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Radiation hardness simulation of silicon thin detectors

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Outline

- Radiation damage modelling (F. Moscatelli)
- Thin structures (M. Petasecca)

Simulation Tool

Simulation tool:

–ISE-TCAD – discrete time and spatial solutions to equations

Damage modelling:

- Deep levels: N_t , E_t, σ_n and σ_p
- SRH statistics.
- Donor removal mechanism
- Other effects: high density defect concentration (clusters) produces an increase of the leakage current.

Radiation Damage Model

- Four levels*:

  - **$V_2^{-/0}$** located at $E=E_C-0.42$

  - **C_iO_i** located at $E=E_V+0.36$

  - **V_2O** located at $E= E_C-0.50$

  - **E(70)** located at $E=E_C-0.45$

- Direct charge exchange between $V_2^{-/0}$ and E(70) to reproduce cluster effects.
- Donor removal mechanism.
- Reproduce variation of the V_{dep} and $I_{leakage}$ as a function of the fluence
- Over $\Phi=2\times10^{14}$ n/cm^2 computational problems

*F. Moscatelli, et al.Nuclear Instruments and Methods in Physics Research B 186 (2002)

ISE-TCAD Damage Model

- Three levels*:

  - **$V_2^{-/0}$** located at $E=E_C-0.42$

  - **C_iO_i** located at $E=E_V+0.36$

  - **V_2O** located at $E= E_C-0.50$

- To reproduce cluster effects, we use increased **$V_2^{-/0}$** occupancy

- **Donor removal mechanism**.

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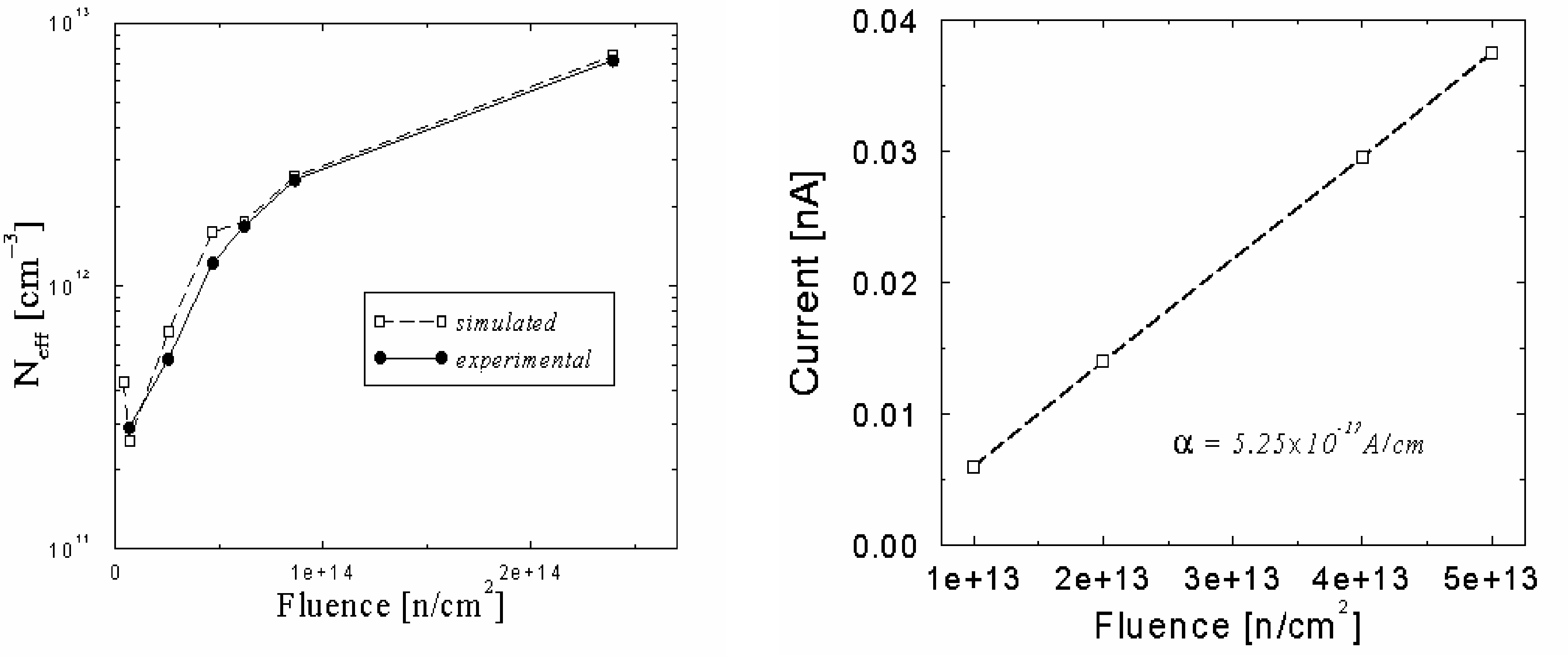
*D. Passeri, P. Ciampolini, G. Bilei and F. Moscatelli, *IEEE Trans. Nucl. Sci.*, vol. 48, pp. 1688, 200

Three-level model

- Level characteristics:

	$\mathbf{V_2^{-/0}}$	$\mathbf{V_2O}$	$\mathbf{C_iO_i}$
E	E_c -0.42eV	E_c -0.50eV	E_v+0.36eV
σ_p	$8 \cdot 10^{-15}$cm^2	10^{-15} cm^2	10^{-16} cm^2
σ_n	10^{-16} cm^2	10^{-16} cm^2	10^{-15} cm^2
η	26 cm^{-1}	0.1 cm^{-1}	1 cm^{-1}

Effective Doping Concentration and Leakage Current



$\Delta I/\mathrm{Volume} = \alpha\Phi$, with

$\alpha = (2.9 \div 10)\ 10^{-17}$ A/cm.

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Simulations results as a function of T

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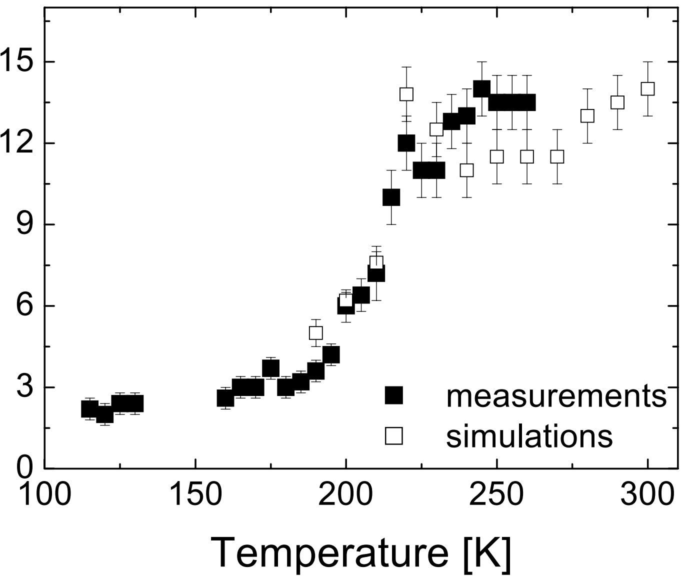
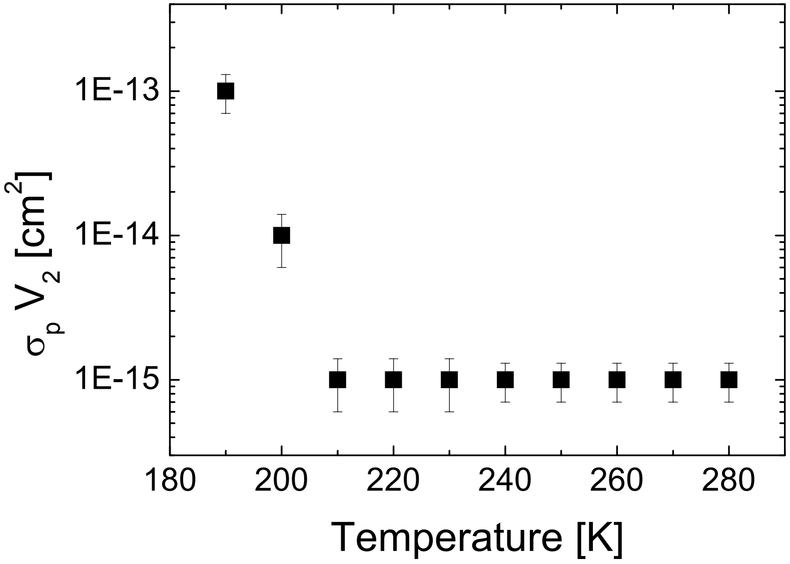
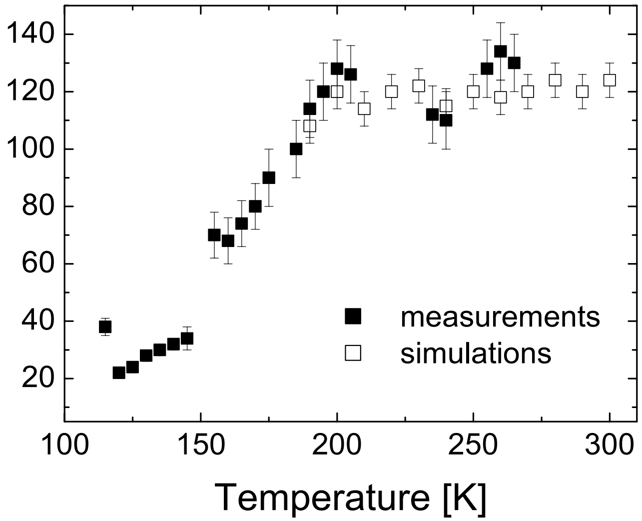
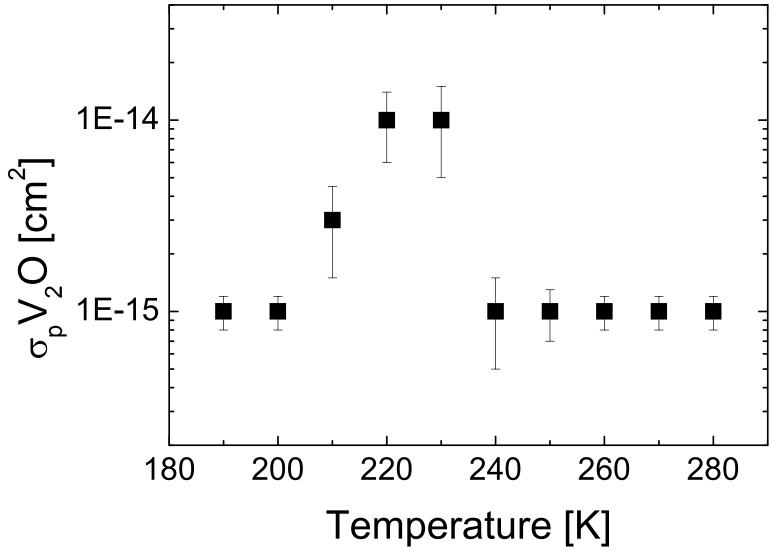


$\Phi=2.2\times10^{13}$ protons/cm^2





$\Phi=4.7\times10^{14}$ protons/cm^2



Thin detectors

- Thin detectors have been proposed to investigate the possibility to get a low depletion voltage and to limit the leakage current of heavily irradiated silicon devices

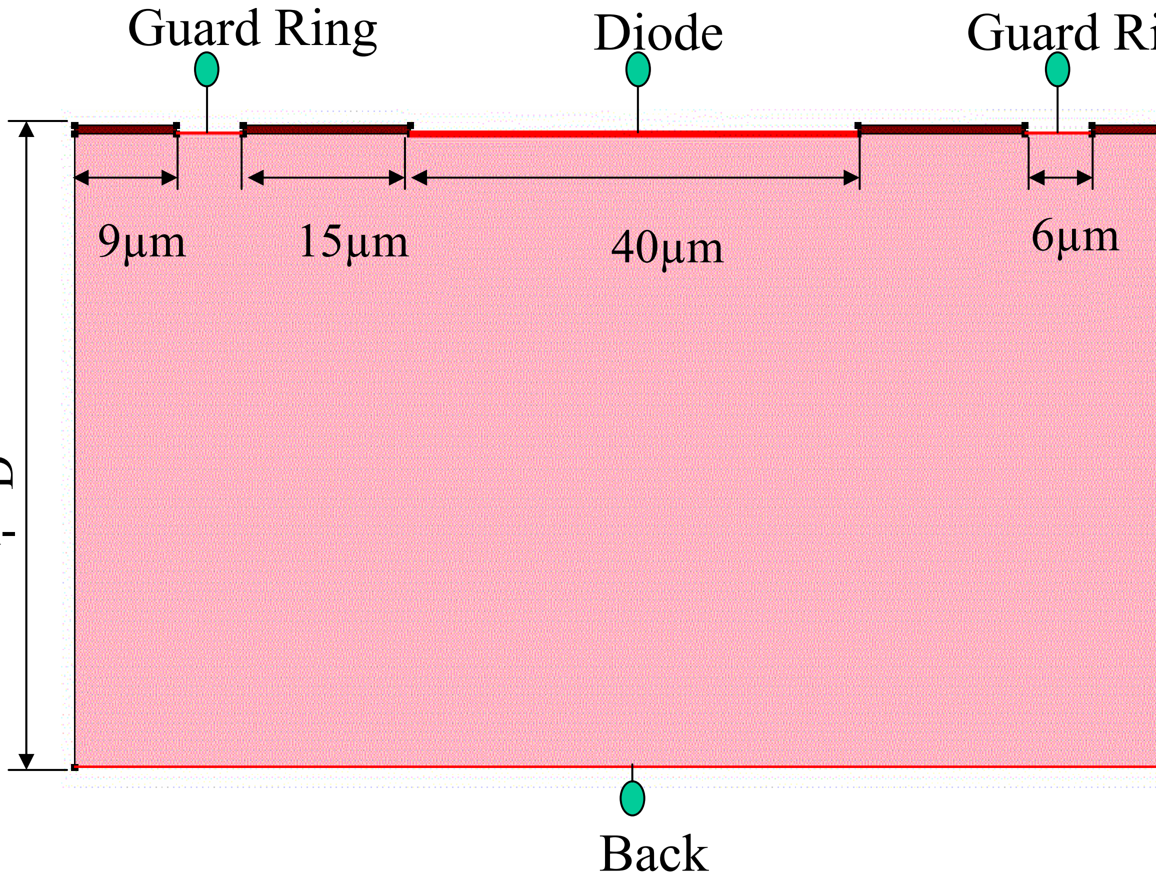
Simulation setup

mulated structures:

$$D = \begin{cases} 58\,\mu m \\ 300\,\mu m \end{cases}$$

→ **thin** device

→ **thick** device



Simulated device structure and parameters

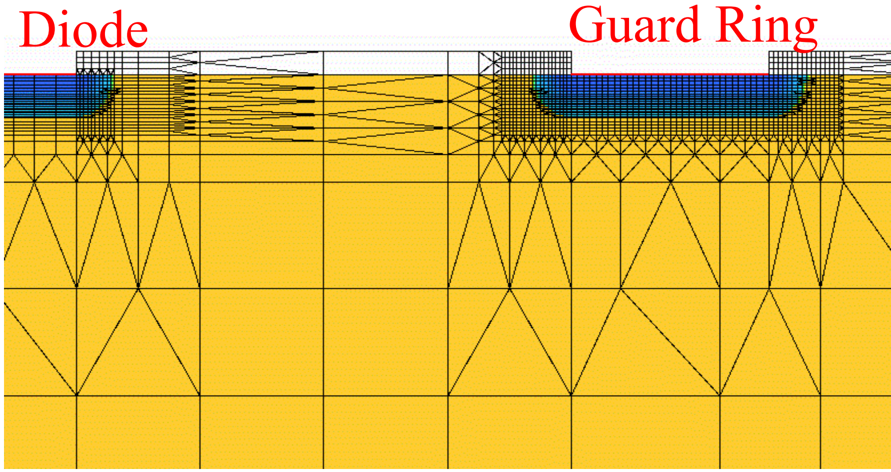
Doping profiles:

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

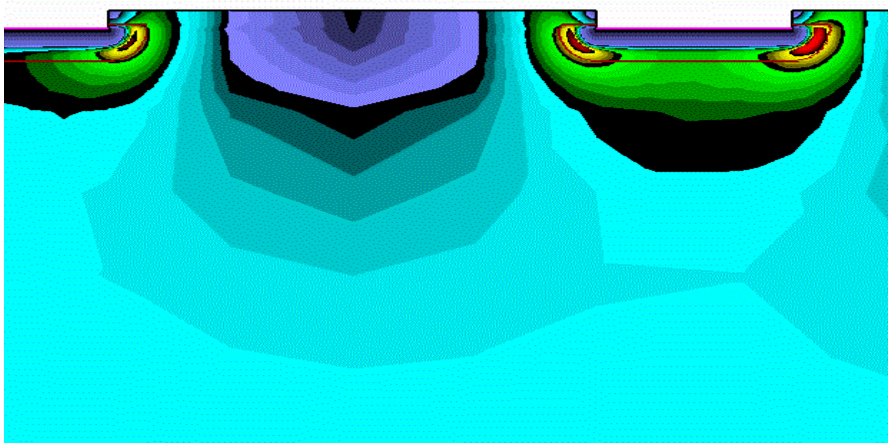
Simulation setup

Variable mesh definition:

- the mesh is better refined in correspondence of the **critical points** of the device to improve simulator performance.

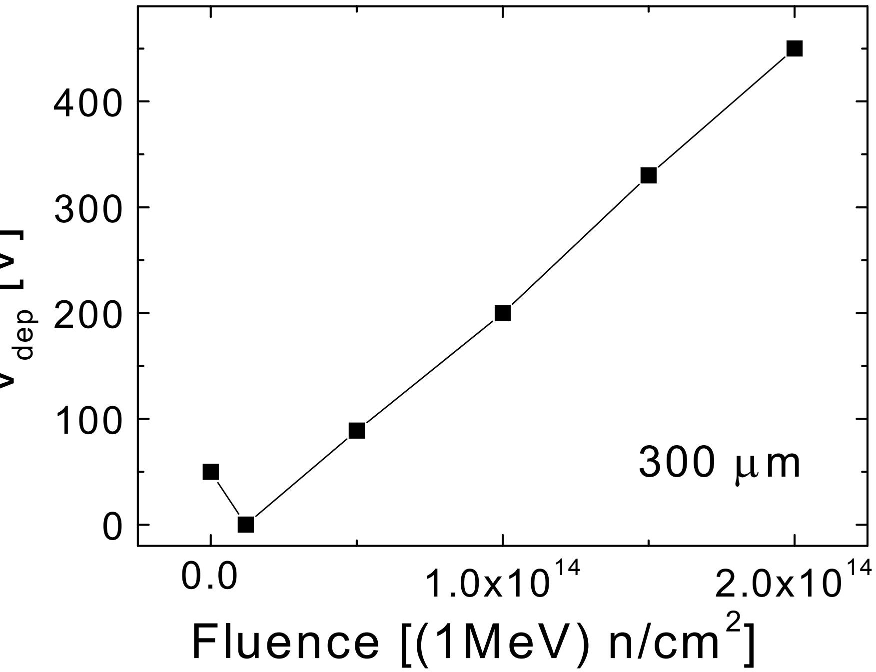


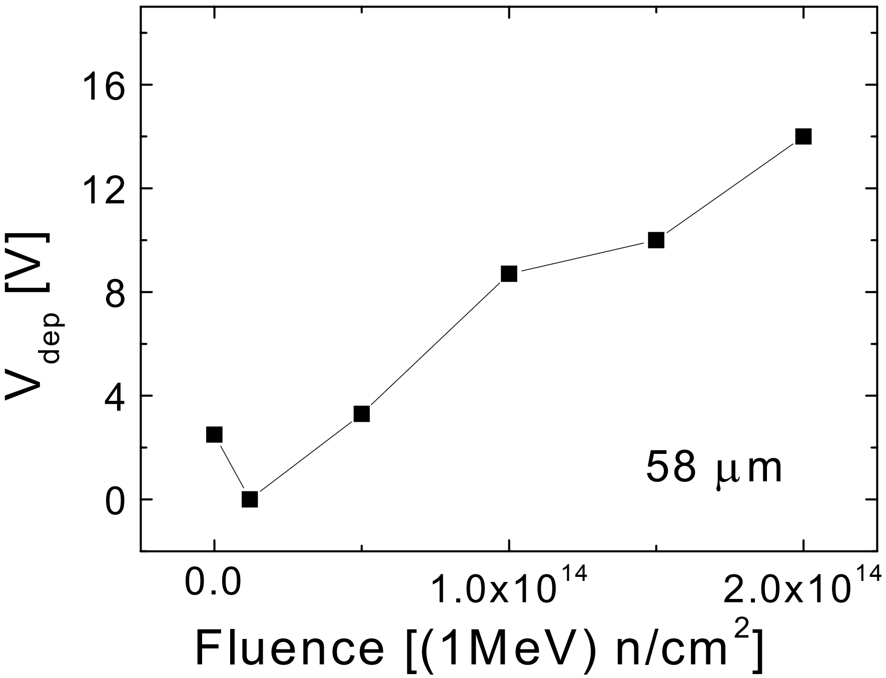
The typical electric field distribution at the full depletion voltage of the diodes: red areas correspond to the maximum



Simulation results

Simulated Depletion Voltage as function of the fluence

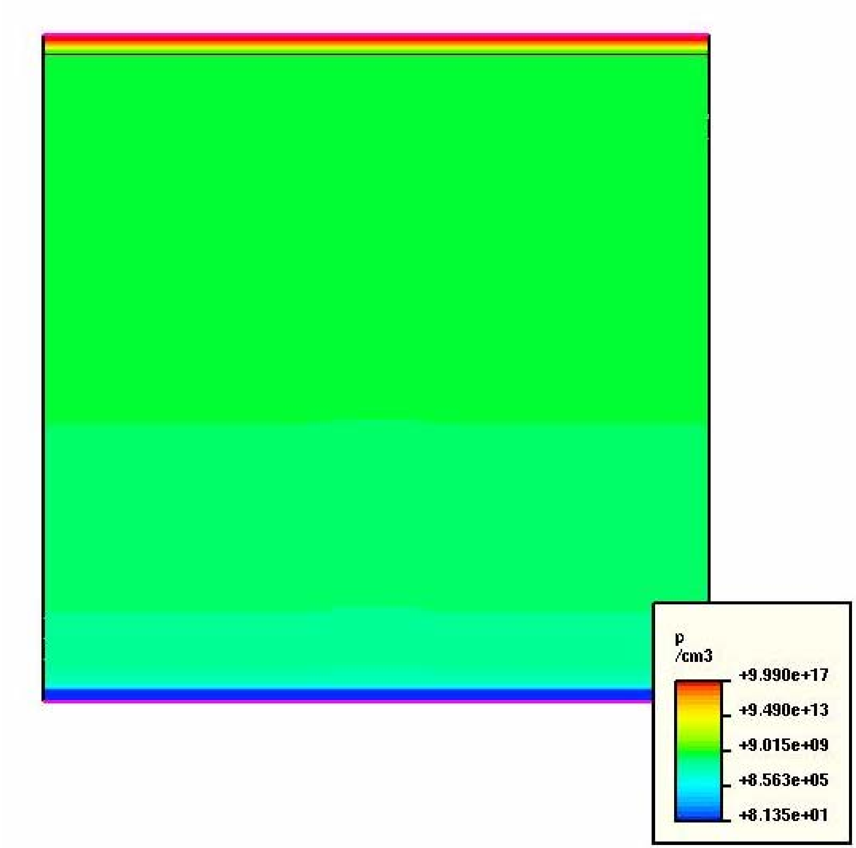


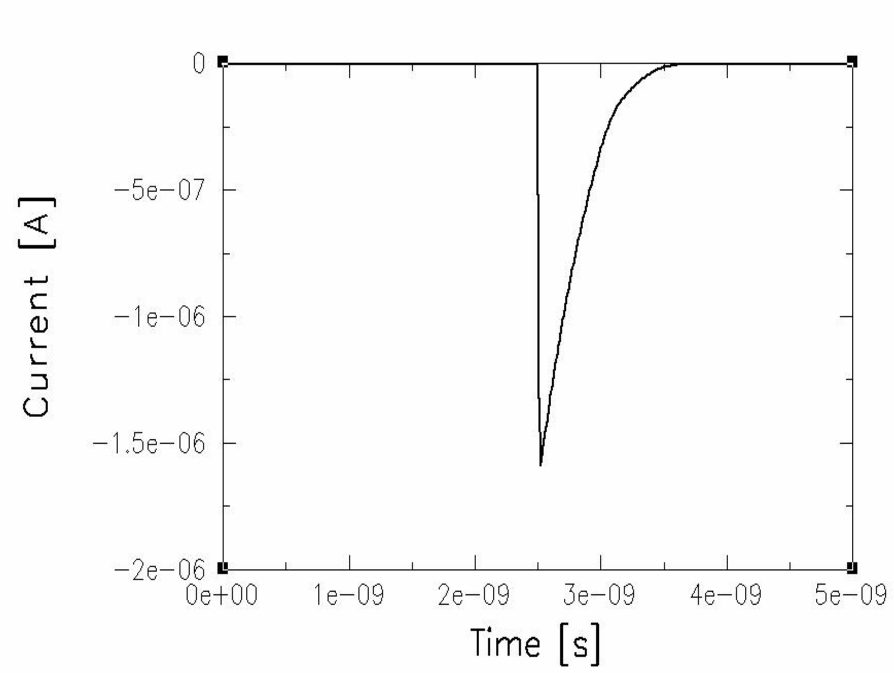


- V_{dep} in thin structures is one order of magnitude lower than in thick one

- V_{dep} of thin diode at a fluence of 1×10^{15} n/cm^2 is about 120 V while in thick diode is more than 3000 V !

CCE Simulation results



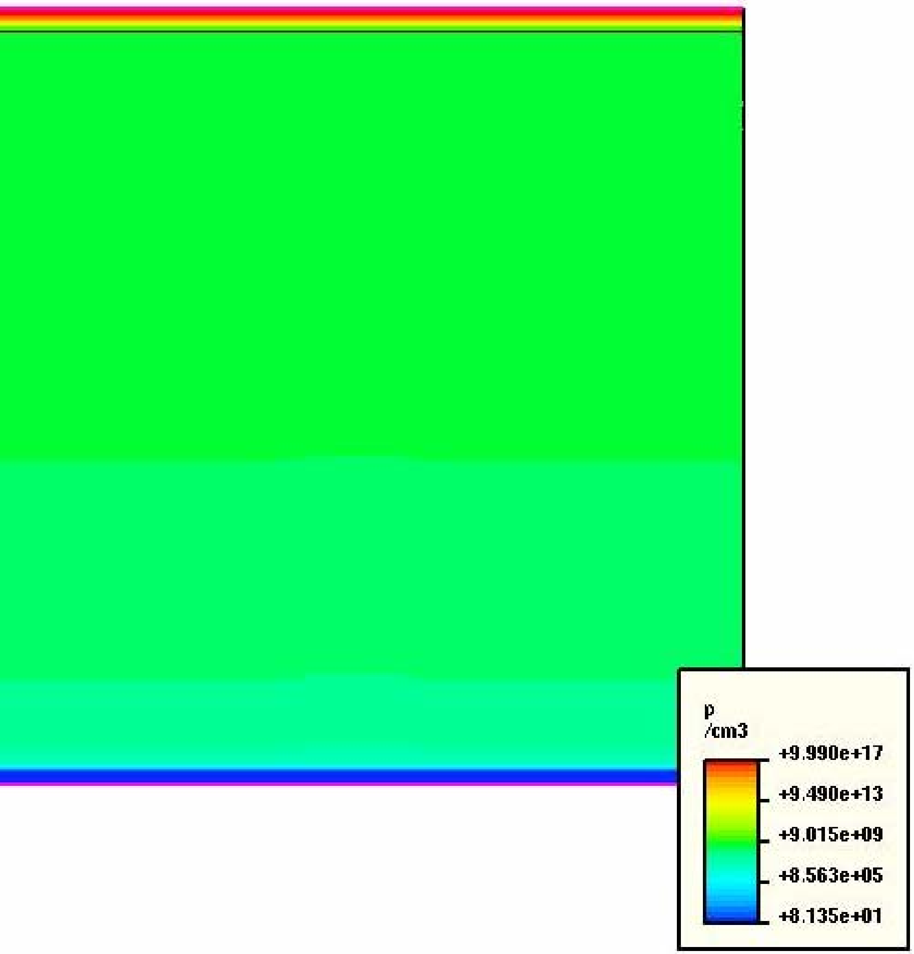


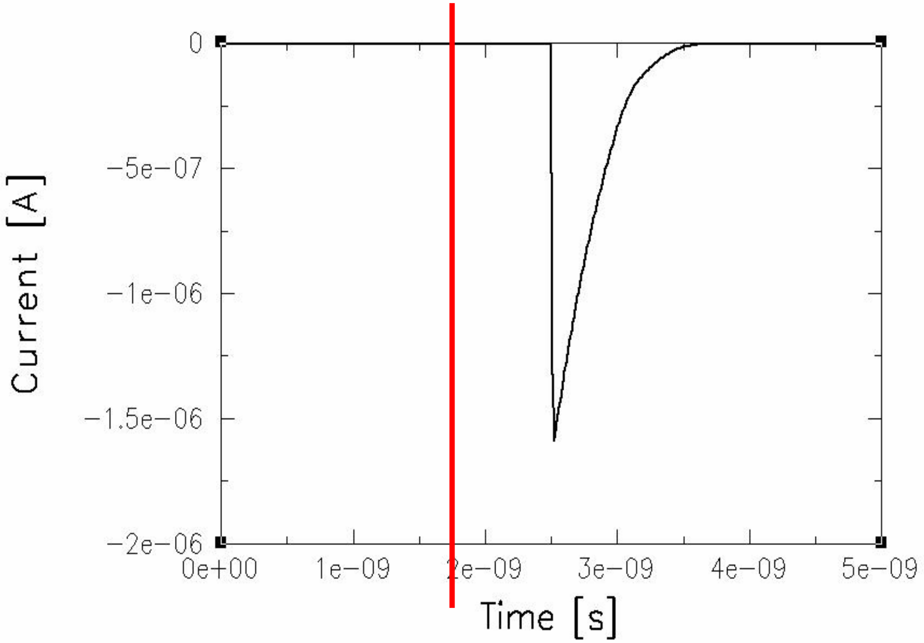
$$Q = \int I(t)dt$$

MIP: 80 e-h pairs/ µm

Cylinder diameter= 2µm

CCE Simulation results





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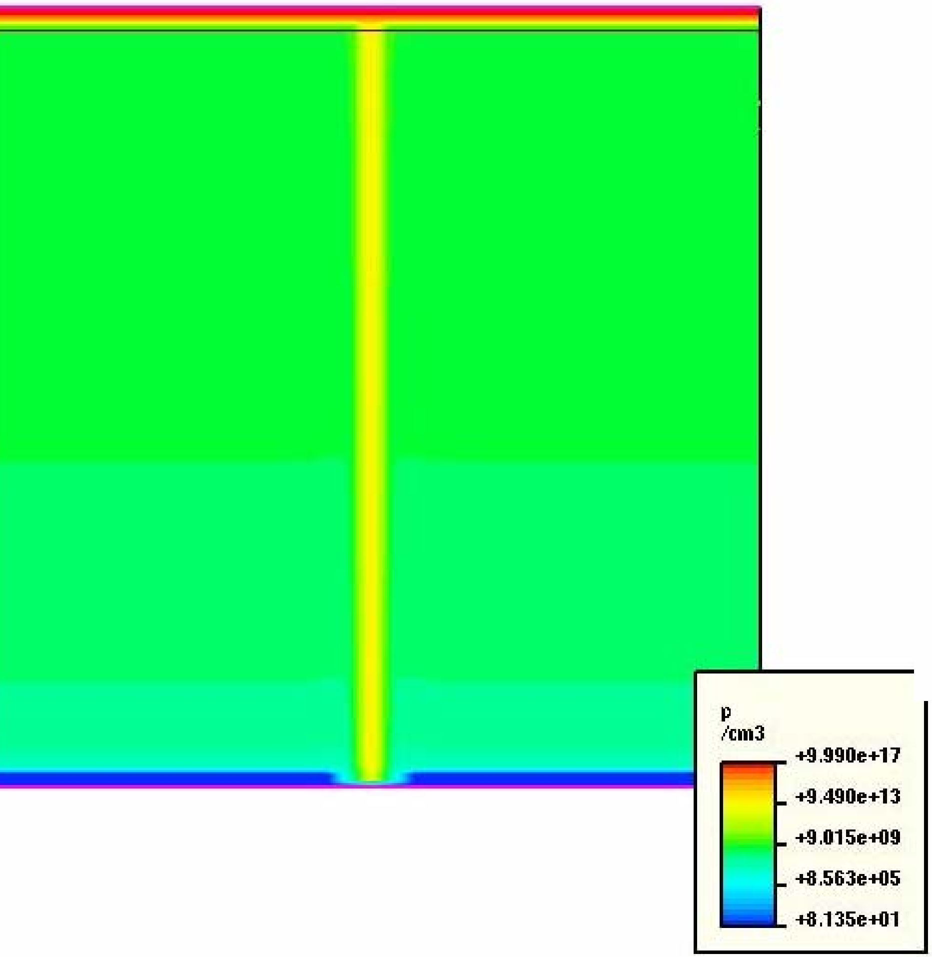

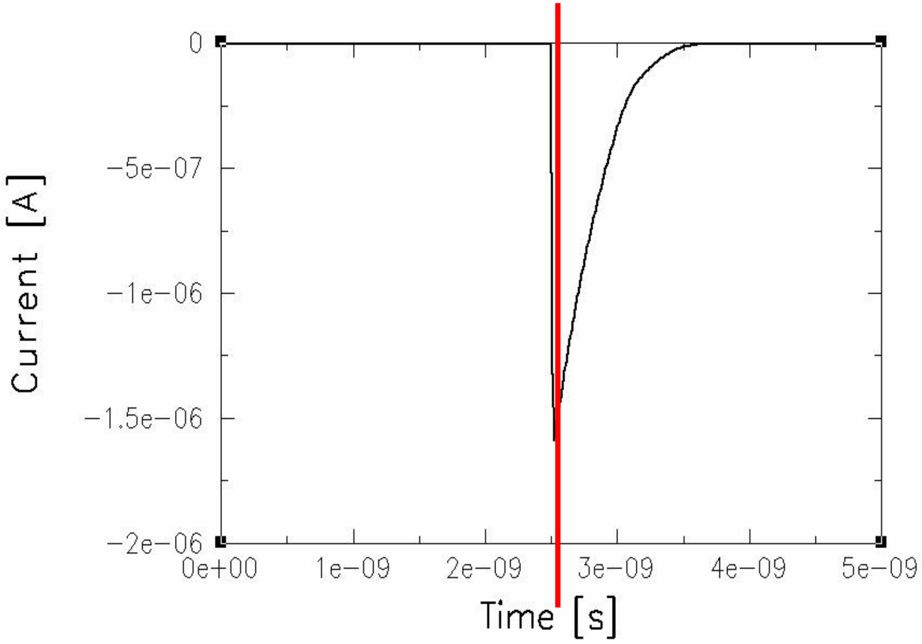

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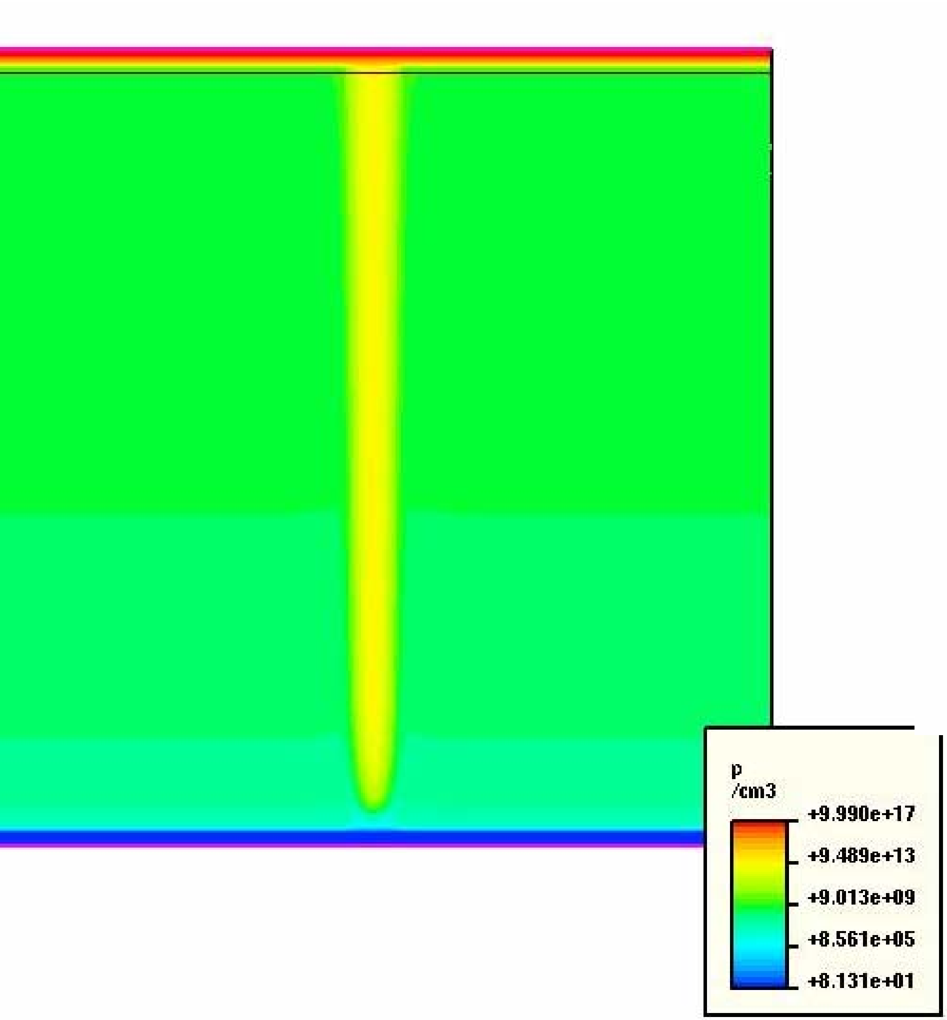

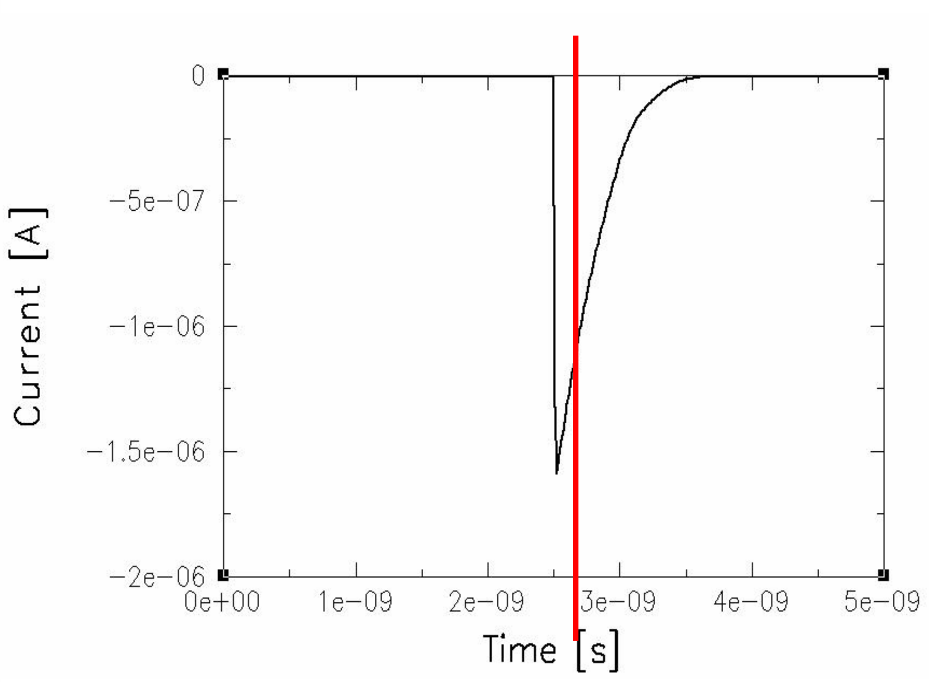

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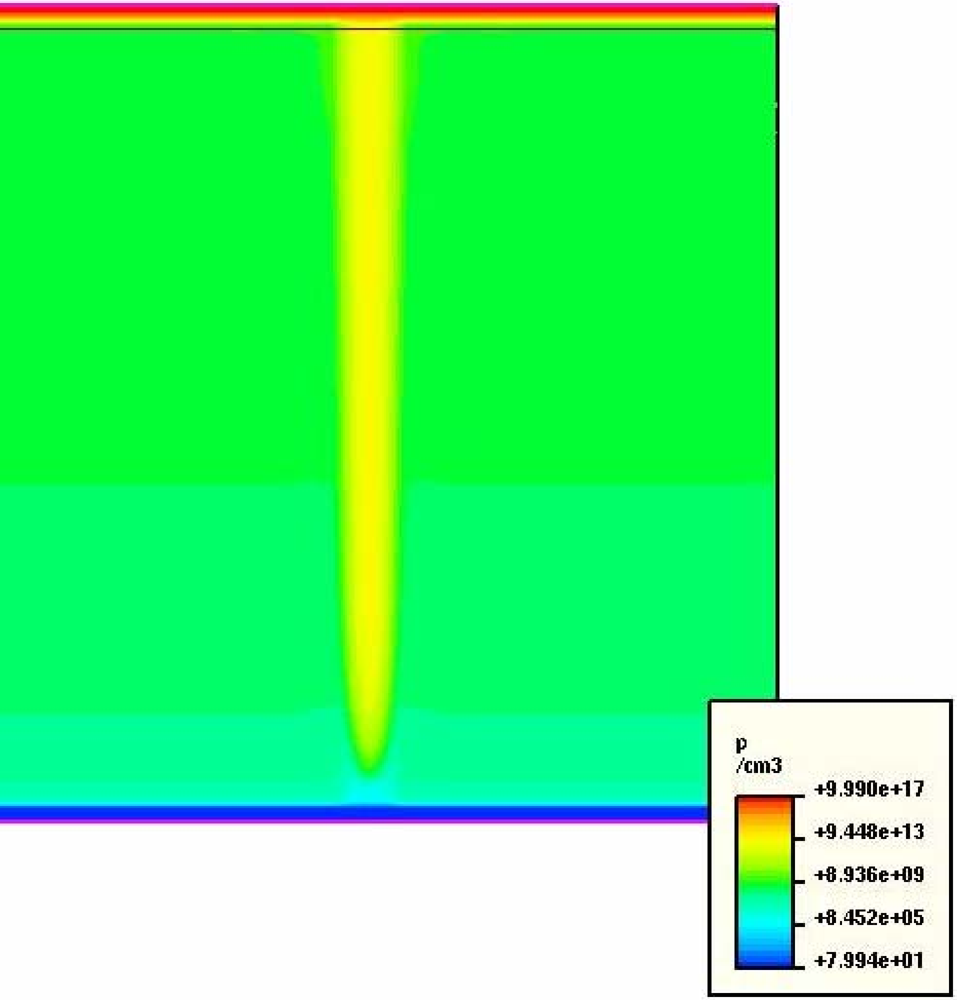

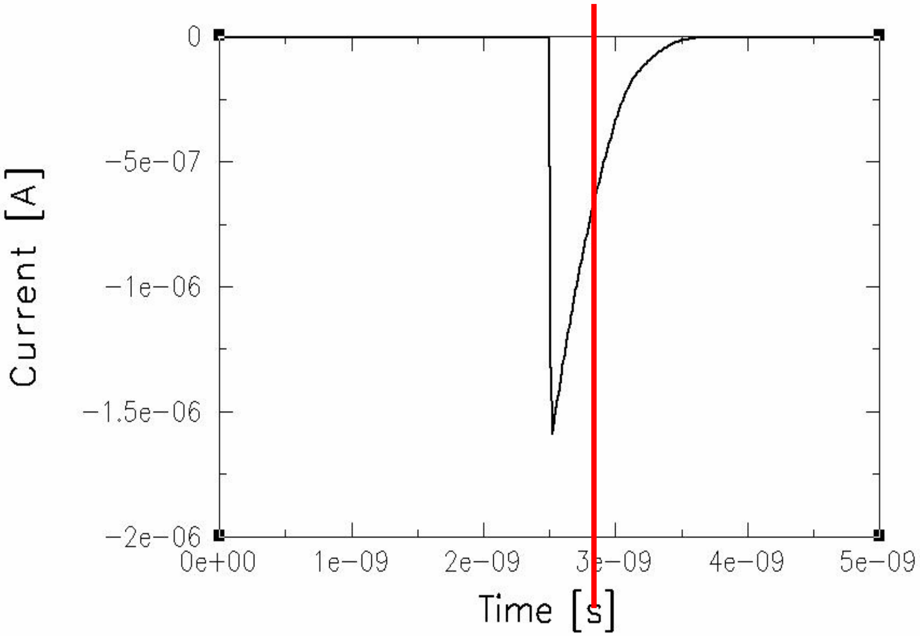

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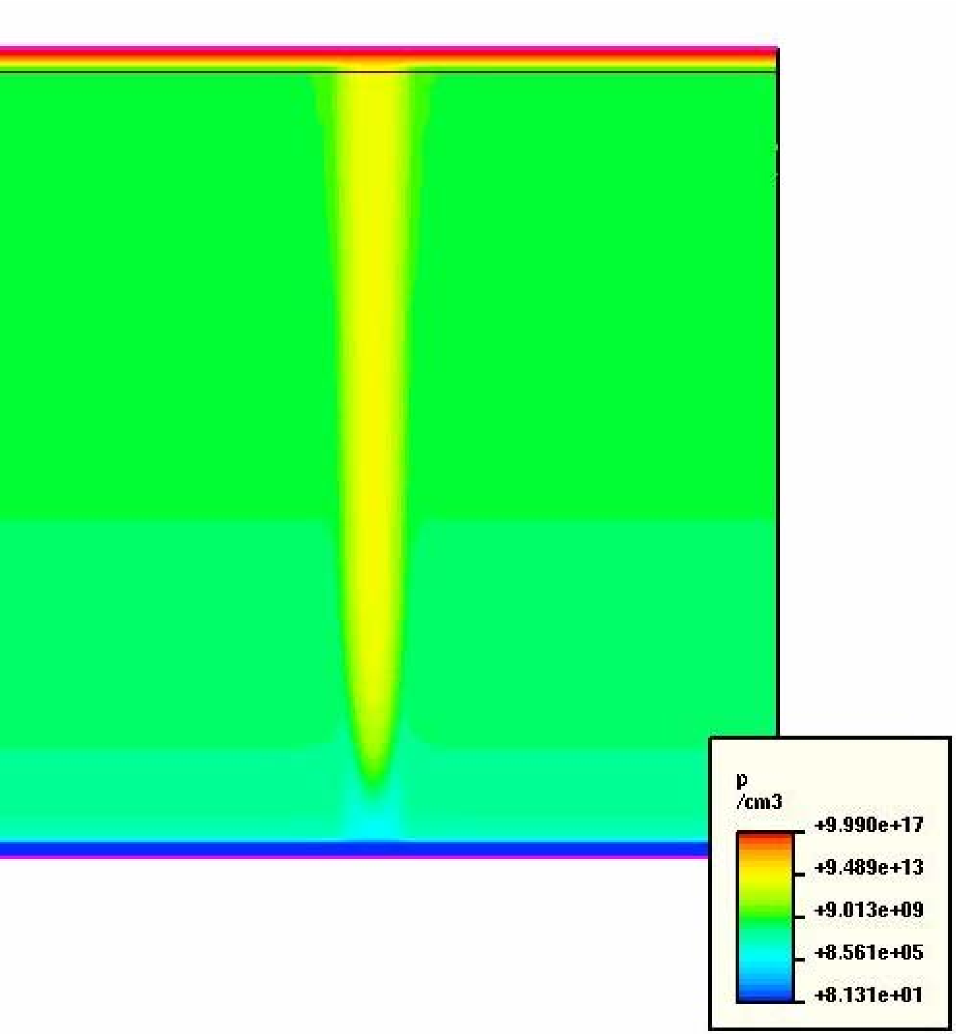

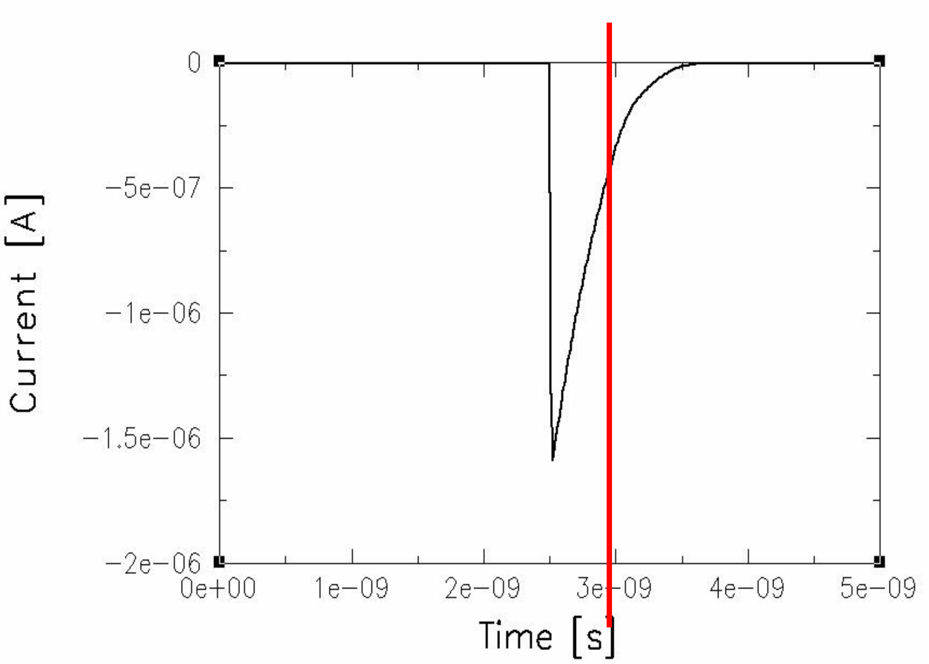

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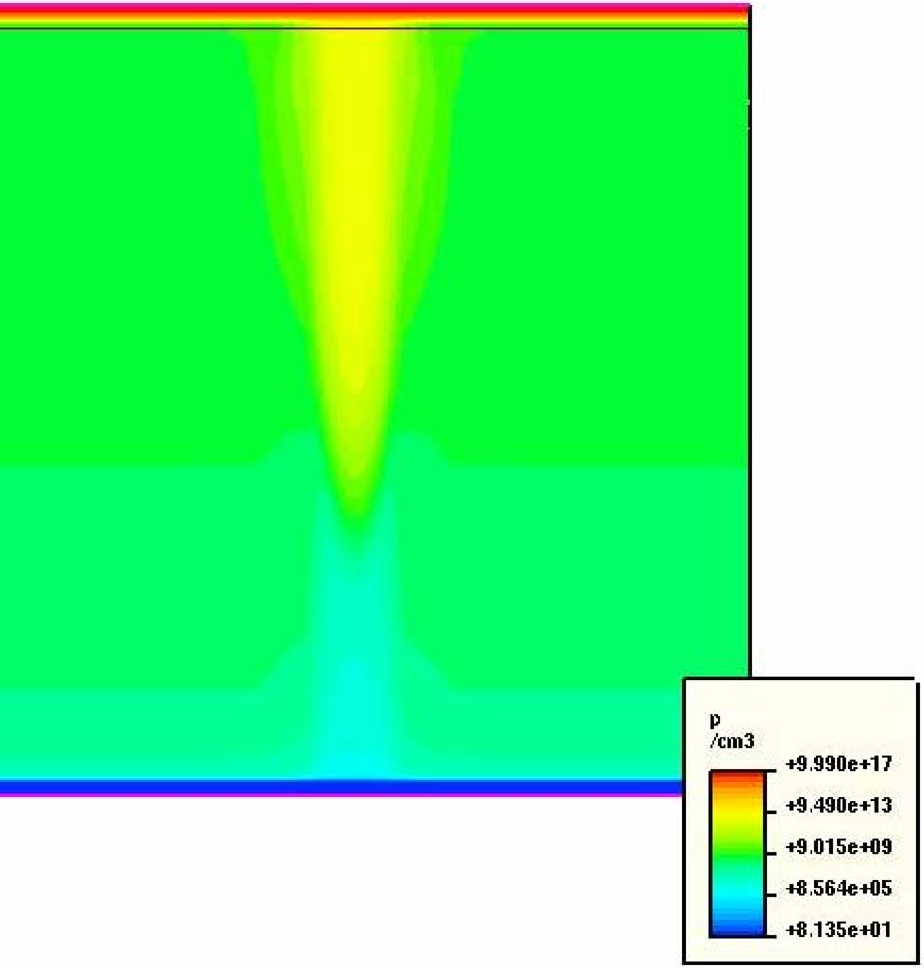

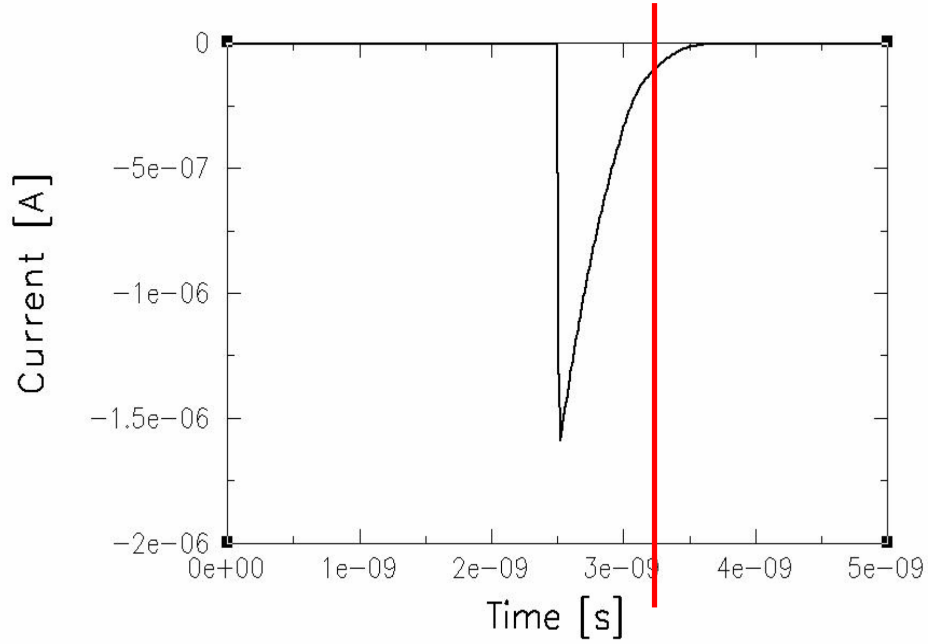

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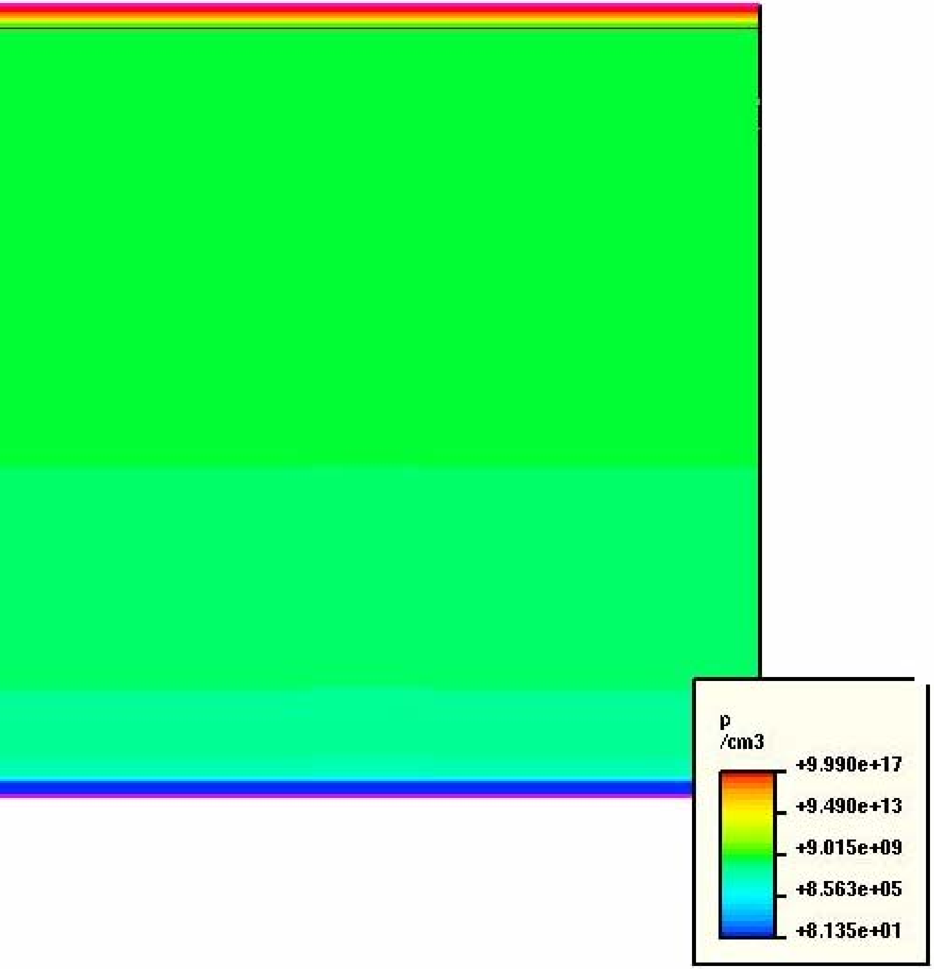

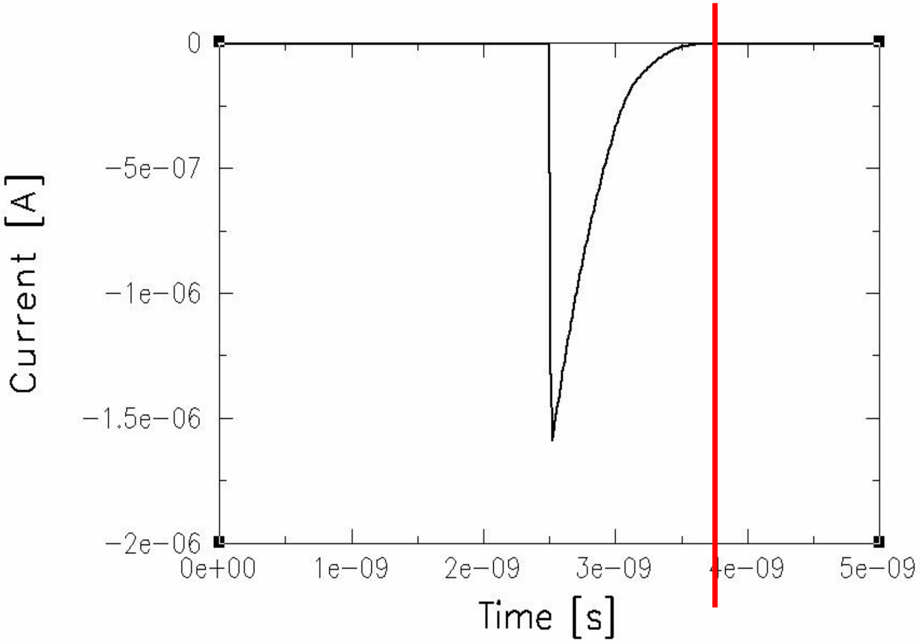

Simulated CCE as function of the fluence

	Thick	Thin
Φ=2e14 n/cm^2	$Q_{@300V}$= 1.6 fC	$Q_{@14V}$= 0.58 fC
	CCE = 45%	**CCE = 98%**
	Exp. [1, 2] CCE = 42%	
Φ=1e15 n/cm^2	$Q_{@VBD=300V}$= 1 fC	$Q_{@120V}$= 0.57 fC
	CCE = 27%	**CCE = 95%**
	Exp.CCE = 20-30%	

For Φ=1e15 n/cm^2

Q_{thin}=57% Q_{thick}

Thin @ 120V NO Breakdown risk and full depleted

[1] L.Beattie et al./
NIM 412A (98)
[2] M.Bruzzi et al./
NIM 61B(98)

Conclusions

Irradiated thin and thick diodes have been analyzed considering hree levels simulation model until Φ=1e15 n/cm^2

Thin features:

- V_{dep} in thin structures is one order of magnitude lower
- CCE at very high fluence (10^{15} n/cm^2) is 95% for th structures.
- Q_{thin}=57% Q_{thick}

Next step is to simulate thin structures at higher fluences (1e1 n/cm^2) and measure irradiated ones.