Advances on TCAD numerical modeling of radiation damage effects in silicon detectors for HL-LHC operations

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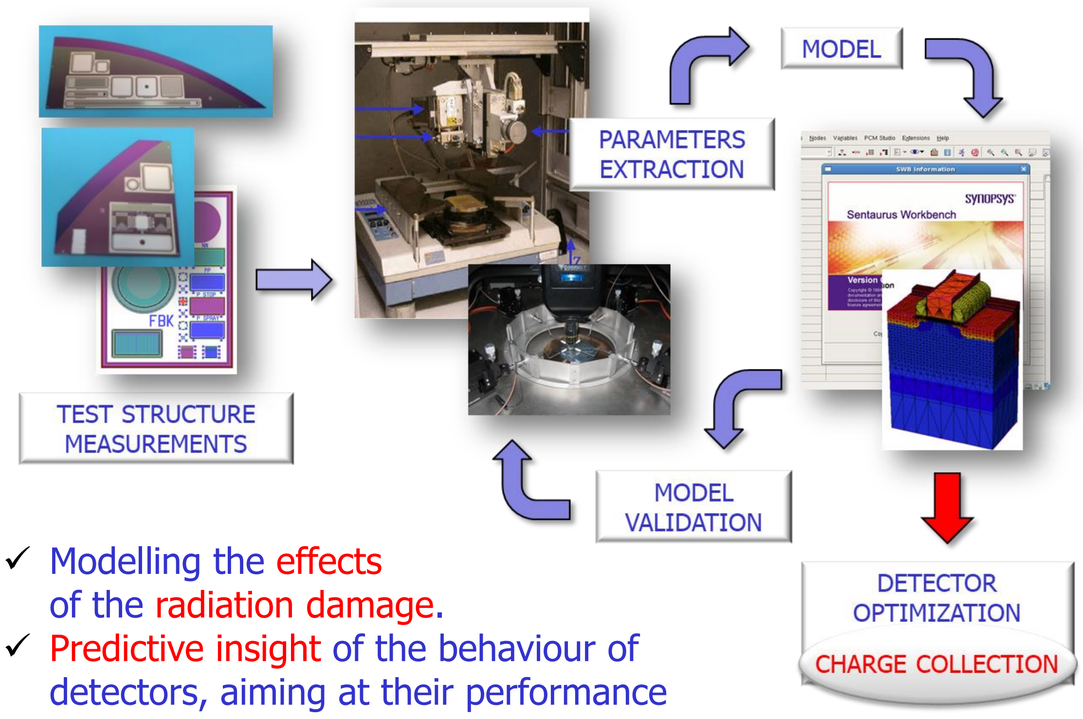
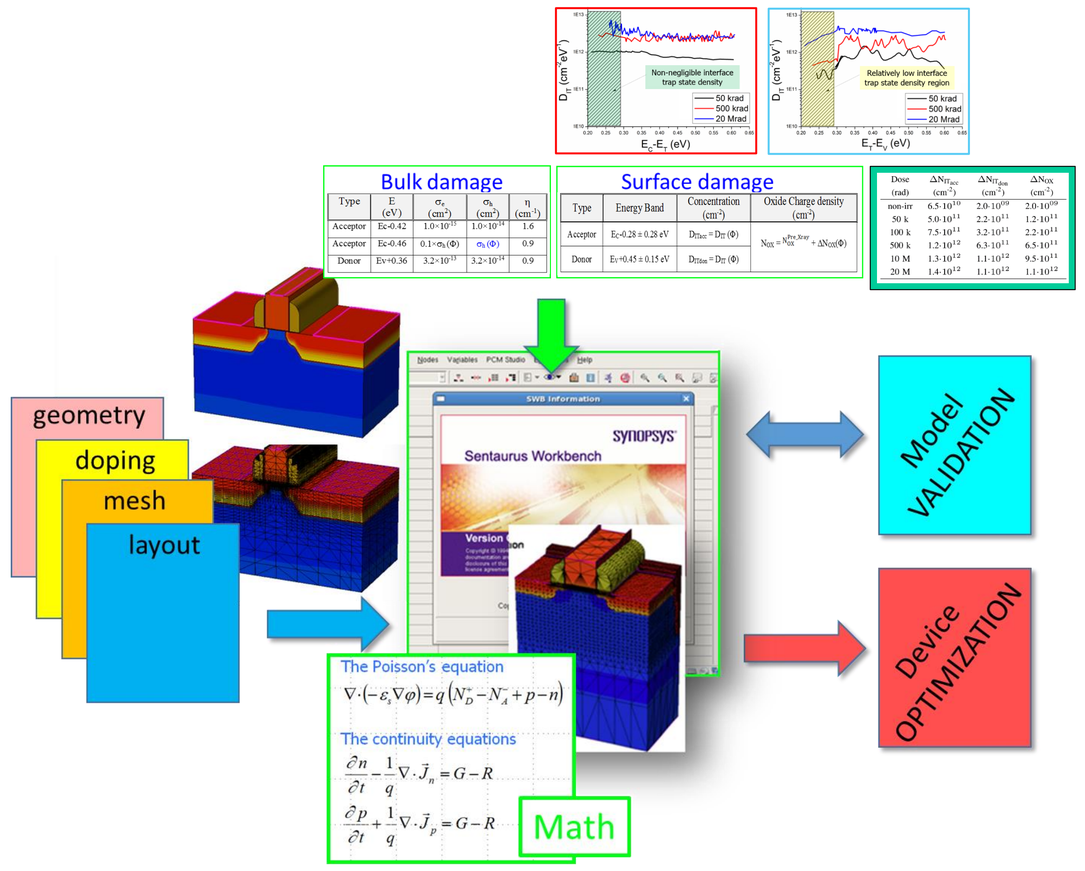
Introduction

- ✓ A Technology CAD (TCAD) combined surface and bulk radiation damage effects model is presented.
- ✓ The surface radiation damage effects model is based on amphoteric, uniform energy band distributed deep-level defects.
- ✓ The main parameters of the surface damage , e.g. the equivalent oxide charge and interface trap densities, have been extracted from experimental measurements carried out on different vendors (e.g. HPK, FBK and Infineon) irradiated test structures.
- ✓ The model has been coupled with a bulk damage model based on multiple level defects with variable capture-cross sections.

TCAD modeling of Radiation Damage Effects



- ✓ Modelling the effects of the radiation damage.
- ✓ Predictive insight of the behaviour of detectors, aiming at their performance optimization.

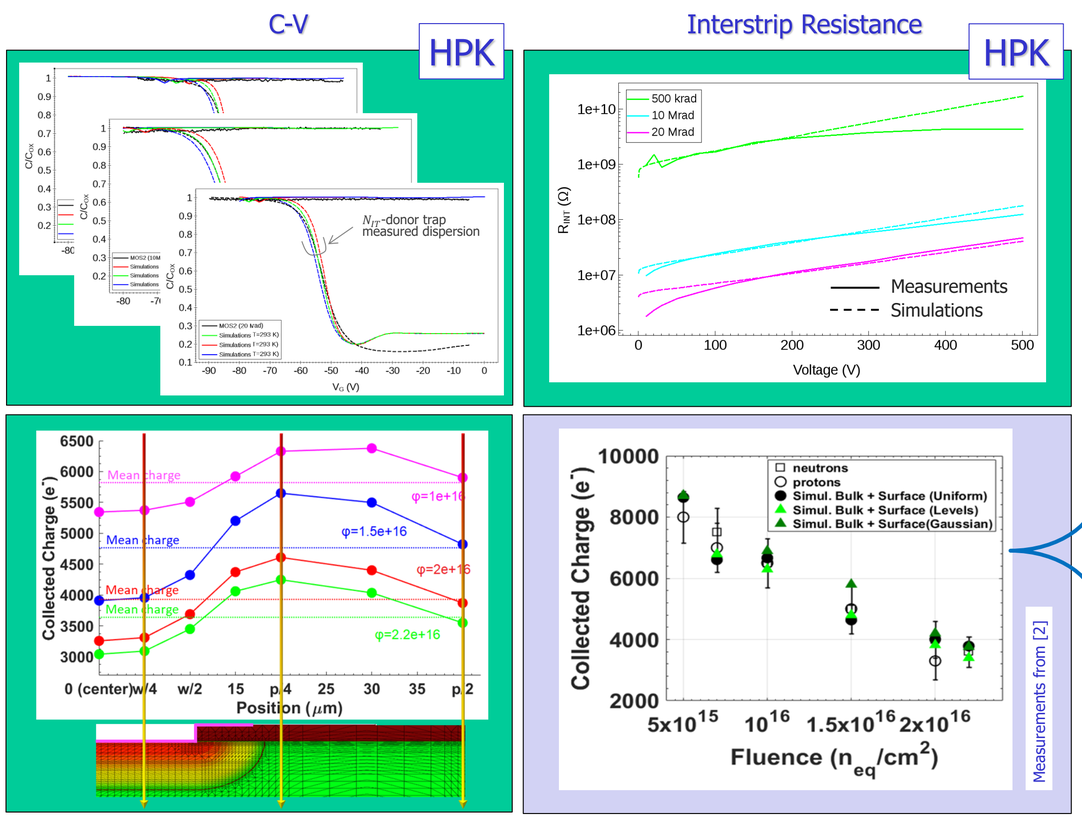


Type	E (eV)	σ_e (cm^2)	σ_h (cm^2)	η (cm^{-1})
Acceptor	Ec-0.42	$1.0\cdot10^{-13}$	$1.0\cdot10^{-14}$	1.6
Acceptor	Ec-0.46	$0.1\times\sigma_h(\Phi)$	$\sigma_h(\Phi)$	0.9
Donor	Ev+0.36	$3.2\cdot10^{-13}$	$3.2\cdot10^{-14}$	0.9

Type	Energy Band	Concentration (cm^2)	Oxide Charge density (cm^2)
Acceptor	Ec-0.28 ± 0.28 eV	$D_{IT,Acc} = D_{IT}(\Phi)$	$N_{OX} = N_{OX}^{Pre\ Xray} + \Delta N_{OX}(\Phi)$
Donor	Ev+0.45 ± 0.15 eV	$D_{IT,Don} = D_{IT}(\Phi)$	

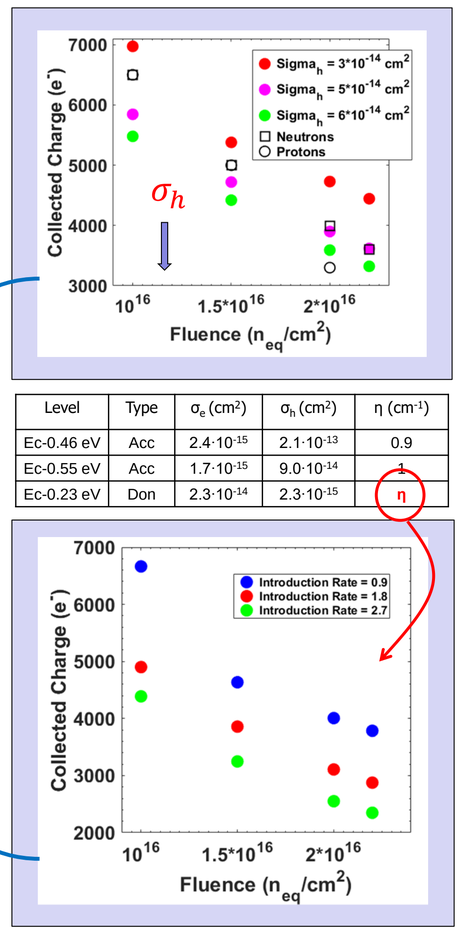
Dose (rad)	$\Delta N_{IT,Acc}$ (cm^{-2})	$\Delta N_{IT,Don}$ (cm^{-2})	ΔN_{OX} (cm^{-2})
non-irr	$6.5\cdot10^{10}$	$2.0\cdot10^{09}$	$2.0\cdot10^{09}$
50 k	$5.0\cdot10^{11}$	$2.2\cdot10^{11}$	$1.2\cdot10^{11}$
100 k	$7.5\cdot10^{11}$	$3.2\cdot10^{11}$	$2.2\cdot10^{11}$
500 k	$1.2\cdot10^{12}$	$6.3\cdot10^{11}$	$6.5\cdot10^{11}$
10 M	$1.3\cdot10^{12}$	$1.1\cdot10^{12}$	$9.5\cdot10^{11}$
20 M	$1.4\cdot10^{12}$	$1.1\cdot10^{12}$	$1.1\cdot10^{12}$

Simulations vs. Measurements



Charge collection vs. hit position

Charge collection vs. fluence



Level	Type	σ_e (cm^2)	σ_h (cm^2)	η (cm^{-1})
Ec-0.46 eV	Acc	$2.4\cdot10^{-15}$	$2.1\cdot10^{-13}$	0.9
Ec-0.55 eV	Acc	$1.7\cdot10^{-15}$	$9.0\cdot10^{-14}$	1
Ec-0.23 eV	Don	$2.3\cdot10^{-14}$	$2.3\cdot10^{-15}$	η

Conclusions

- ✓ A combined surface and bulk radiation damage effects model, suitable for commercial TCAD tools, has been further developed [1].
- ✓ The parameters of the surface damage model can be extracted from test structures fabricated by different vendors.
- ✓ Tools for to the optimization of active behaviour (i.e. charge collection) of pixel detectors (3D, 2D planar, …) for HL-LHC operations.

References

[1] F. Moscatelli et al., Combined Bulk and Surface Radiation Damage Effects at Very High Fluences in Silicon Detectors: Measurements and TCAD Simulations, IEEE Trans. on Nucl. Sci.63 (5) (2016) 2716-2723.

[2] Affolder et al., Collected charge of planar silicon detectors after pion and proton irradiations up to 2.2x10^{16} n/cm^2 NIM A, Vol. 623 (2010).

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