Modeling Radiation Damage Effects in Oxygenated Silicon Detectors

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OUTLINE

- Introduction: modeling set-up
- Summary of present p-type and n-type Silicon radiation damage models
- Results on proton irradiated FZ Oxygen Enriched Silicon (DOFZ)
- Conclusions

Geometrical Definition of the simulated structure

Sample structure: PAD detector with a Guard Ring (1μm torward the 3rd direction)

<111> FZ – Substrate:

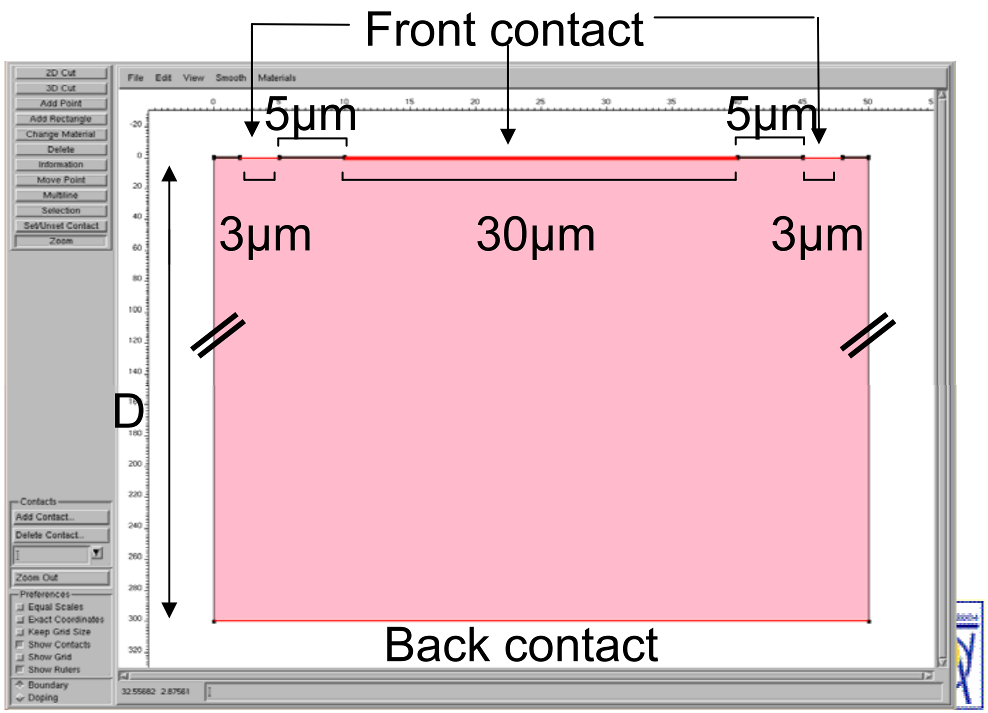
- **n-doped (7×10^{11} cm^{-3})→ 6kΩcm**
- **p-doped (5×10^{12} cm^{-3})→ 3kΩcm**
- **Charge concentration at the silicon-oxide interface:**
  - **4×10^{11} cm^{-3} pre-irradiation**
  - **1×10^{12} cm^{-3} post-irradiation**

Thickness:

p-type devices D = 300μm

n-type devices with different thickness:

D = 50-100-300 μm



Defect Energy Levels

Assignement	Energy Level	Conc.
$VO^{(-/0)}$	Ec-0.17±0.01 eV	$6\div7\times10^{11}cm^{-3}$/Mrad **
$V_2^{(-/0)}$ (neutron irradiation)	Ec-0.415±0.015 eV	$1.0\times10^{10}cm^{-3}$/Mrad **
E(240) $V_2O^{(-/0)}$ (gamma irradiation)	Ec-0.545 eV	0.8×10^{9} cm^{-3} ***
Γ - (V_2O - V_3 ?) (p+,e- irradiation)	Ec-0.46 eV	9.6×10^{9} cm^{-3} *
H(160) CiOi $^{(+/0)}$	Ev+0.37±0.01 eV	$4\div7\times10^{10}$ cm^{-3}/Mrad **

VO, always present in DLTS spectra, important because VO+V→V_2O

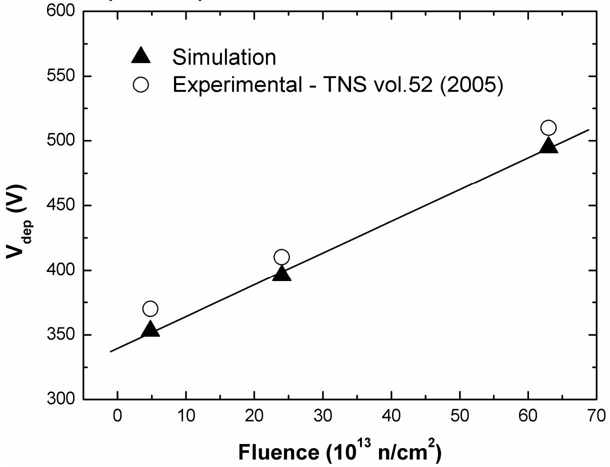
[*] CERN-LHCC-2003-058 RD50 Status Report 2003.
[**] Pintilie Ioana, RESMDD'06, Florence 10-13 October 2006.
[***] visible only on high resistivity Si above 15Mrad of γ irradiation.
[*] Pirollo et al. "Radiation damage on p-type silicon detectors" NIM A 426 (1999)

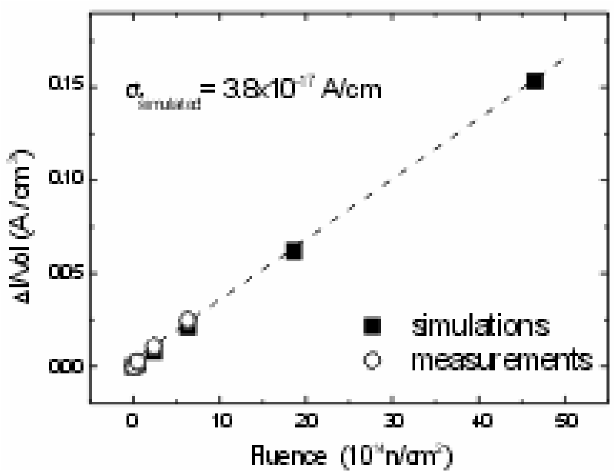
Radiation Damage Model: P-TYPE Si

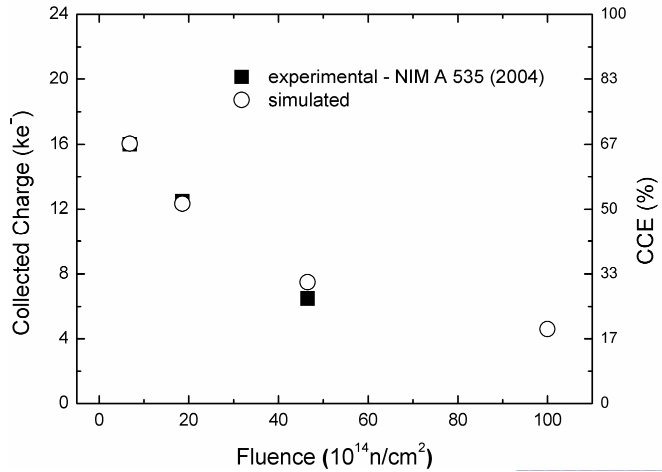
Level	Ass.	$\sigma_n(cm^2)$	$\sigma_p(cm^2)$	$\eta(cm^{-1})$	Ref.
E_C – 0,42eV	$VV^{(-/0)}$	2e-15	2e-14	1,613	[2]
E_C – 0,46eV	$VVV^{(-/0)}$	5e-15	5e-14	0,9	[1,3]
E_V + 0,36eV	C_iO_i	2,5e-14	2,5e-15	0,9	[1,2,3]

Note: in p-type Si the 0.46 level is not attributed to V_2O but to V_3 (vacancy related defects)

[1] Pirollo et al. "Radiation damage on p-type silicon detectors" NIM A 426 (1999)
[2] Zangenberg et al "On-line DLTS investigations of the mono and divacancy in p-type Si" NIM B 186 (2002)
[3] Ahmed et al. "DLTS studies of Si detectors after 24GeV p irradiation and 1 MeV neutron irradiation" NIMA 457 (2001)



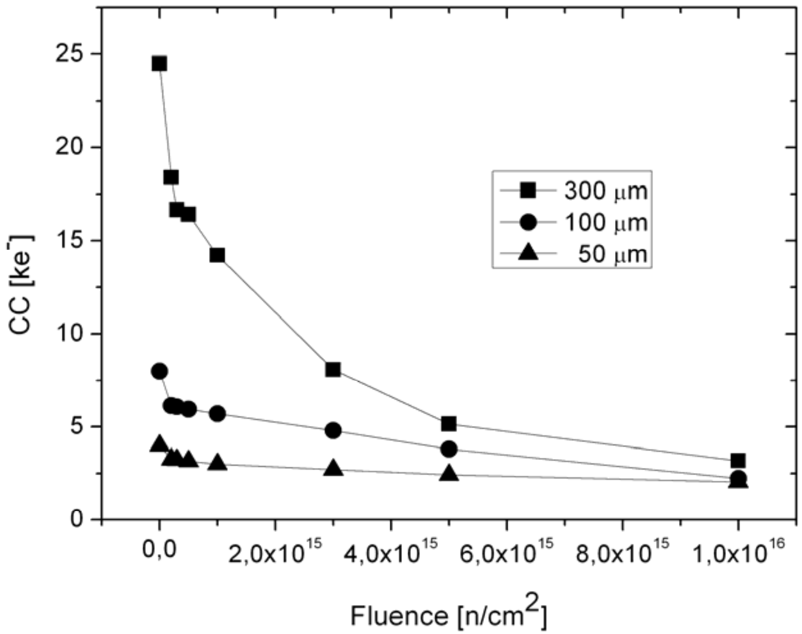


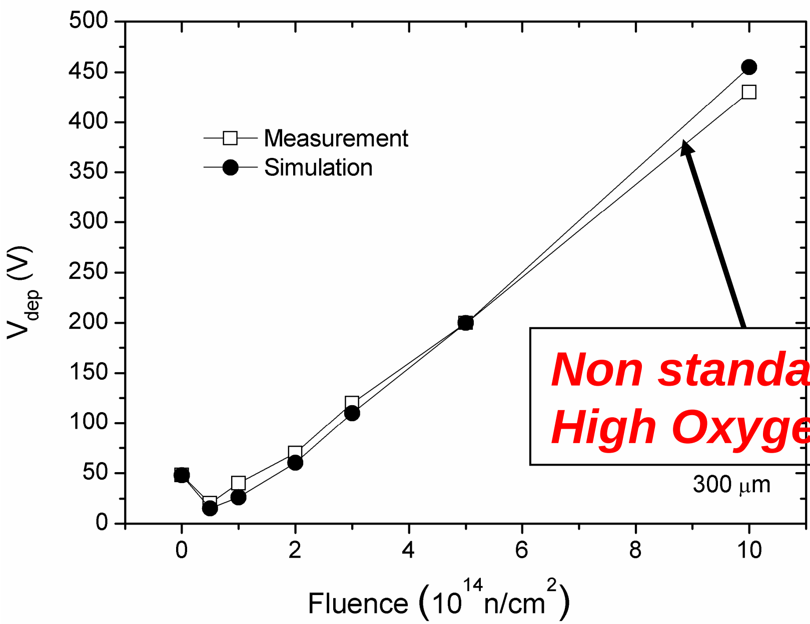


Radiation Damage Model: N-TYPE Si

Level	Ass.	$\sigma_n(cm^2)$	$\sigma_p(cm^2)$	$\eta(cm^{-1})$	Ref.
E_C – 0,42eV	$VV^{(-/0)}$	2.2e-15	1.2e-14	13	[*]
E_C – 0,50eV	V_2O	4e-15	3.5e-14	0.08	[*]
E_V + 0,36eV	C_iO_i	2e-18	2.5e-15	1.1	[*]

[*] M.Petasecca, F.Moscatelli, D.Passeri, and G.U.Pignatel, IEEE TNS 53-5 (2006) 1-6.

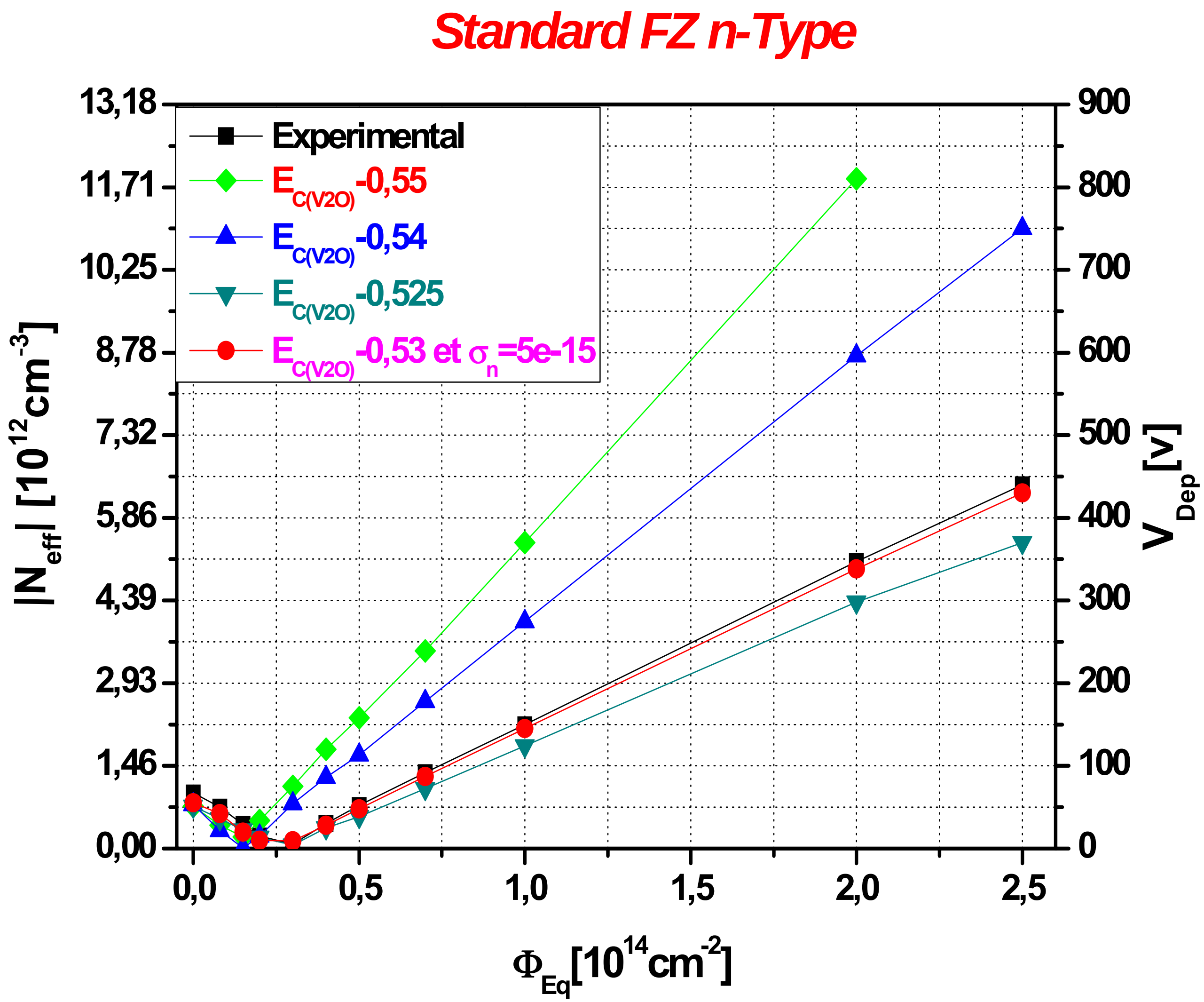




Non standard FZ!
High Oxygen Conc.

samples from SMART collaboration

Standard FZ n-type Si, 23GeV proton irradiated



Standard Fz n-Type
[WE – 7k]

N_{eff0} = 7 x 10^{11} cm^{-3}

g_C*N_0 =0,03
(donor removal constant)

ρ = 6 kΩcm
(substrate resistivity)

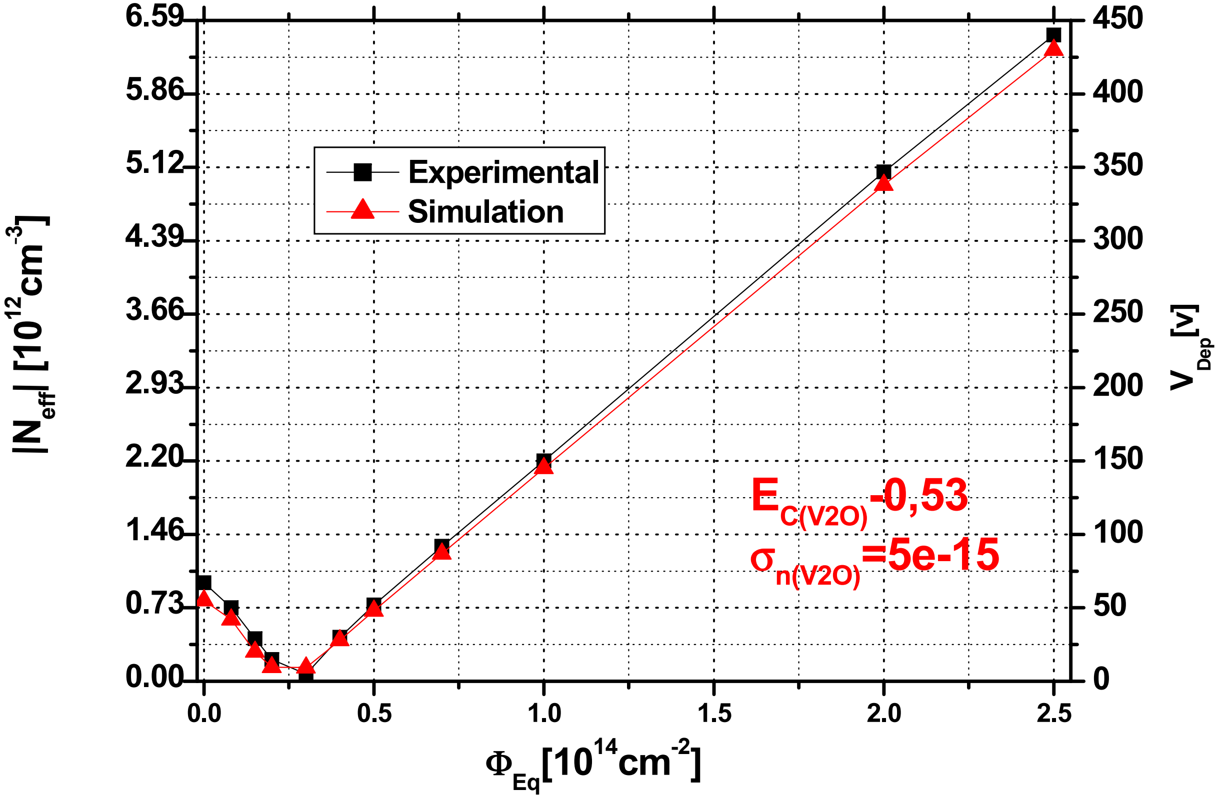
$[O_i]$ < 3÷5 x 10^{16}[cm^{-3}]

crystal orientation <111>

Experimental data from Lindstrom G. et al., NIM A 466 (2001) – RD48-ROSE

Level	Ass.	$\sigma_n(cm^2)$	$\sigma_p(cm^2)$	$\eta(cm^{-1})$
E_C – 0,42eV	$VV^{(-/0)}$	2e-15	1,2e-14	13
E_C – 0,53eV	VVO	5e-15	5e-14	0,08
E_V + 0,36eV	C_iO_i	2,5e-14	2,5e-15	1,1

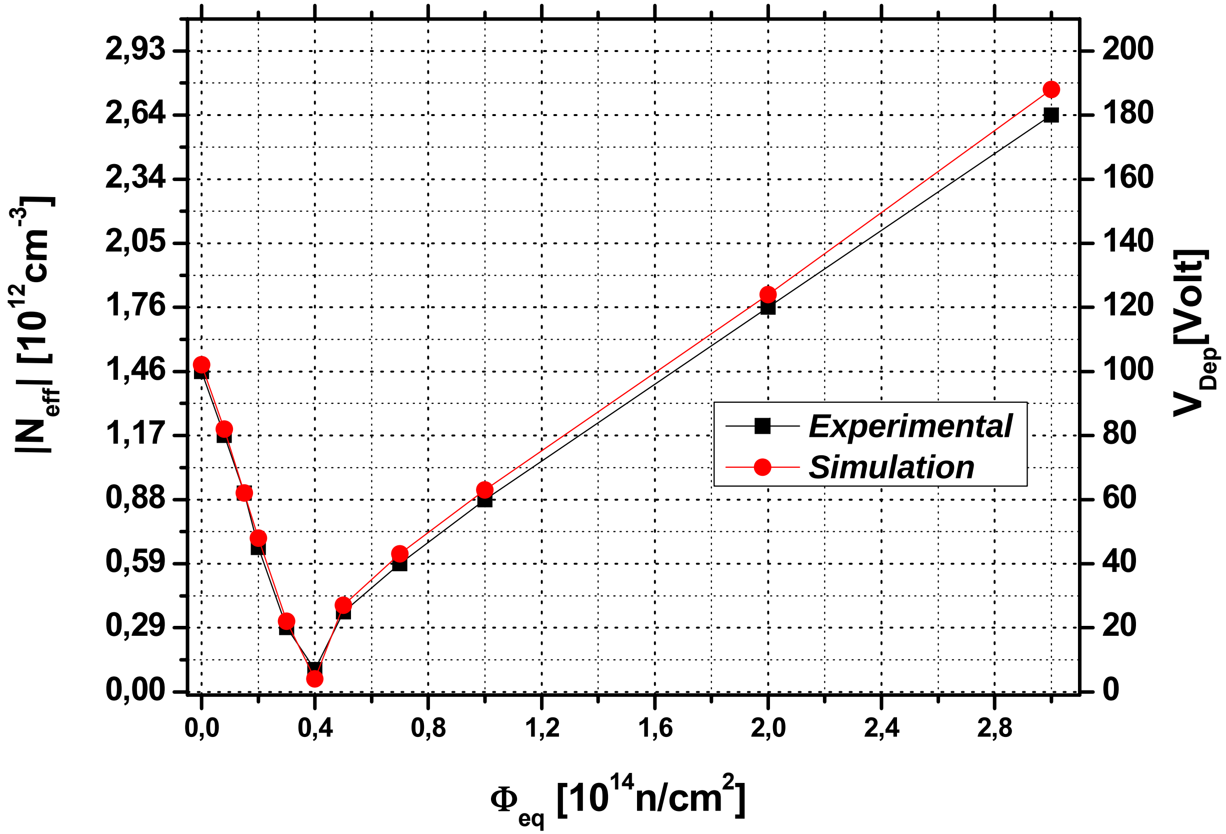
Fz- Standard 300 micron



Experimental data from Lindstrom"Radiation damage in silicon detectors"
Nuclear Instruments and Method in Physics Research A 512 (2003) 30-43

DOFZ n-type Si, 23 GeV proton irradiated

n-Type Oxigenated



Experimental data from Lindstrom"Radiation damage in silicon detectors"
Nuclear Instruments and Method in Physics Research A 512 (2003) 30-43

Oxigen rich Fz n-Type
[WS – 3k]

N_{eff0}=1,5 x 10^{12} cm^{-3}

$g_C * N_0 = 0,03$
(donor removal constant)

ρ = 3 kΩcm
(substrate resistivity)

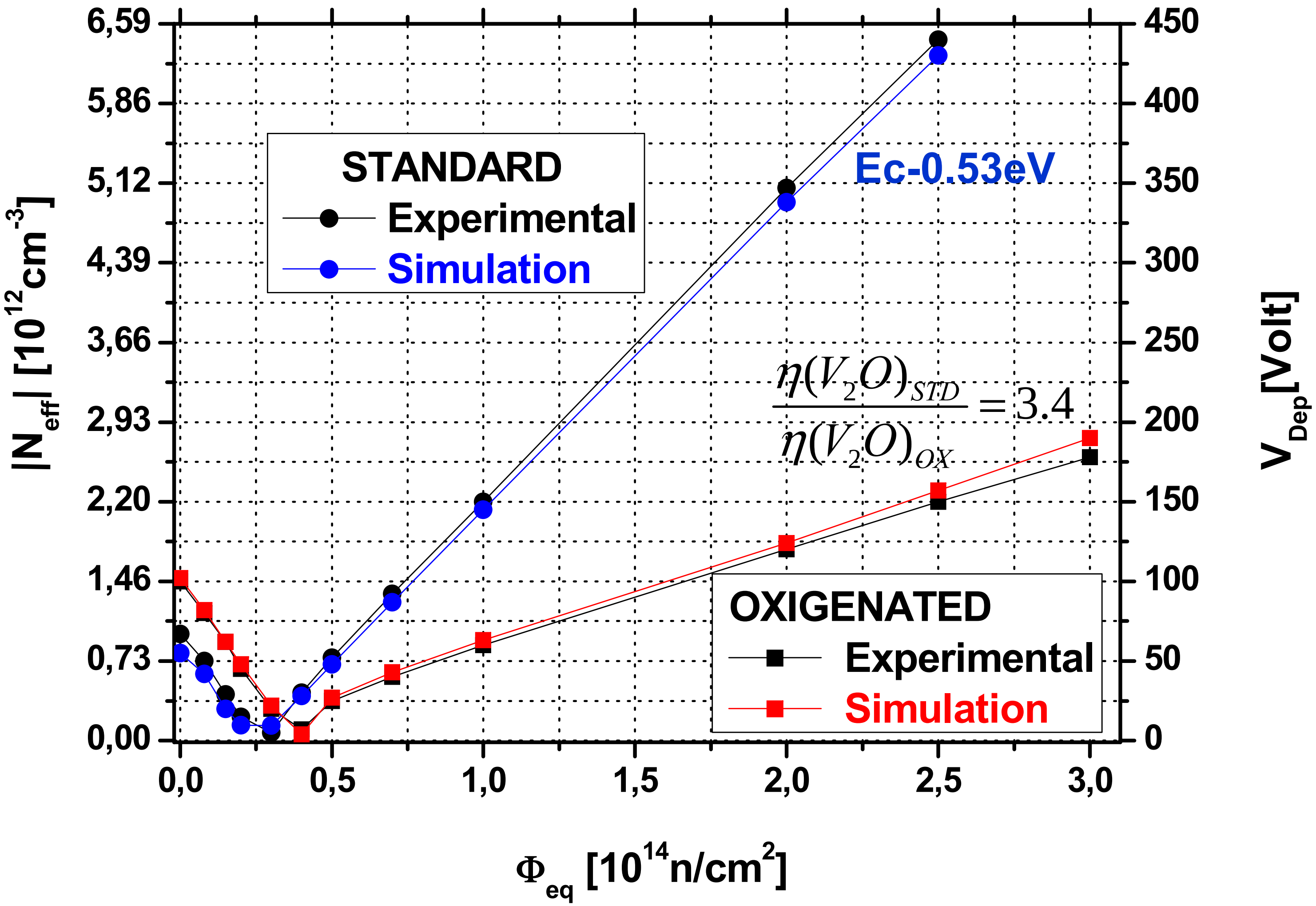
$[O_i]$ = 1.5 x 10^{17}[cm^{-3}]

crystal orientation <111>

Ratio of acceptors Introduction rates between Standard-FZ and Oxigenated-FZ (DOFZ)

$$\frac{\eta(V_2O)_{Std}}{\eta(V_2O)_{Ox}} = 3,4$$

Comparison between Stand. FZ (n-type) and DOFZ Si, 23GeV proton irradiated



Conclusions

All the simulations made so far, compared with experimental data, are consistent with the following defect model scenario:

- V_2 → E_c-0.42 ÷ 0.43eV *(η >>1 → n irrad., clusters)*
- C_iO_i → E_v+0.36eV *(trap for holes → CCE)*
- Γ (V_2O or V_3 ?) → E_c-0.46eV *(p,e irradiation)*
- V_2O → E_c-0.53 ÷ 0.545eV *(p,γ irradiation)*

V_2O level very sensitive to initial O_2 concentration !

p-type puzzle: E_c-0.46 is NOT attributed to V_2O (!?!)

Oxygenated p-type ?