INFN and University of Perugia

TCAD model of radiation damage at High Fluence HL-LHC silicon detectors

D. Passeri(1,2), F. Moscatelli(2,3), A. Morozzi(1,2), E. Fiandrini(2), G.M. Bilei(2)

(1) Dipartimento di Ingegneria - Università di Perugia, Italy
(2) Istituto Nazionale Fisica Nucleare - Sezione di Perugia, Italy
(3) IMM CNR Bologna, Italy

Outline

- ✓ INFN and University of Perugia are involved in WP7.
- ✓ 7.2 TCAD simulations:
  - development of a TCAD model for the description of radiation damage in silicon detectors valid up to the particle fluences expected in the inner layers of the HL-LHC vertex detectors
- ✓ Main goal synopsis:

i. extension of the TCAD model to simulate the effects of radiation damage on silicon devices, up to now able to reproduce the sensor behaviour at the fluences at LHC operation (1×10^{15} n/cm^2);

ii. development of bulk damage as well as interface trap states build up modelling for a particle fluence > 2×10^{16} n/cm^2, expected at the end of HL-LHC operations in the inner layers of the pixel systems of ATLAS and CMS.

- ✓ Participants: G.M. Bilei (INFN PG staff), D. Passeri (UniPG staff), F. Moscatelli (INFN PG and CNR-IMM staff), E. Fiandrini (UniPG staff), A. Morozzi (UniPG PhD student).

Background: "University of Perugia" model

- ✓ Hierarchical approach based on increasing number of deep-level recombination centres / trap states.
- ✓ Comprehensive modelling of device behaviour of with fluence:
  - depletion voltage, leakage current (α), "double peak" shaped electric field, charge collection efficiency,…
- ✓ Meaningful and physically sounded parametrization.
- ✓ Three levels with donor removal and increased introduction rate (to cope with direct inter-defect charge exchange – numerically overwhelmed effect).
- ✓ n type and p type substrate
- ✓ Suitable for fluences up to 10^{15} cm^{-2} 1 MeV neutrons.

New "University of Perugia" model

- ✓ Extend the predictive capabilities to HF HL-LHC radiation damage levels (e.g. fluences > 2.0×10^{16} cm^{-2} 1 MeV neutrons).
- ✓ Keep low the number of traps (e.g. fitting parameters).
- ✓ New effects (e.g. charge multiplication <- avalanche effects).
- ✓ Physically grounded approach.
- ✓ No over-specific modelling (one model fits all…).
- ✓ Capture cross-section variations (σ_n, σ_p), keeping the same (already characterized) defects: energy levels, introduction rates, …
- ✓ Predictive capabilities @Φ, @T, @V_{bias}, … (e.g. device independent).

Work plan: simulations

- ✓ Bulk radiation damage modelling:

  - extension of the three-level UniPG modelling (capture cross section, charge multiplication, avalanche effects).

- ✓ Interface radiation damage modelling:

  - oxide fixed charge and interface trap state @fluence;

  - systematic study of acceptor/donor states at different energies.

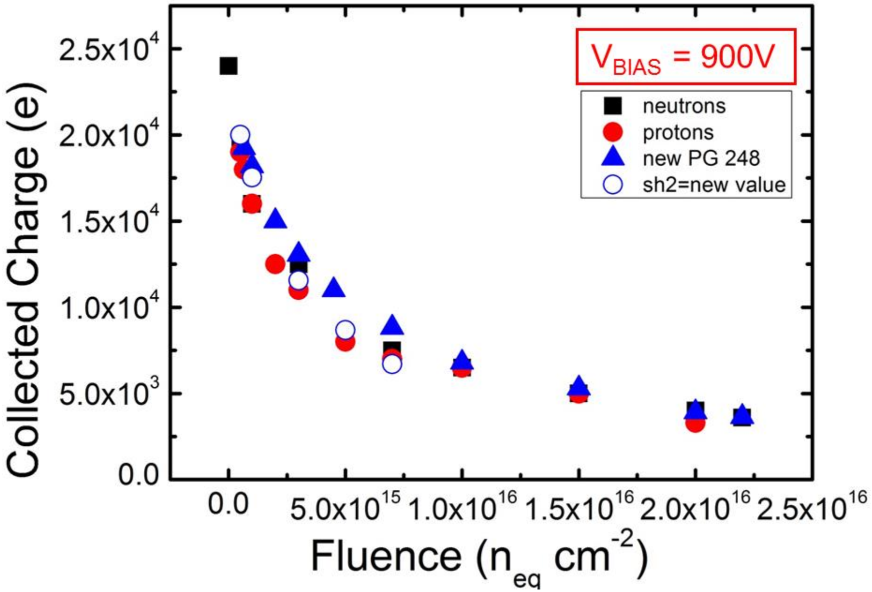
- ✓ Technology (process) dependent effect -> deep level parameterization, oxide charge density, interface trap energy and density, cross sections (e/h), trap type (acceptor or donor).

- ✓ Comparison with literature data/dedicated measurements in terms of static parameters (R, C) and charge collection properties.

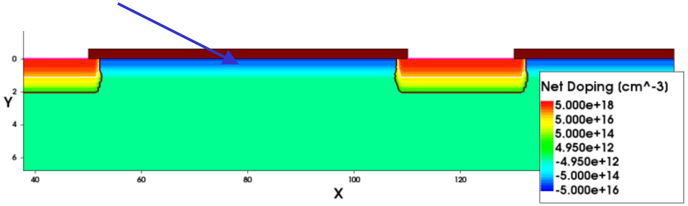
- ✓ Comprehensive modelling (bulk + interface, 2D/3D).

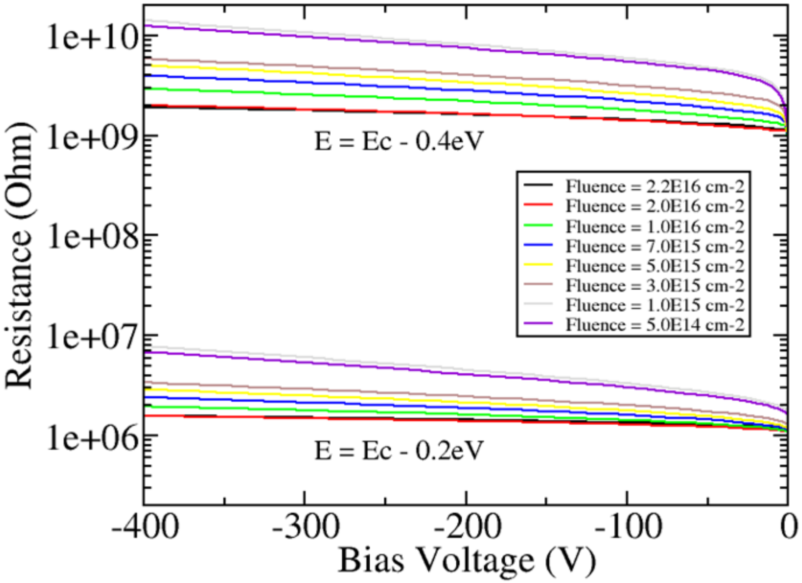
- Simulations vs. measurements.
- Charge collection as a function of radiation fluences at T=248K, V_{BIAS}=900V [1].

[1] Affolder et al., NIM A, Vol. 623 (2010).



- Interstrip resistance as a function of bias voltage at different radiation fluences.
- Effect of the acceptor Si/SiO_2 trap state – accumulation layer modulation.



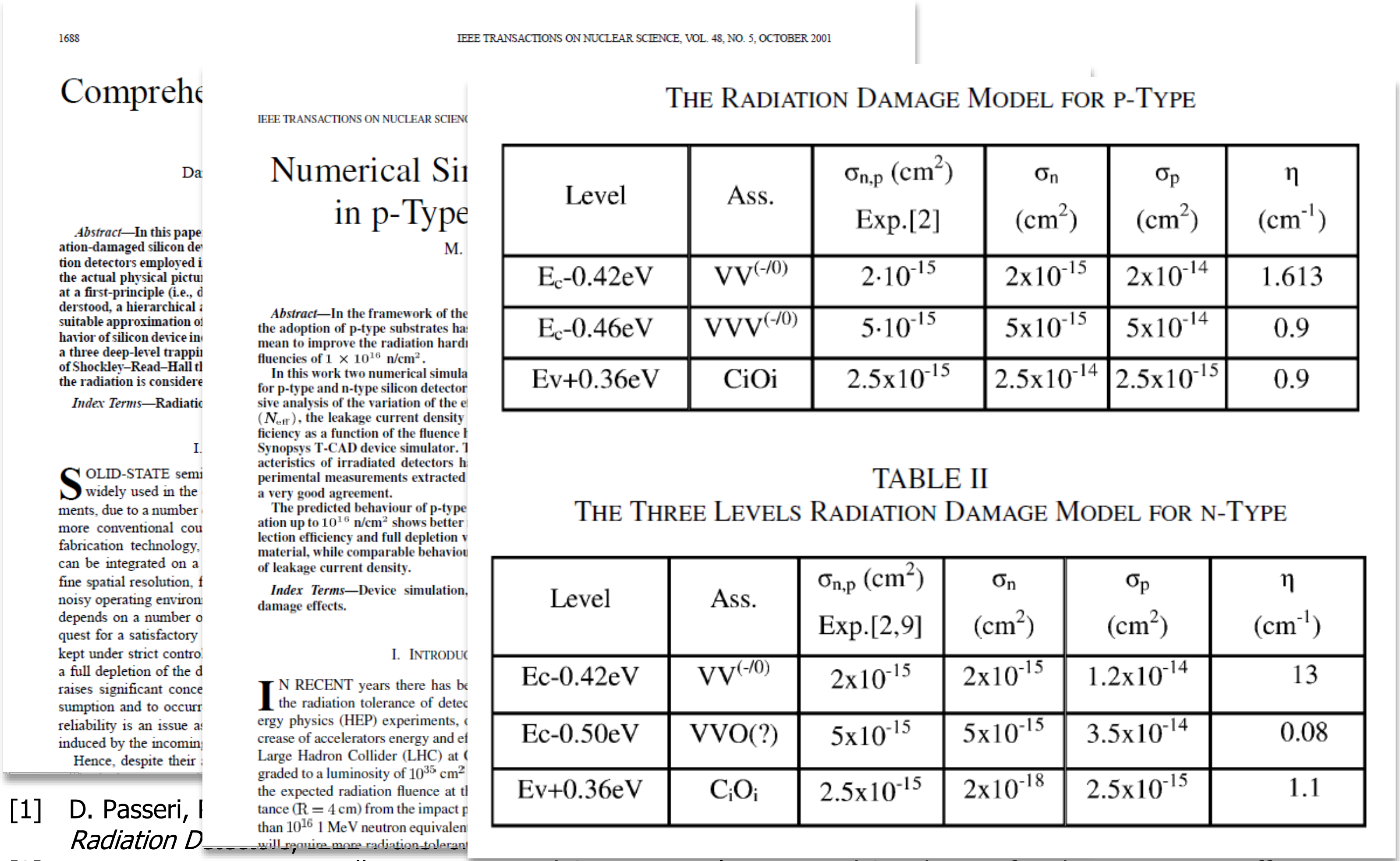


Work plan: measurements

- ✓ Measurements on dedicated test structures e.g. gated diodes, MOS capacitors and MOSFETs on p-spray/different substrates.
- ✓ Different technologies (e.g. FBK, IMM, …).
- ✓ High-Frequency and Quasi-Stationary C , MOSFET V_{TH} and I-V characteristics, …
- ✓ Irradiation campaign with gammas, x-ray and protons/neutrons at very high fluences ($2x10^{16}$ n_{eq}/cm^2).
- ✓ Measurements after irradiation -> trap parameter extraction, TCAD model validation.
- ✓ Predictive application of the model -> sensor design and optimization.
- ✓ Deliverable D7.4 TCAD model radiation damage (month 46).
- ✓ TCAD simulation activity already started (13th Pisa meeting poster presentation, NSS 2015 abstract submitted).

Backup

“University of Perugia” model (2)



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Comprehe

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Abstract—In this pape
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at a first-principle (i.e., d
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Index Terms—Radiatio

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SOLID-STATE semi
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IEEE TRANSACTIONS ON NUCLEAR SCIEN

Numerical Si
in p-Type

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Abstract—In the framework of the
the adoption of p-type substrates ha
mean to improve the radiation hard
fluencies of 1×10^{16} n/cm^2.
In this work two numerical simula
for p-type and n-type silicon detector
sive analysis of the variation of the e
(N_{eff}), the leakage current density
ficiency as a function of the fluence
Synopsys T-CAD device simulator. T
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a very good agreement.
The predicted behaviour of p-type
ation up to 10^{16} n/cm^2 shows better
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material, while comparable behaviou
of leakage current density.

Index Terms—Device simulation,
damage effects.

I. INTRODUC

IN RECENT years there has be
the radiation tolerance of detec
ergy physics (HEP) experiments,
crease of accelerators energy and ef
Large Hadron Collider (LHC) at
graded to a luminosity of 10^{35} cm^2
the expected radiation fluence at t
tance ($R = 4$ cm) from the impact p
than 10^{16} 1 MeV neutron equivalen
will require more radiation-toleran

THE RADIATION DAMAGE MODEL FOR P-TYPE

Level	Ass.	$\sigma_{n,p}$ (cm^2) Exp.[2]	σ_n (cm^2)	σ_p (cm^2)	η (cm^{-1})
E_c-0.42eV	VV$^{(-/0)}$	$2\cdot10^{-15}$	$2\mathrm{x}10^{-15}$	$2\mathrm{x}10^{-14}$	1.613
E_c-0.46eV	VVV$^{(-/0)}$	$5\cdot10^{-15}$	$5\mathrm{x}10^{-15}$	$5\mathrm{x}10^{-14}$	0.9
Ev+0.36eV	CiOi	$2.5\mathrm{x}10^{-15}$	$2.5\mathrm{x}10^{-14}$	$2.5\mathrm{x}10^{-15}$	0.9

TABLE II
THE THREE LEVELS RADIATION DAMAGE MODEL FOR N-TYPE

Level	Ass.	$\sigma_{n,p}$ (cm^2) Exp.[2,9]	σ_n (cm^2)	σ_p (cm^2)	η (cm^{-1})
Ec-0.42eV	VV$^{(-/0)}$	$2\mathrm{x}10^{-15}$	$2\mathrm{x}10^{-15}$	$1.2\mathrm{x}10^{-14}$	13
Ec-0.50eV	VVO(?)	$5\mathrm{x}10^{-15}$	$5\mathrm{x}10^{-15}$	$3.5\mathrm{x}10^{-14}$	0.08
Ev+0.36eV	C_iO_i	$2.5\mathrm{x}10^{-15}$	$2\mathrm{x}10^{-18}$	$2.5\mathrm{x}10^{-15}$	1.1

[1] D. Passeri, I
Radiation D

[2] M. Petasecca, F. Moscatelli, D. Passeri, and G. U. Pignatel, *Numerical Simulation of Radiation Damage Effects in p-Type and n-Type FZ Silicon Detectors*, IEEE Trans. on Nuclear Science, vol. 53, no. 5, October 2006.