DIEGM – Gruppo Elettronica
Via delle Scienze, 208 – 33100 Udine

Capacitance and breakdown measurements on virgin and neutron irradiated DDTC and STC diodes

A. Cristofoli, A. Dalla Costa, P. Palestri, M.P. Giordani and L.Selmi

UNIVERSITY OF UDINE

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Prof. Gian-Franco Dalla Betta (DISI, UniTN), **dr. Vladimir Cindro (IJS, Ljubljana), dr. Maurizio Boscardin (FBK, Trento), dr. Elisa Vianello (FBK, Trento).**

Outline:

- ***Effect of Radiation on the Impact Ionization coefficients***
- CV and IV measurements on STC and DDTC 3D-FBK
- CV and IV measurements after irradiation with reactors neutrons
- DDTC TCAD simulations

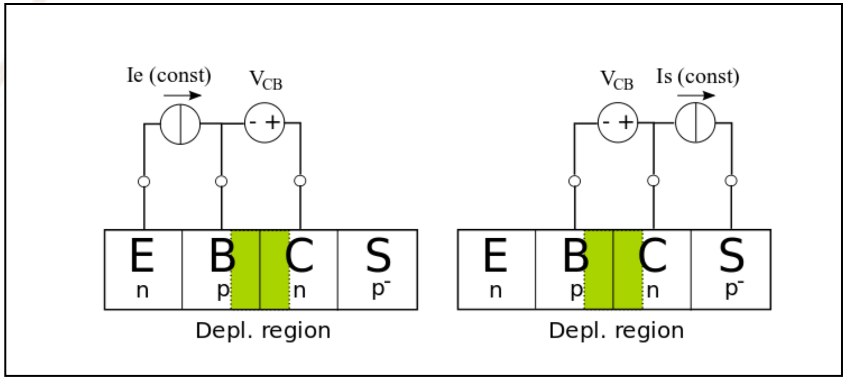
Effect of Radiation on the Impact Ionization Model

Motivations:

- Operation @ full depletion ↔ Detector Breakdown
- Charge Multiplication @ Very high fluences → Calibration of avalanche multiplication for simulations

Devices:

- Planar BJTs;
- Irradiations: TRIGA reactor in Ljubljana;
- Fluences : $1x10^{14}$ n·cm^{-2} and $1x10^{15}$ n·cm^{-2};



Work submitted to IEEE Transactions on Nuclear Science:

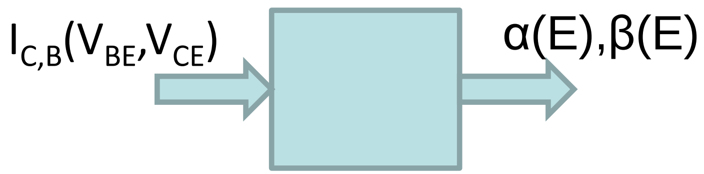
A. Cristofoli, P. Palestri, M.P. Giordani, V. Cindro, G.-F. Dalla Betta and L. Selmi:

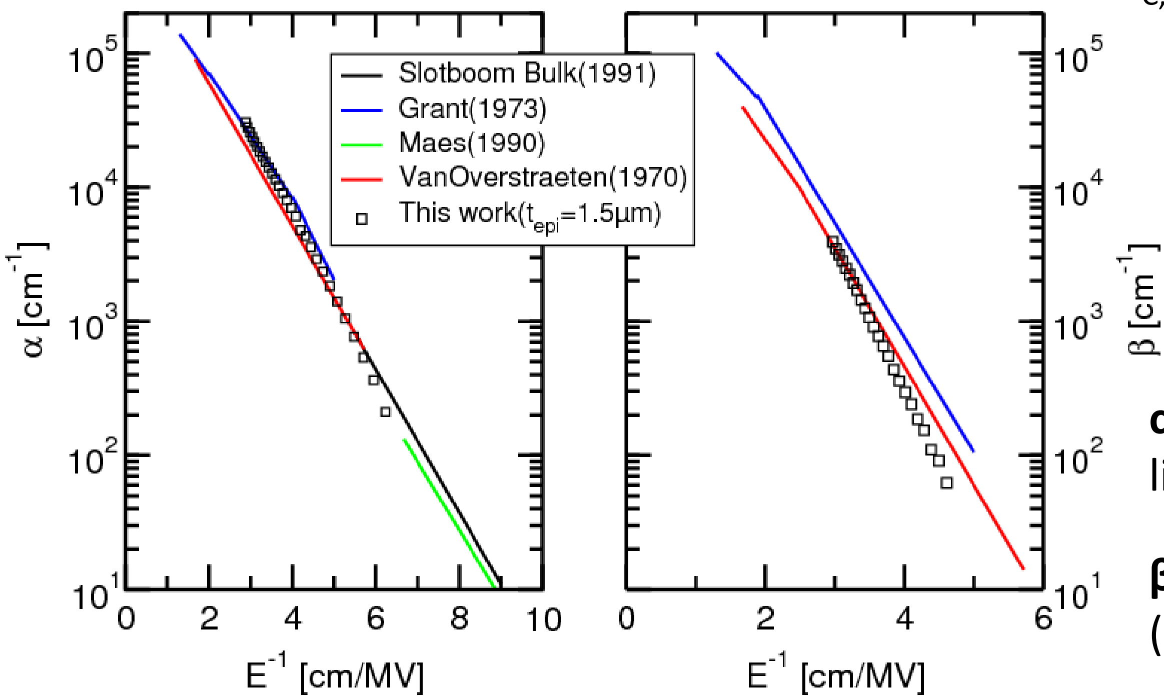
" Experimental Determination of the Impact Ionization Coefficients in Irradiated Silicon"

α and β extraction before irradiation

- TCAD: Generation of e-h pairs is described by the I.I. coefficients;

$$G_{II}(\vec{r}) = \alpha\left(\left|\vec{E}\right|\right)\frac{\left|\vec{J}_n(\vec{r})\right|}{q} + \beta\left(\left|\vec{E}\right|\right)\frac{\left|\vec{J}_p(\vec{r})\right|}{q}$$





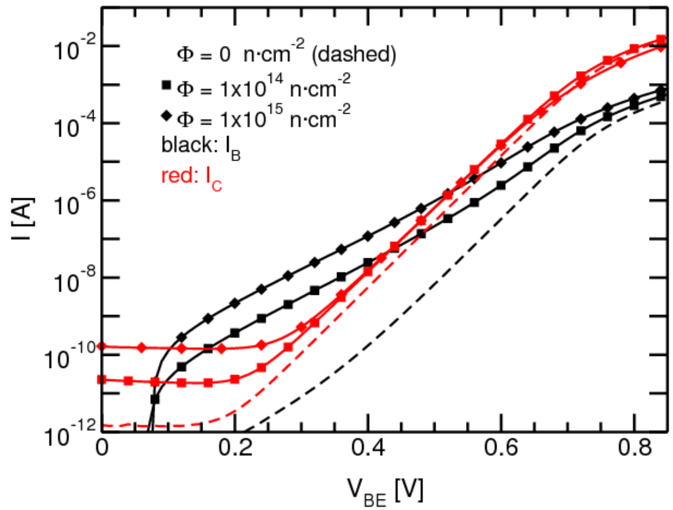
Further details in: ***Palestri et al., IEDM, 1998***

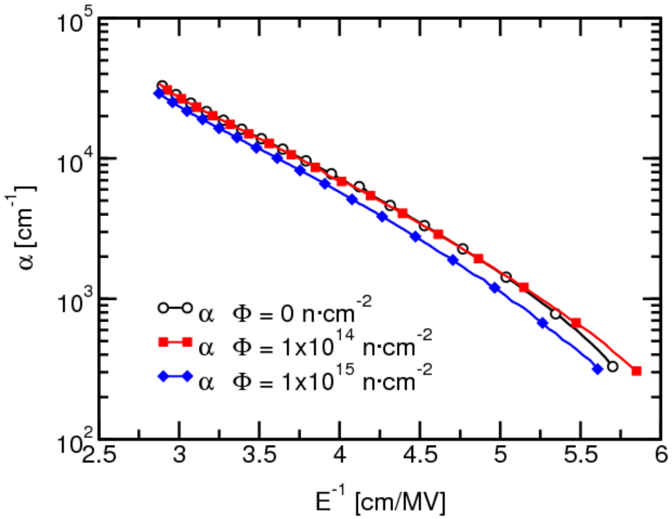
α: complete agreement with literature (Grant);

β: very close to literature data (VanOverstraeten);

Parasitics affect hole multiplication measurements.

α extraction after irradiation





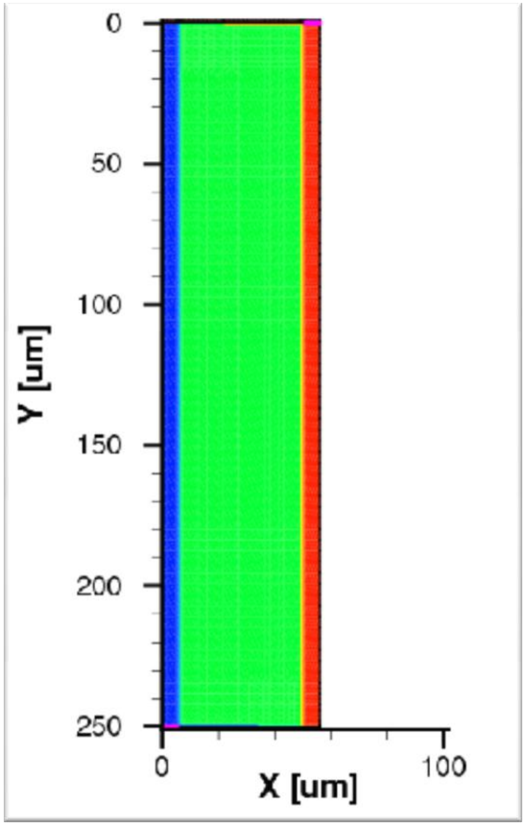
- Strong degradation of I_B: visible increase of SRH recombination in base region;
- npn gain (β_F) degradation in line with [Mandic et al., TNS 04].
- pnp devices not operable after irradiation.

•Study limited to α;

- Almost no variation for $\Phi = 1x10^{14}$ n·cm^{-2};
- Clear reduction for $\Phi = 1x10^{15}$ n·cm^{-2};

Effect on 3D sensor breakdown: TCAD Simulations

- Simulations with Sentaurus TCAD tool;
- Test Structure: 3D-4E detector:
  - Substrate thickness: 250 µm
  - Column pitch: 56 µm
  - Electrodes etched through the entire substrate;
  - Template p-spray and superficial implantation profiles;
  - $Q_{ox} = 1x10^{11}$ cm^{-2};



Effects on Breakdown Simulations

Φ $[n \cdot cm^{-2}]$	MODEL ADOPTED	V_{BR} [V]
0	α, β from [VanOverstraeten70]	172
0	α, β this work (α from [Grant73], β from [VanOverstraeten70])	163.5
1×10^{15}	α, β this work No Radiation Damage Effects	169
1×10^{15}	α from [Grant73], β from [VanOverstraeten70] Substrate Radiation Damage Effects: Doping & Carrier Lifetimes	158.1
1×10^{15}	α, β this work Substrate Radiation Damage Effects: Doping & Carrier Lifetimes	163

Default TCAD calibration

α from [Grant73]
β from [VanOverstraeten70]
=OUR WORK

I.I. coefficients measured in irradiated silicon
No other radiation effects

Bulk Radiation damage (N_{eff} & $\tau_{e,h}$)
I.I. coefficients measured in irradiated silicon

- Reduction of α at high fluence → 4% increase in the breakdown voltage.
- LHC Phase I & LHC Phase II: 5x to 10x higher fluences w.r.t. this work → changes of the I.I. coefficients may strongly impact performance

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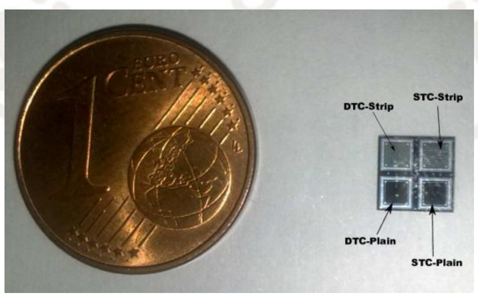
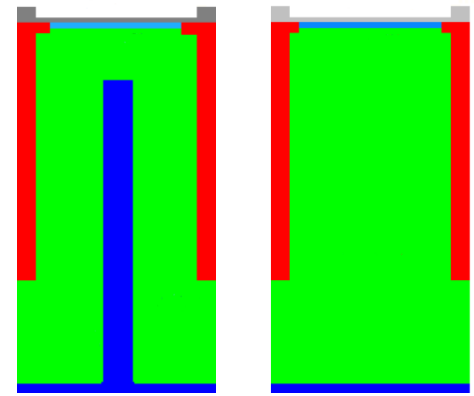
- ***CV and IV measurements on STC and DDTC 3D-FBK***
- CV and IV measurements after irradiation with reactors neutrons
- DDTC TCAD simulations

Pre-irrad. measures on 3D-FBK diodes

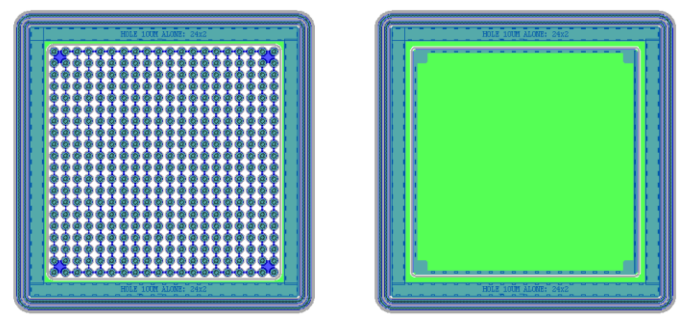
- 3D diodes: STC and DDTC
- PLAIN & STRIP
- Column pitch: 80 and 100 µm
- Wafer thickness: 200 µm
- Array of 20x20 or 16x16 columns
- Guard ring surrounding the array



- CV and IV characterization to tune simulations.

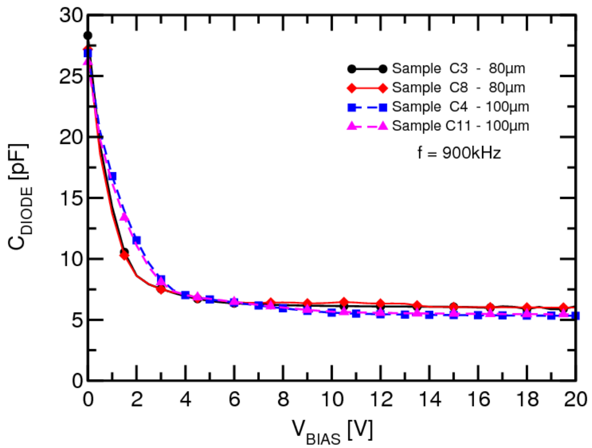


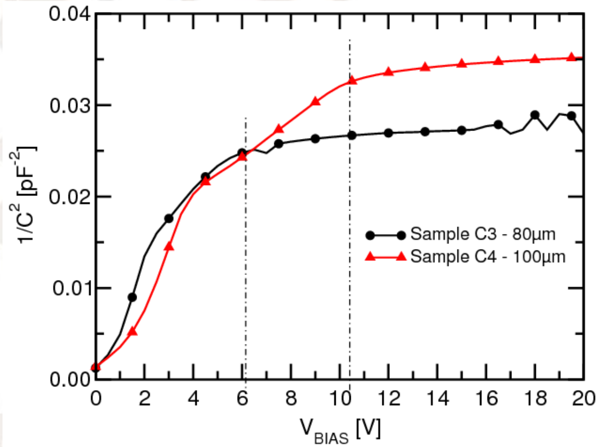
DDTC   STC

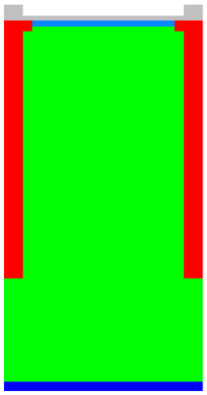


STRIP   PLAIN

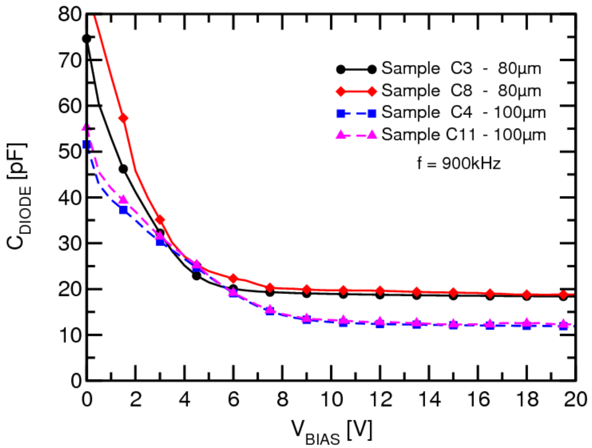
CV: STC vs DDTC

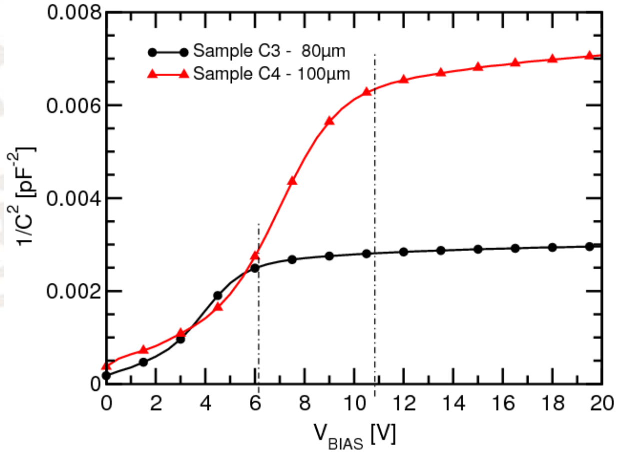


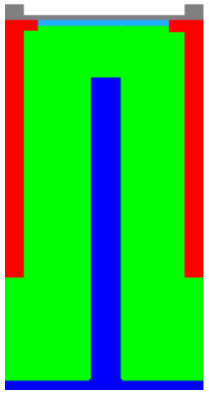




STC-strip





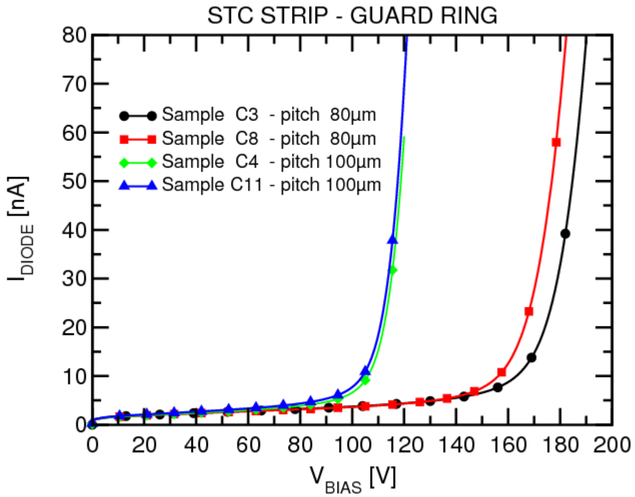


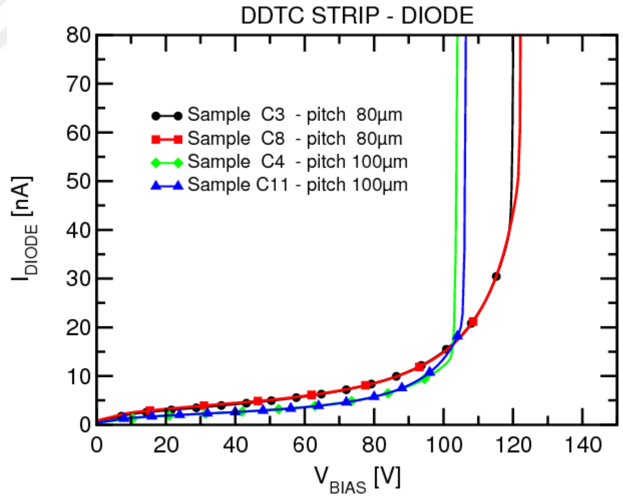
DDTC-strip

Plain diodes = Strip

IV: STC vs DDTC @ 23°C

V_{BR}	Samples C3 & C8 Pitch: 80µm		Samples C4 & C11 Pitch: 100µm	
	Diode	*Guard Ring*	*Diode*	*Guard Ring*
STC – Plain	> 200V	130V	> 200V	90V
STC – Strip	> 200V	160V	> 200V	100V
DDTC – Plain	> 200V	140V	> 200V	100V
DDTC – Strip	120V	> 200V	100V	> 200V





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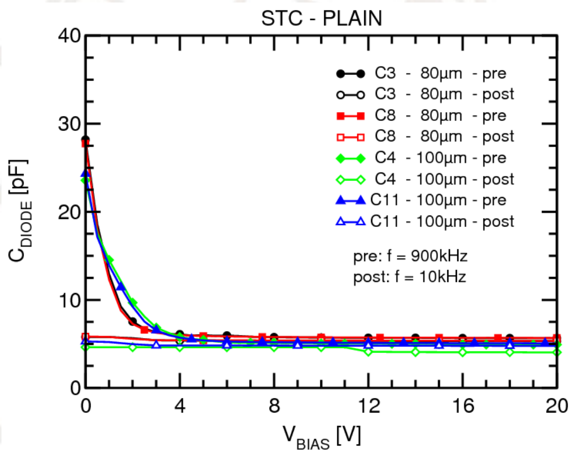
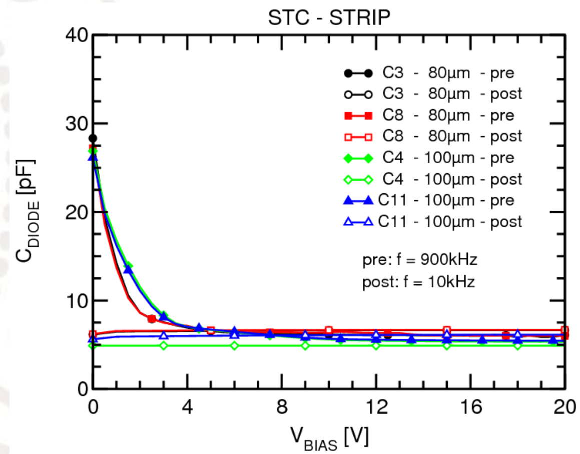
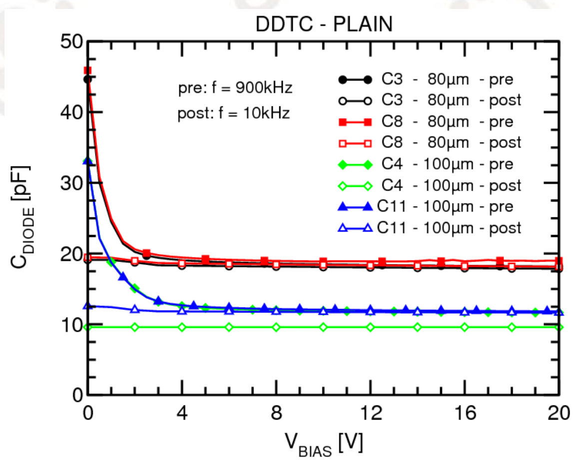
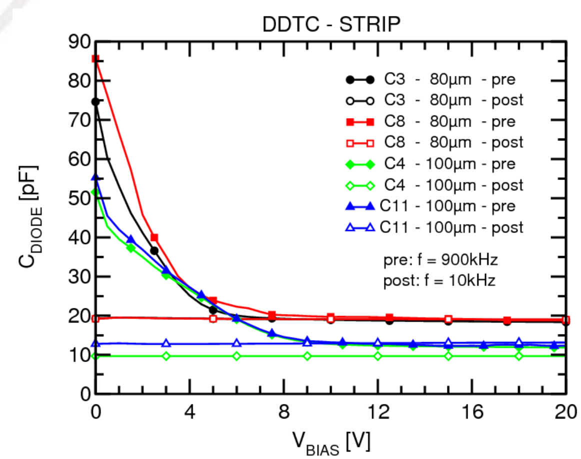
CV Post-Irradiation @ -20°C

Reactor's neutrons, $\Phi = 1\text{x}10^{15}\ \text{n}\cdot\text{cm}^{-2}$









IV Post-Irradiation: V_{BR} @ 23°C

Reactor's neutrons, $\Phi = 1x10^{15}\ n\cdot cm^{-2}$

V_{BR} [V]	Samples C3 & C8 Pitch: 80µm				Samples C4 & C11 Pitch: 100µm			
	Diode		*Guard Ring*		*Diode*		*Guard Ring*	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
STC – Plain	> 200	180	130	120	> 200	170	90	110
STC – Strip	> 200	190	160	120	> 200	170	100	110
DDTC – Plain	> 200	140	140	120	> 200	150	100	110
DDTC – Strip	120	110	> 200	110	100	120	> 200	110

IV Post-Irradiation: I_{LEAK} @ 60V

I_{LEAK} [A]		DIODE			GUARD RING		
		Pre	Post		Pre	Post	
		23°C	23°C	-20°C	23°C	23°C	-20°C
80 µm							
STC	PLAIN	0.12n	26µ	338n	2.9n	14µ	168n
	STRIP	1.7n	25µ	327n	3.3n	14µ	166n
DDTC	PLAIN	0.25n	27µ	355n	1.6n	14µ	167n
	STRIP	3.8n	29µ	340n	3.4n	13µ	167n
100 µm							
STC	PLAIN	0.12n	26µ	300n	1.8n	14µ	190n
	STRIP	1.4n	20µ	358n	3.3n	14µ	181n
DDTC	PLAIN	0.22n	27µ	321n	1.6n	14µ	186n
	STRIP	6n	22µ	267n	3.4n	13µ	178n

Higher I_{LEAK} w.r.t. uncutted samples.

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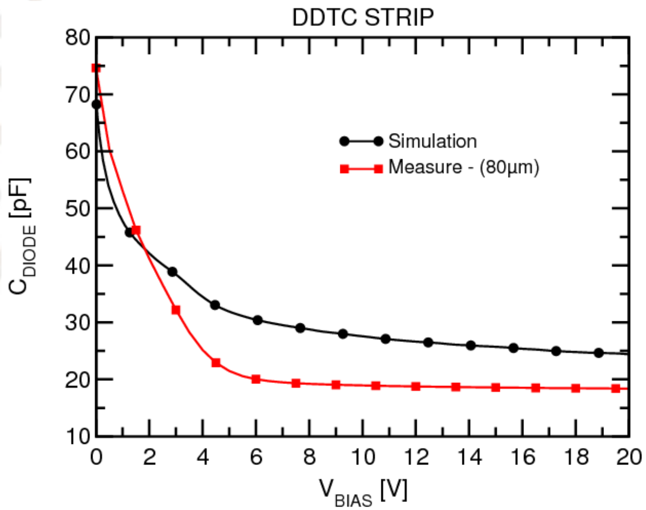
Pre-irradiation simulations (DDTC)

Original Mesh

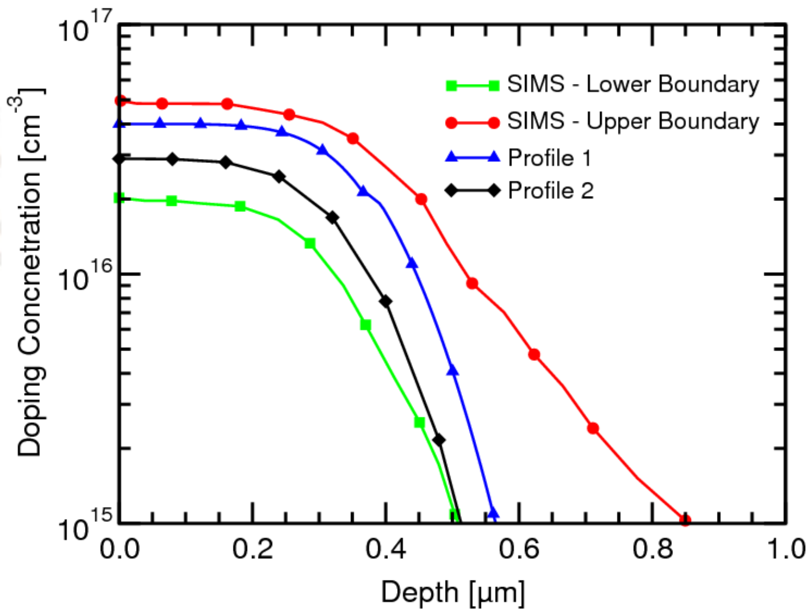
PARAMETER	VALUE
Wafer Thickness [µm]	200
Junction Column Depth [µm]	135
Ohmic Column Depth [µm]	190
Pitch [µm]	$40\sqrt{2}$
Oxide Thickness [µm]	1
Lateral Diffusion Radius [µm]	22
Substrate Dop. Conc. [cm^{-3}]	$2 \cdot 10^{12}$
P-*spray* Peak Dop. Conc. [cm^{-3}]	$4 \cdot 10^{16}$
Column & Lateral Diffusion [cm^{-3}]	$5 \cdot 10^{19}$
Positive Oxide Charge Conc. [cm^{-2}]	$1 \cdot 10^{11}$



Pre-irradiation simulations (DDTC): V_{BR}

PARAMETER	ORIGINAL MESH	OPTIMIZED
Ohmic Column Depth [µm]	190	180
P-spray	**Profile 1**	**Profile 2**
V_{BR} [V]	**78**	**119.5**

V_{BR} measured: 120V

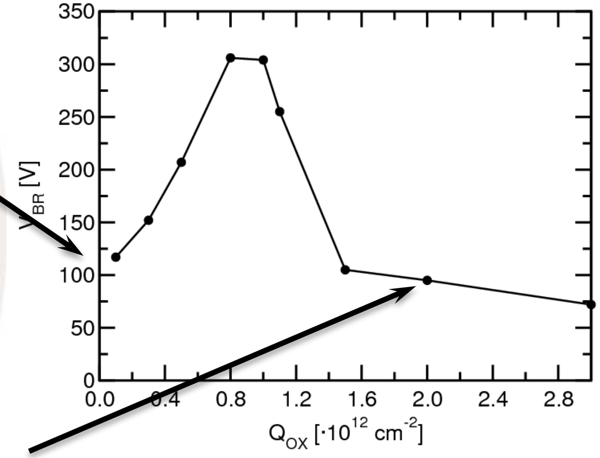


Post-irradiation simulations (DDTC)

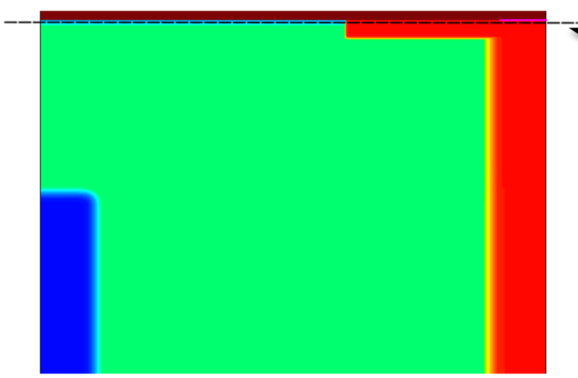
$\Phi = 1 \times 10^{15}\ n \cdot cm^{-2}$

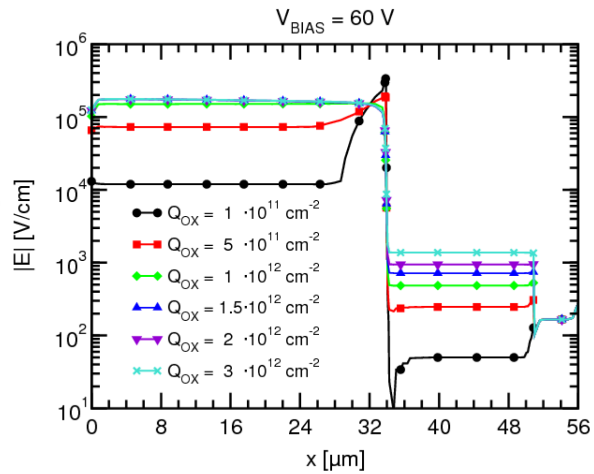
CONDITION	V_{BR} [V]
Pre-Irradiation	120
N_{EFF} & I.I. coeff. α	117

$V_{BR,\ MES} = 120V$



$V_{BR,\ MES} = 110V$
$(@10^{15} n \cdot cm^{-2})$





Conclusions

- Electron I.I. coefficient α affected by radiation damage
  - Possible non negligible effects at higher fluences
- V_{BR} in DDTC samples seems to marginally depend on radiation damage
  - Simulations suggest a strong dependence from Q_{OX}, not visible in the measures for the saturation of Q_{OX}.
  - Could be interesting to perform measures of V_{BR} vs. Q_{OX} to calibrate this effect