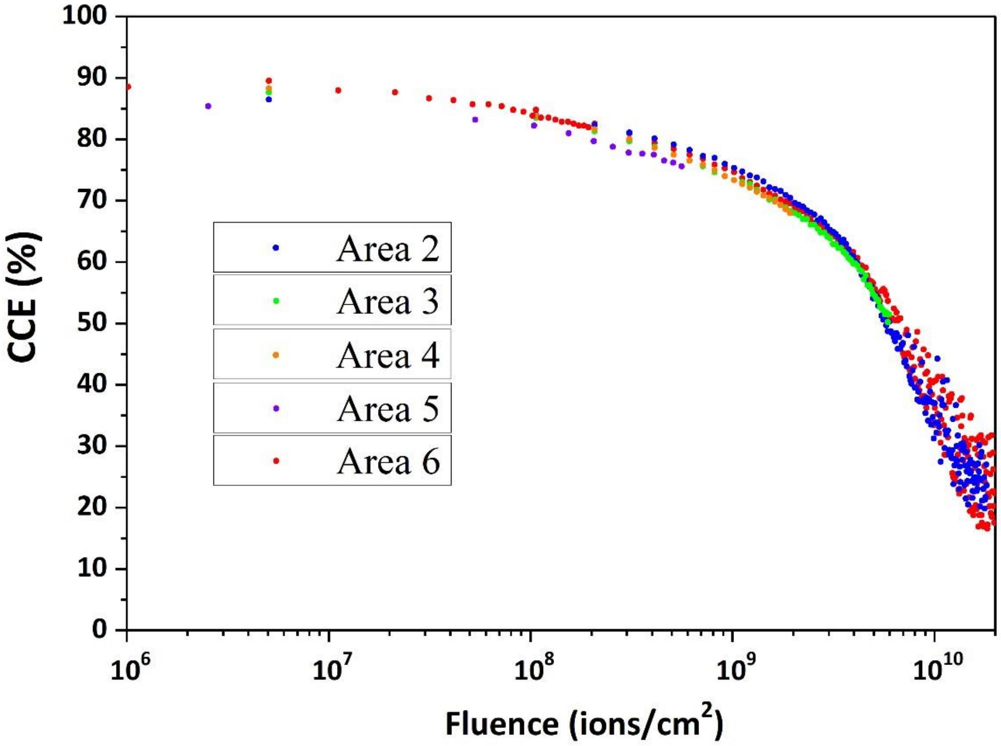
Area 2 : $180 \cdot 10^8$

Area 3 : $61 \cdot 10^8$

Area 4 : $20 \cdot 10^8$

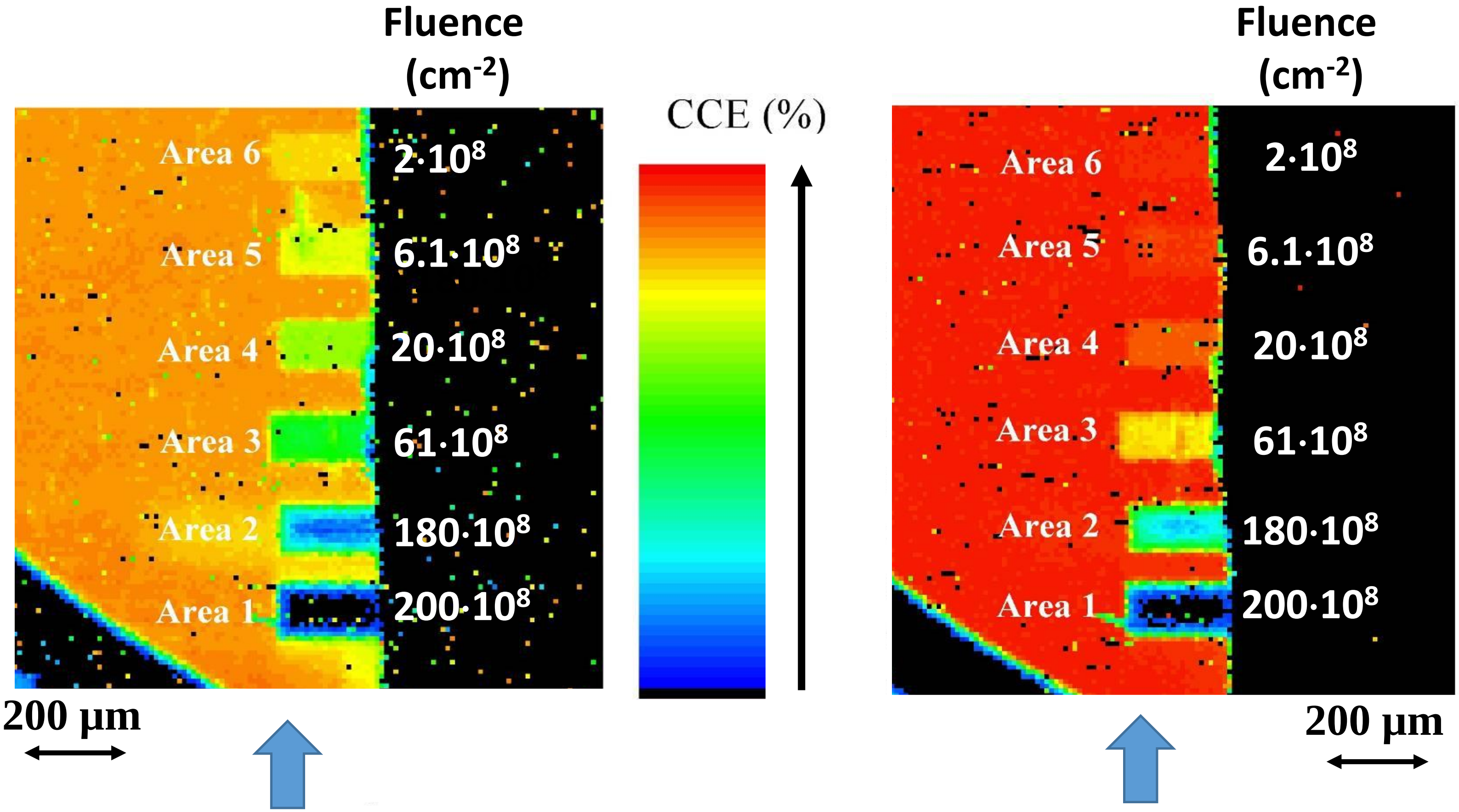
Area 5 : $6.1 \cdot 10^8$

Area 6 : $2.0 \cdot 10^8$



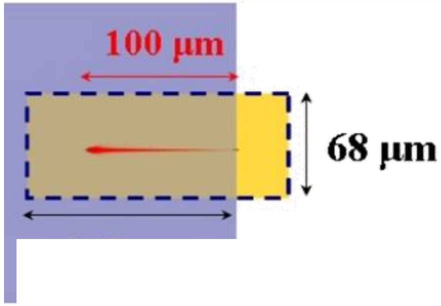
2 – Frontal irradiation

Damaging ions: C, 20 MeV

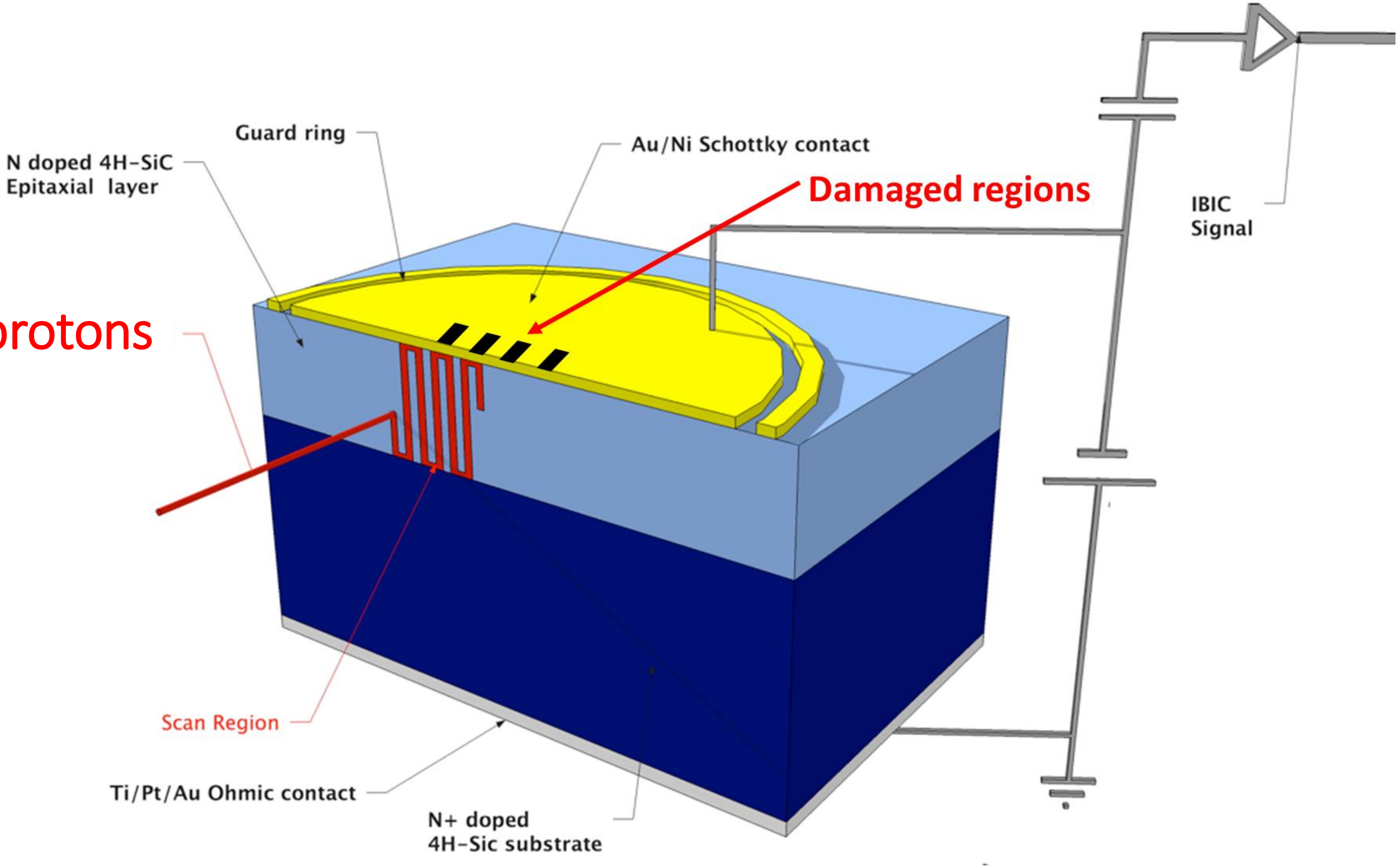


10 V Applied bias voltages 50 V

3 – Lateral IBIC



4 MeV protons



3 – Lateral IBIC

Recombination centers ← Radiation damage

↓

Decrease of the carrier lifetime

↓

CCE degradation

Electrically active deep-level defects

↓

Doping compensation

↓

Modification of the Electrostatics

JOURNAL OF APPLIED PHYSICS **104**, 093711 (2008)

Electrical properties of high energy ion irradiated 4*H*-SiC Schottky diodes

G. Izzo,[1] G. Litrico,[1] L. Calcagno,[1,a)] G. Foti,[1] and F. La Via[2]
[1] *Physics Department, Catania University, Via S. Sofia 64, 95123 Catania, Italy*
[2] *CNR-IMM, Sezione di Catania, Stradale Primosole 50, 95121 Catania, Italy*

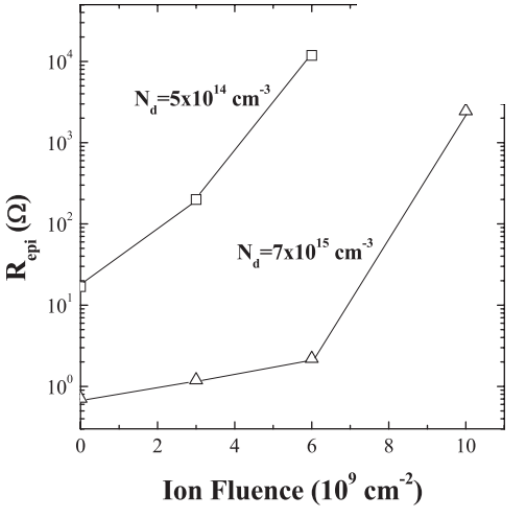
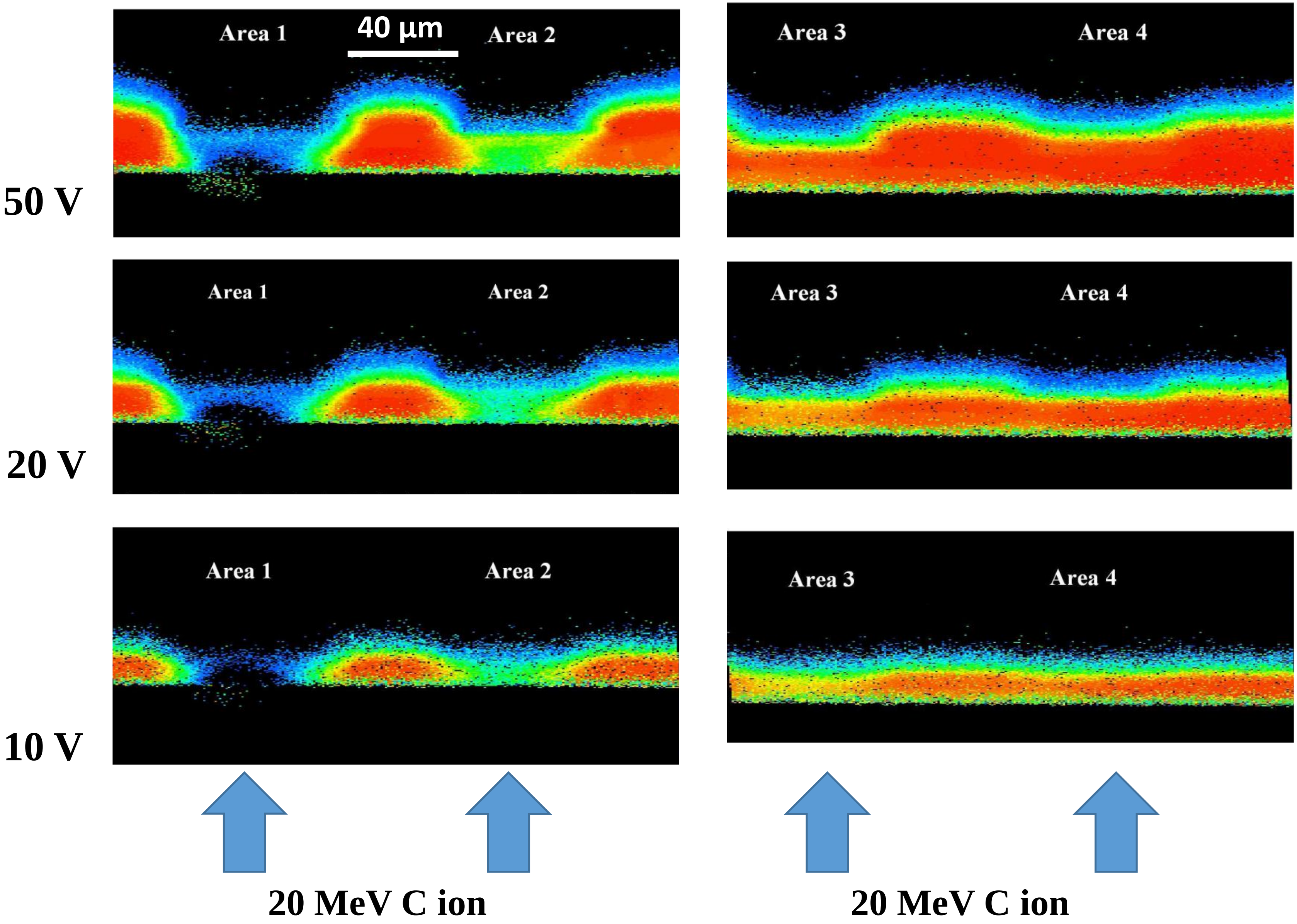
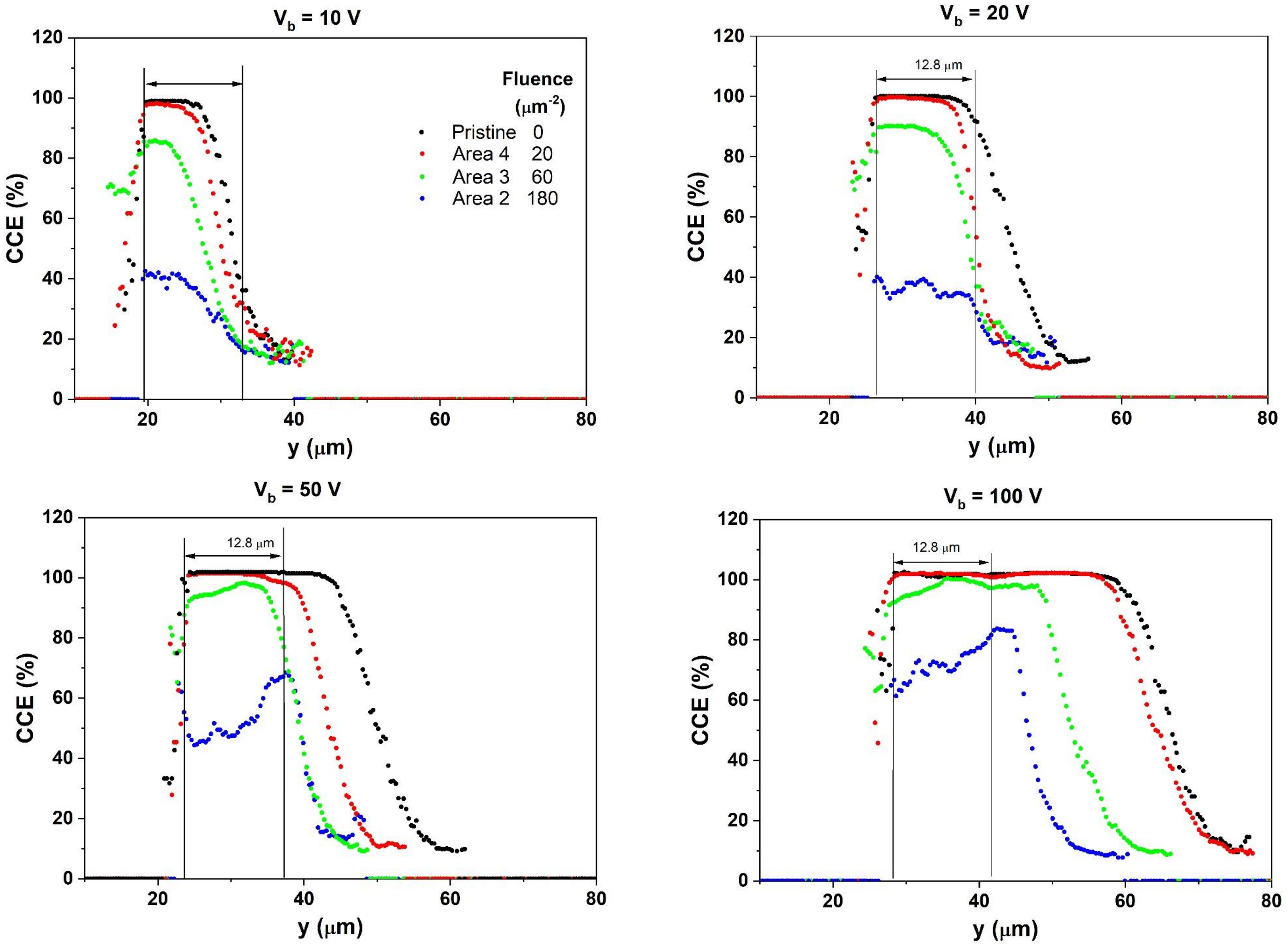


FIG. 2. Epilayer resistance as a function of ion fluence for two different epilayer concentrations.

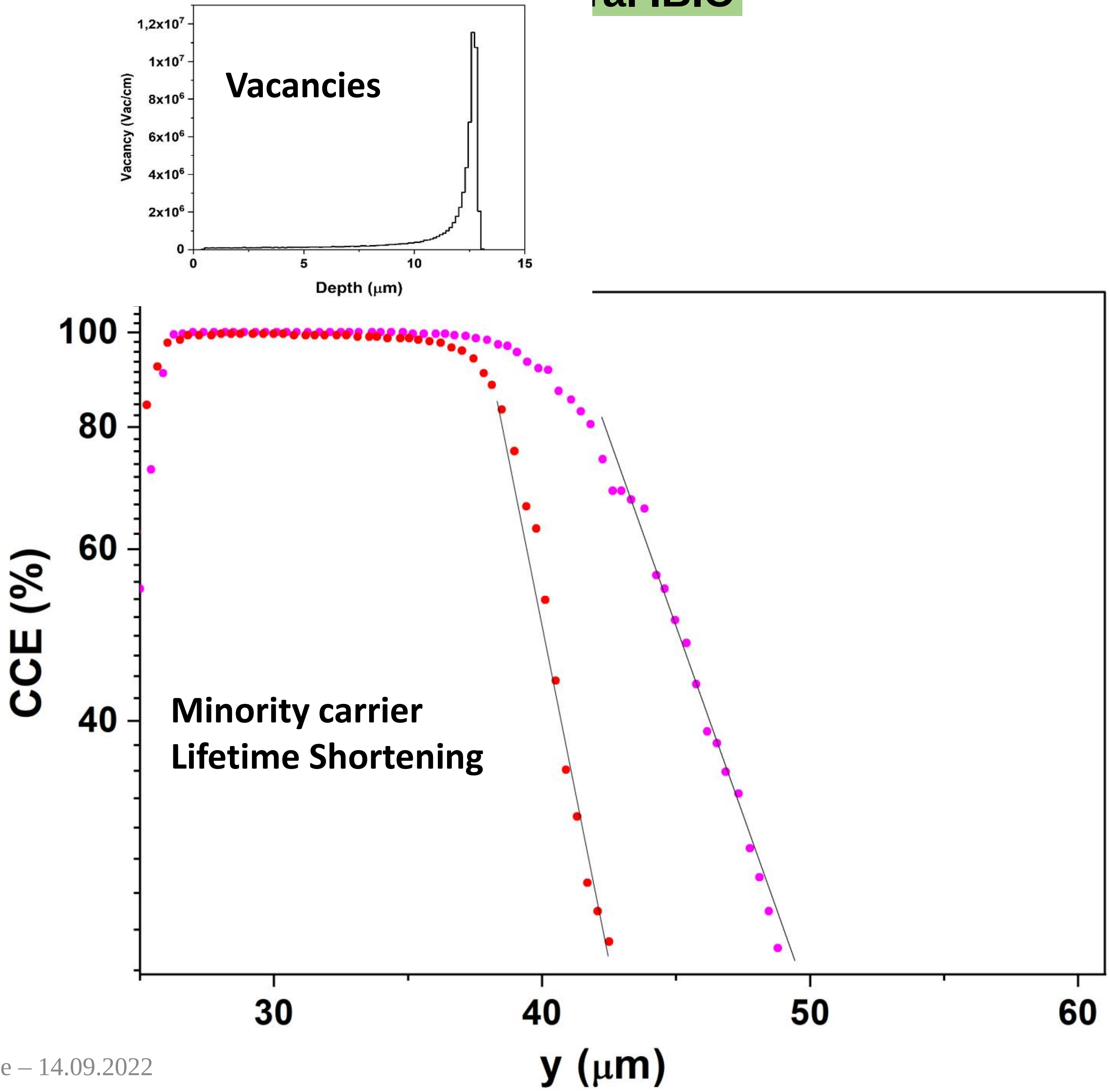
3 – Lateral IBIC



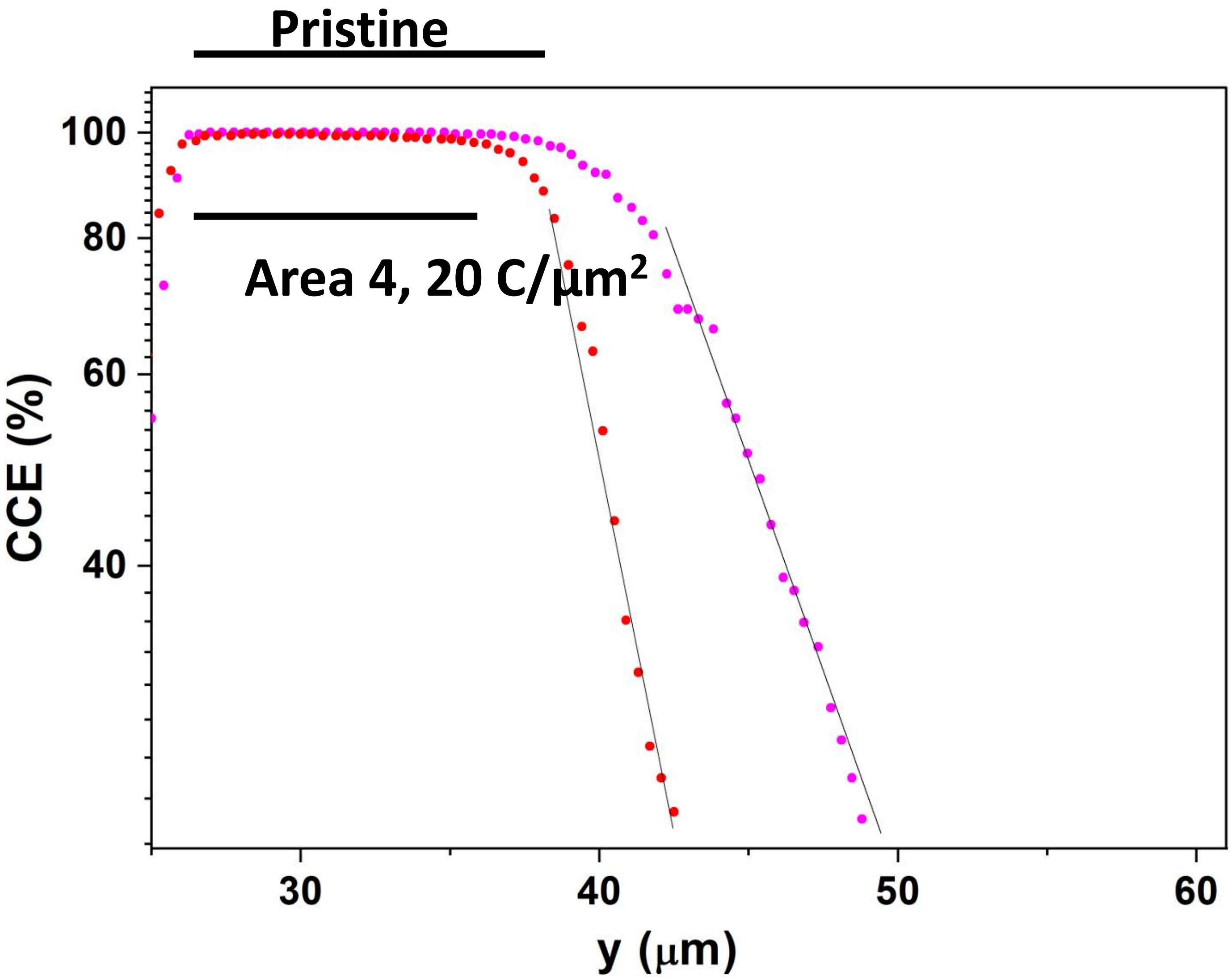
3 – Lateral IBIC



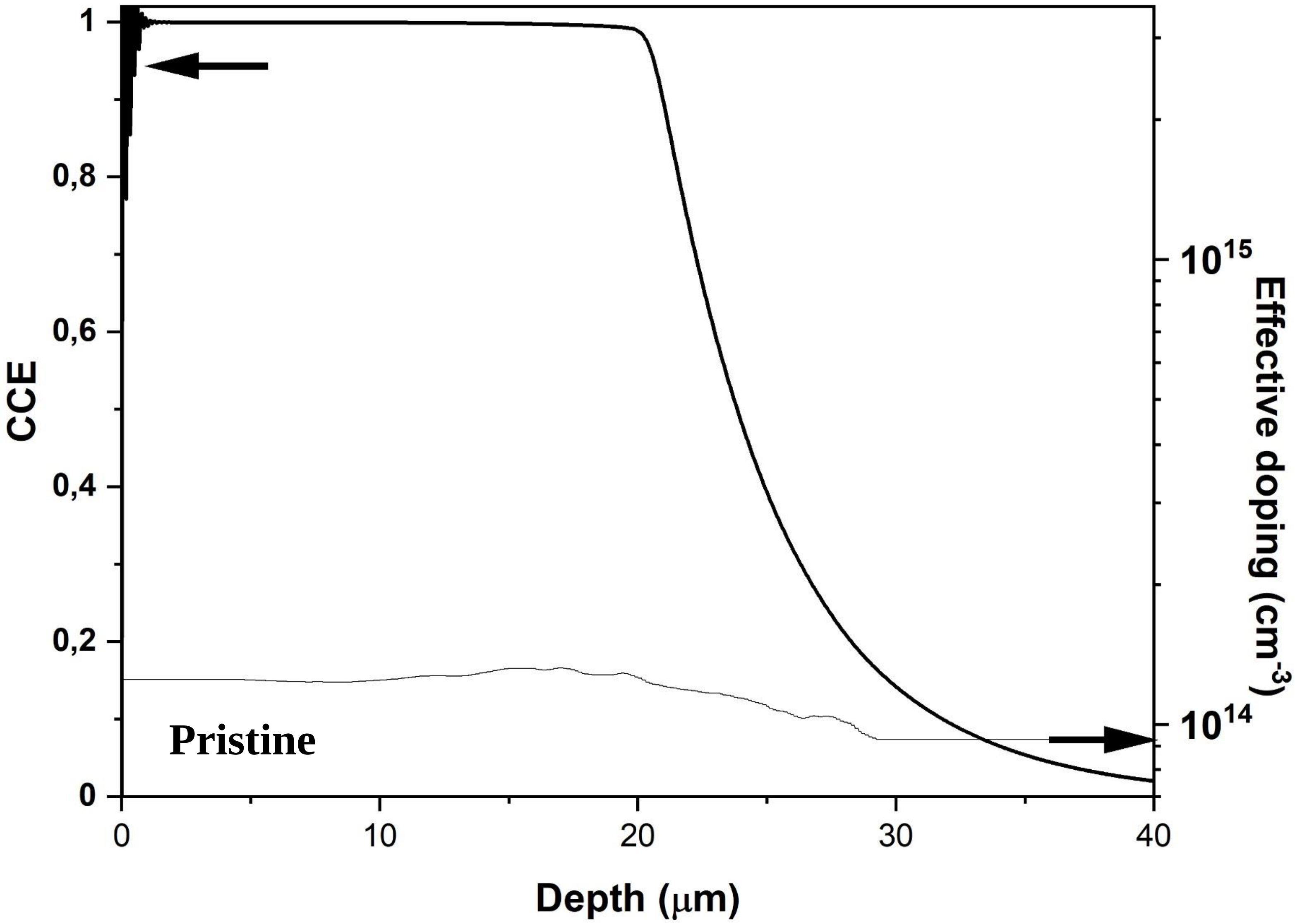
ral IBIC


Vacancies
Vacancy (Vac/cm)
1,2x10^7
1x10^7
8x10^6
6x10^6
4x10^6
2x10^6
0
0
5
10
15
Depth (μm)
CCE (%)
100
80
60
40
30
40
50
60
y (μm)
Minority carrier
Lifetime Shortening

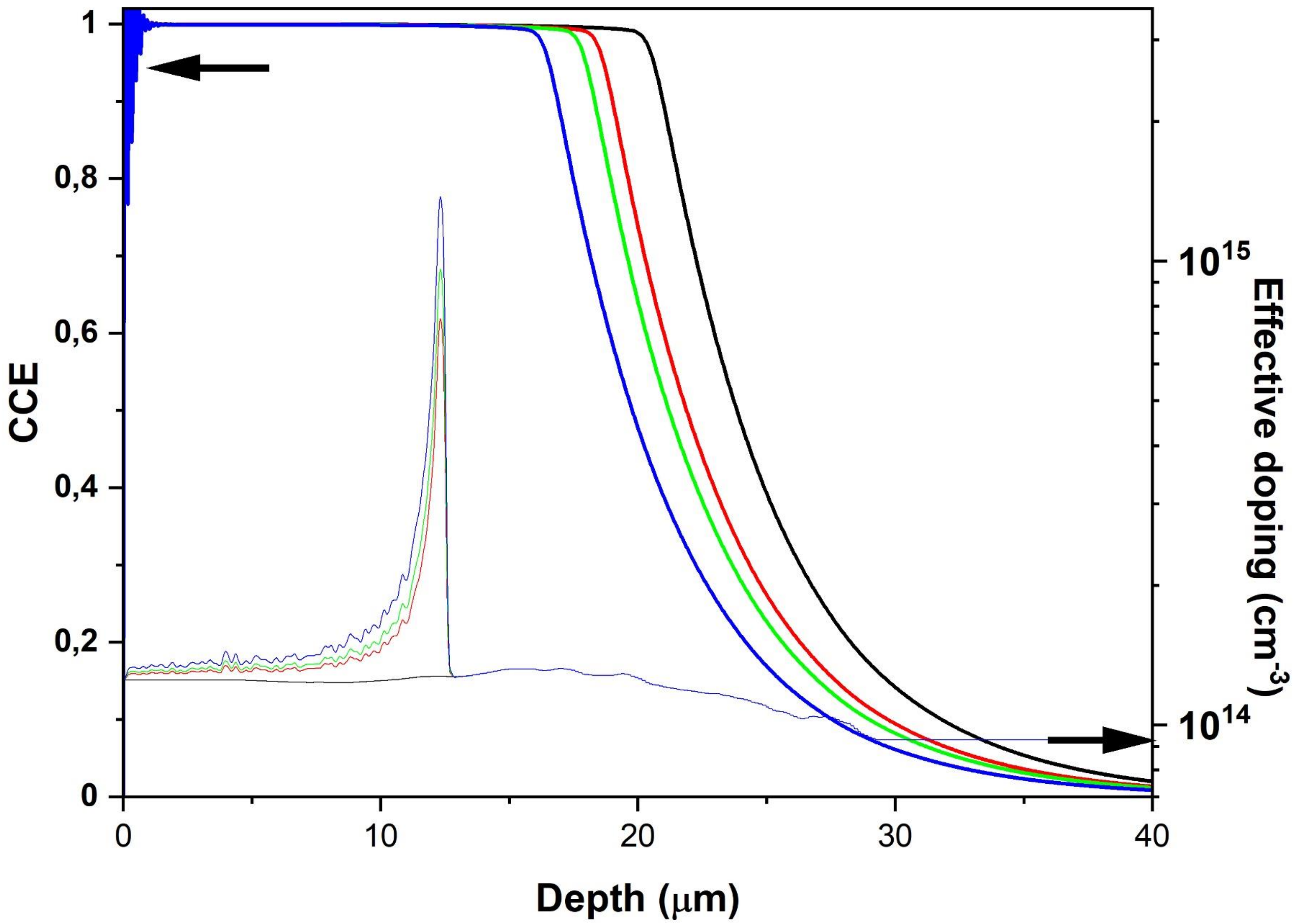
3 – Lateral IBIC



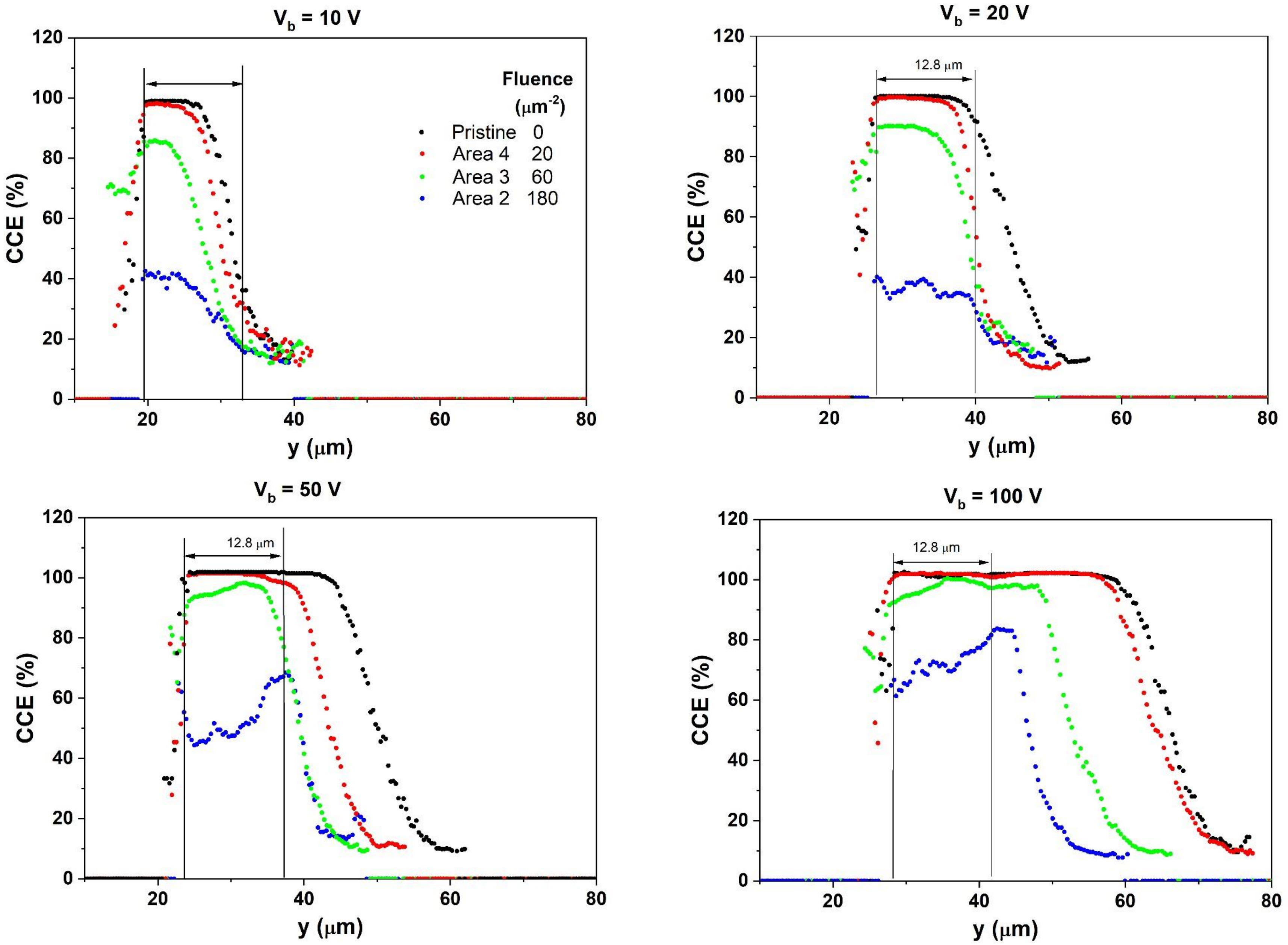
3 – Lateral IBIC



3 – Lateral IBIC



Lateral IBIC



ICNMTa 2022

Conclusions

Lateral IBIC for the functional characterization of a 4H-Schottky diode

The CCE profiles of the pristine diode

- **Show an evolution of the depletion layer in agreement with that extracted from the C-V characterization**
- **From the analysis of the exponential decay of CCE in the neutral regions → minority carrier (hole) lifetime = 80 ns.**

Irradiation of selected regions with 20 MeV C ions at different fluences

The CCE profiles of the irradiated regions

- **Show a decreasing of the CCE, which is compatible with the decreasing of the carrier lifetimes induced by radiation damage**
- **The shrinkage of the depletion layer as a function of the damaging ion fluence can be interpreted as due to the formation of charge defects following the damage profile, which act as donor traps**