Analysis and Simulation of Charge Collection Efficiency in Si Thin Detectors

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Outline

- Introduction
- Radiation damage modelling
- Simulation of Silicon Thin structures:
    - Depletion Voltage as a function of Fluence
    - Charge Collection Efficiency as a function of thickness and Fluence

Introduction

- Simulation of thin diodes:
  - Activity included in the framework of CERN **RD50 - Radiation hard semiconductor devices for very high luminosity colliders -** collaboration
  - Study of new structures which improve detector radiation hardness

Simulation Tool

- **Simulation tool**:

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

- **Damage modelling**:

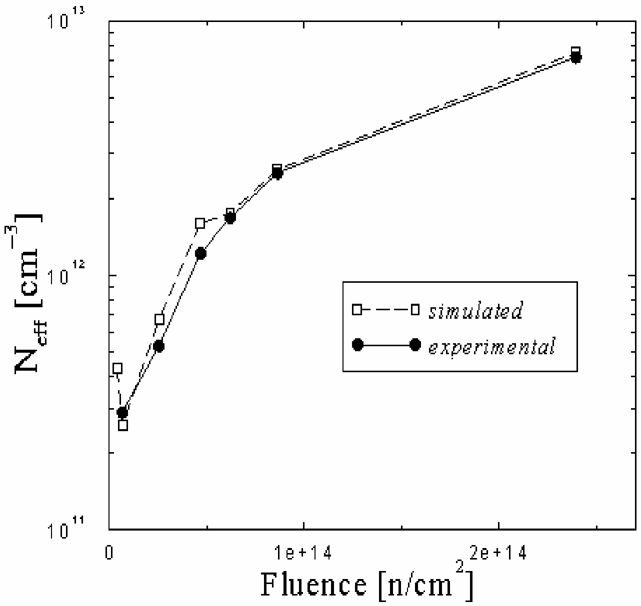
  - Deep levels: E_t, σ_n and σ_p
  - SRH statistics
  - Donor removal mechanism
  - Other effects: high density defect concentration (clusters) produces an increase of the leakage current

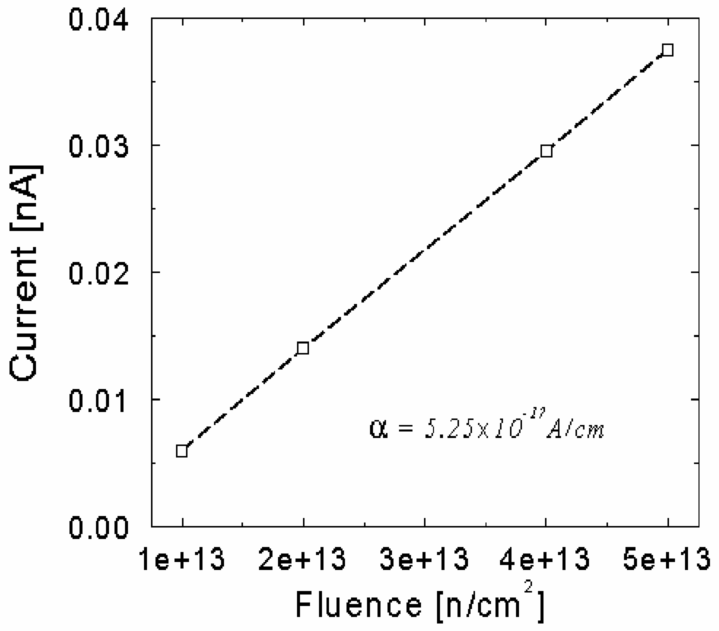
Three-level model

- Level characteristics*:

	Acceptor	Acceptor	Donor
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}

Comparison between simulated and experimental data shows that results have been well reproduced





*Passeri, D.; et al. Nuclear Science, IEEE Transactions on , vol. 48 (2001).

Thin detectors

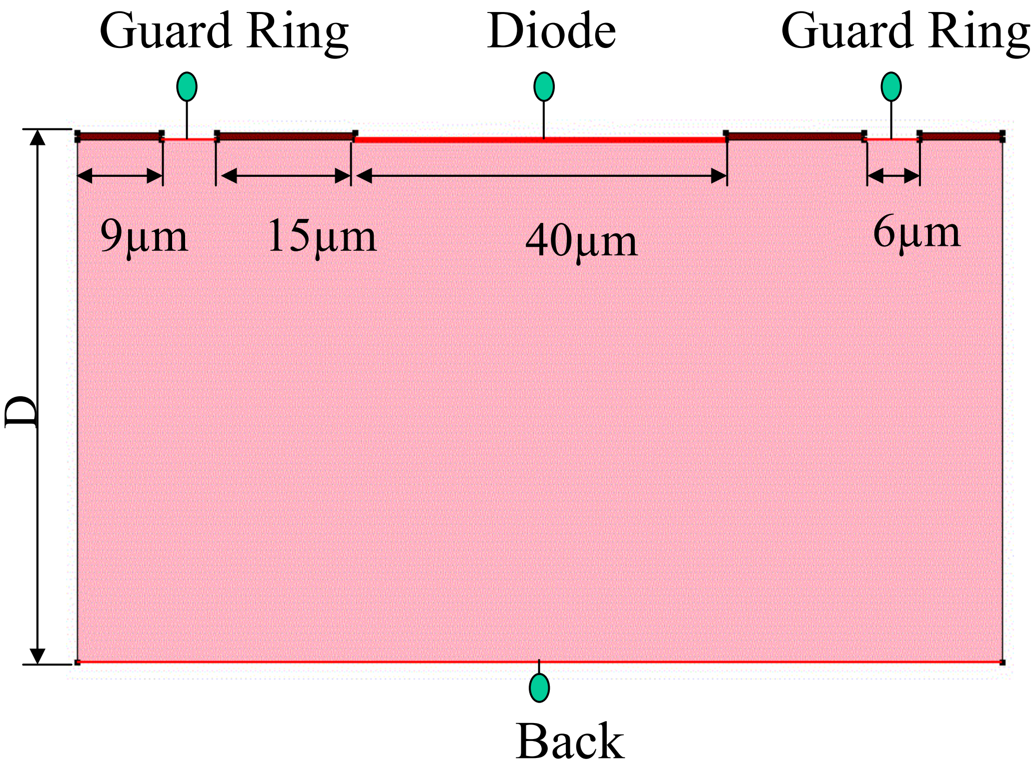
- Thin detectors have been proposed to investigate the possibility to get a **low depletion voltage** and to **limit the leakage current** of heavily irradiated silicon devices

Simulation setup

Simulated device structure and parameters:

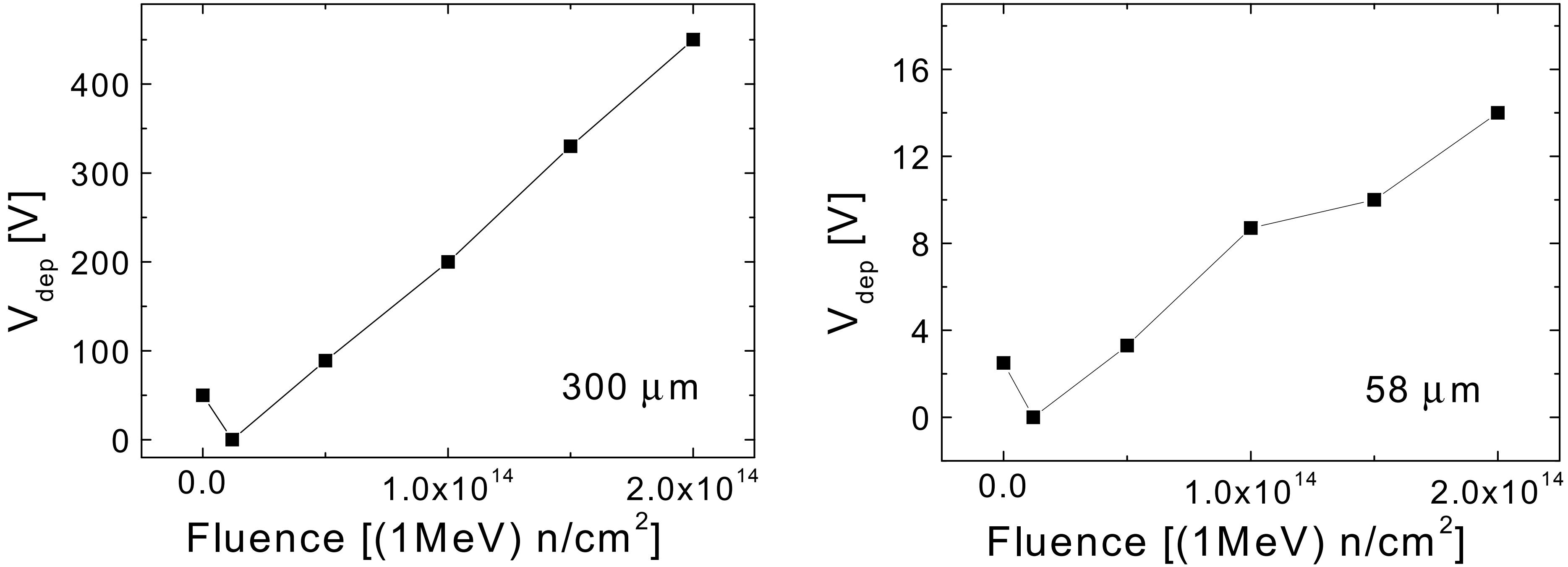
- –Doping profiles:
  - •n-doped substrate (7×10^{11} cm^{-3})→ **6kΩcm**.
  - •Charge concentration at the silicon-oxide interface of :
    - –4×10^{11} cm^{-3} pre-irradiation
    - –1×10^{12} cm^{-3} post-irradiation
- –Optimized variable mesh definition
- – Temperature at 300 K
- – Different thickness devices:

  D = 20-50-100-200-300 μm



Simulation results

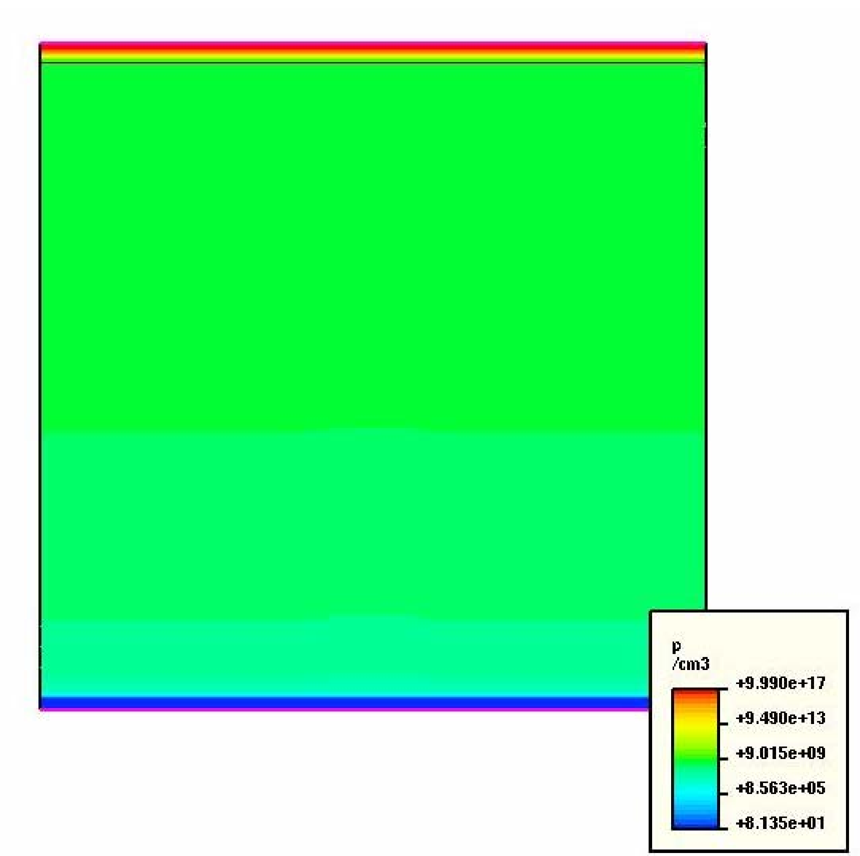
Simulated Depletion Voltage as function of the fluence

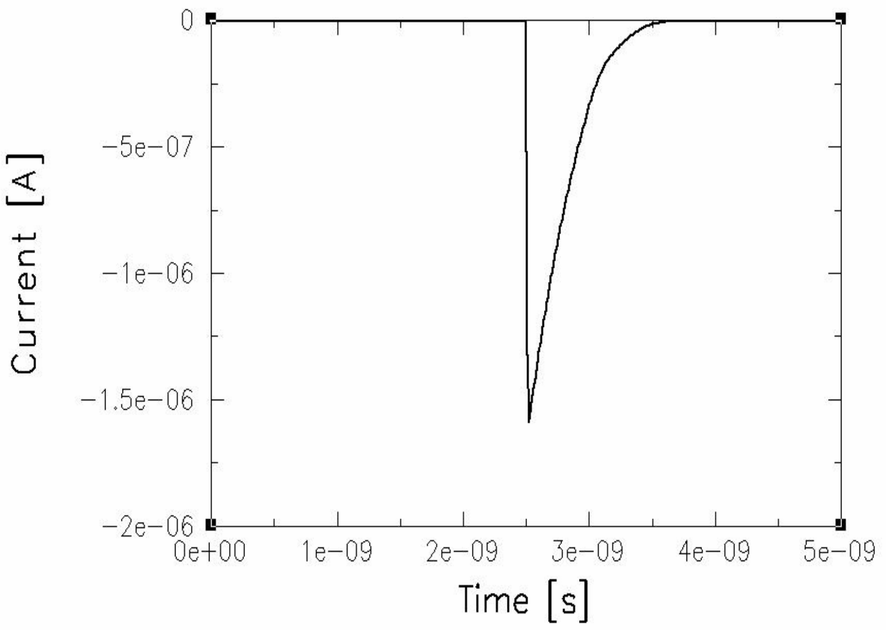


- V_{dep} in thin structures is one order of magnitude lower than in thick one

- 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



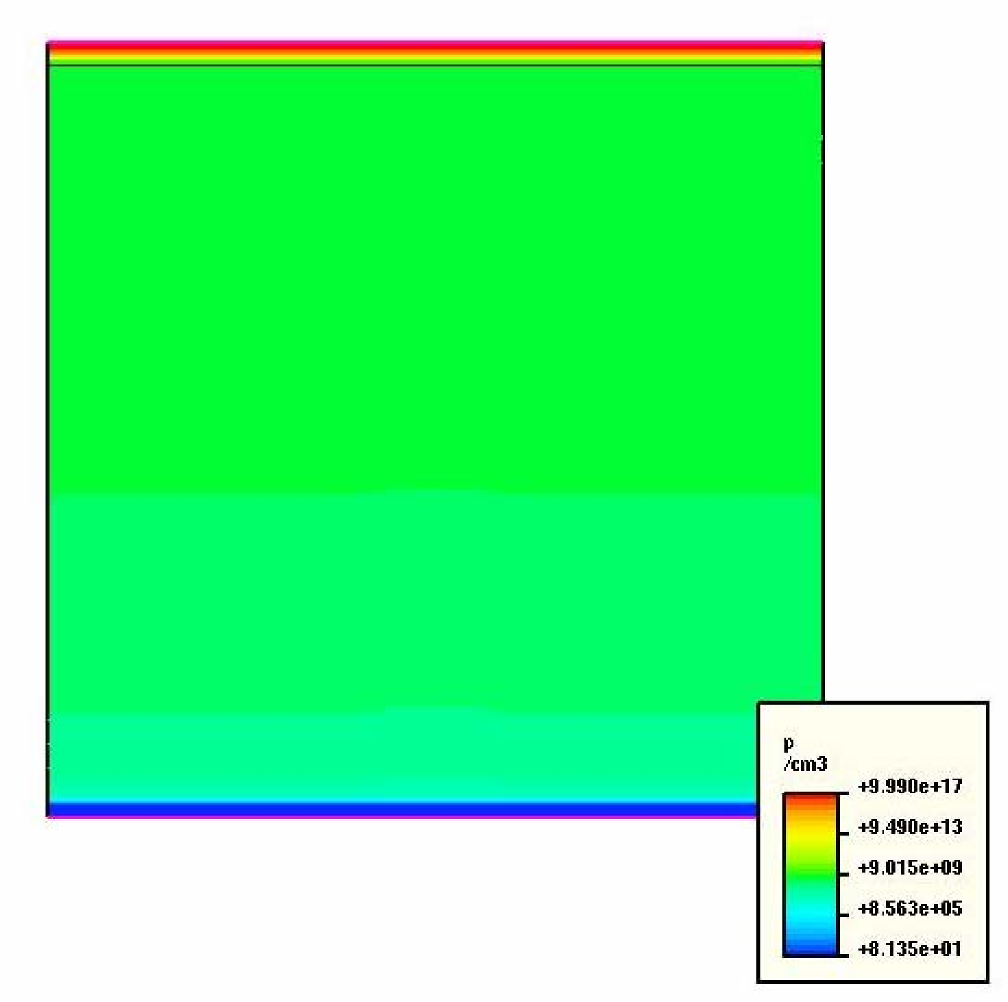


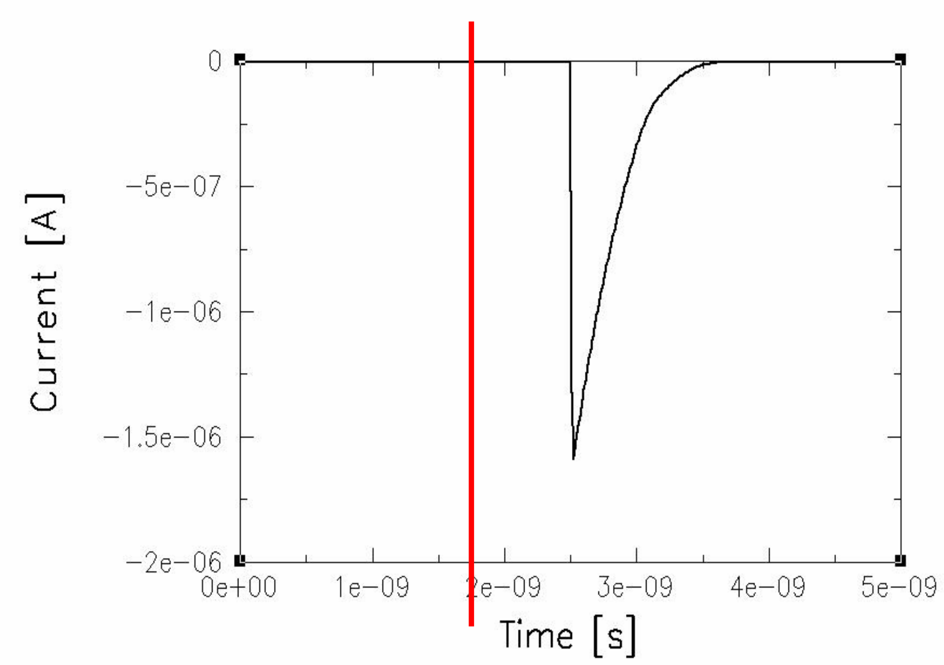
$$Q = \int I(t)dt$$

MIP: 80 e-h pairs/ µm

Cylinder diameter= 2µm

CCE Simulation results





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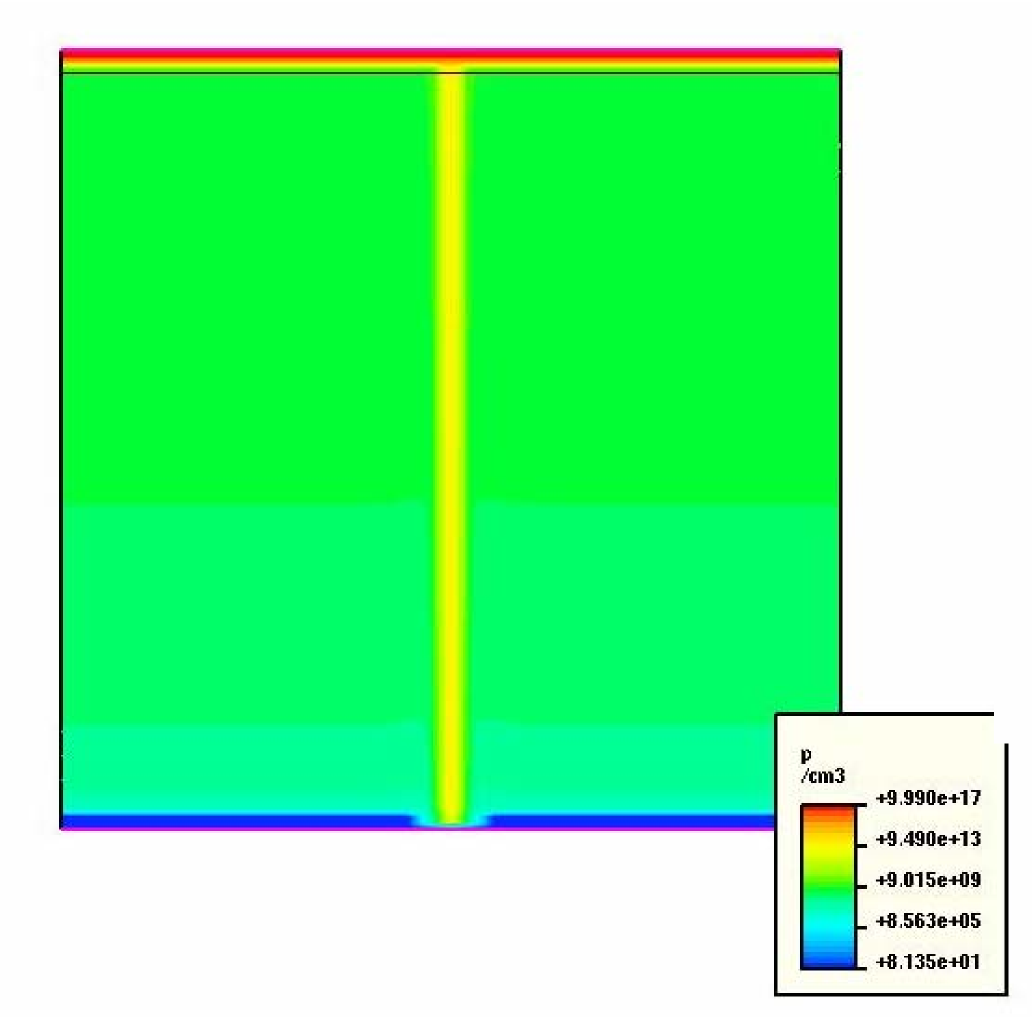

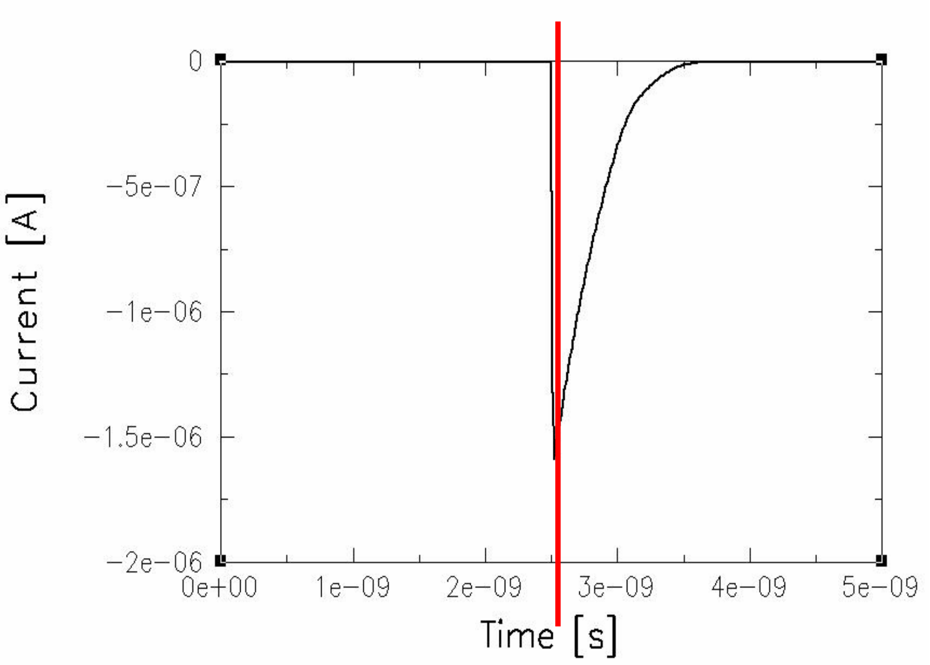

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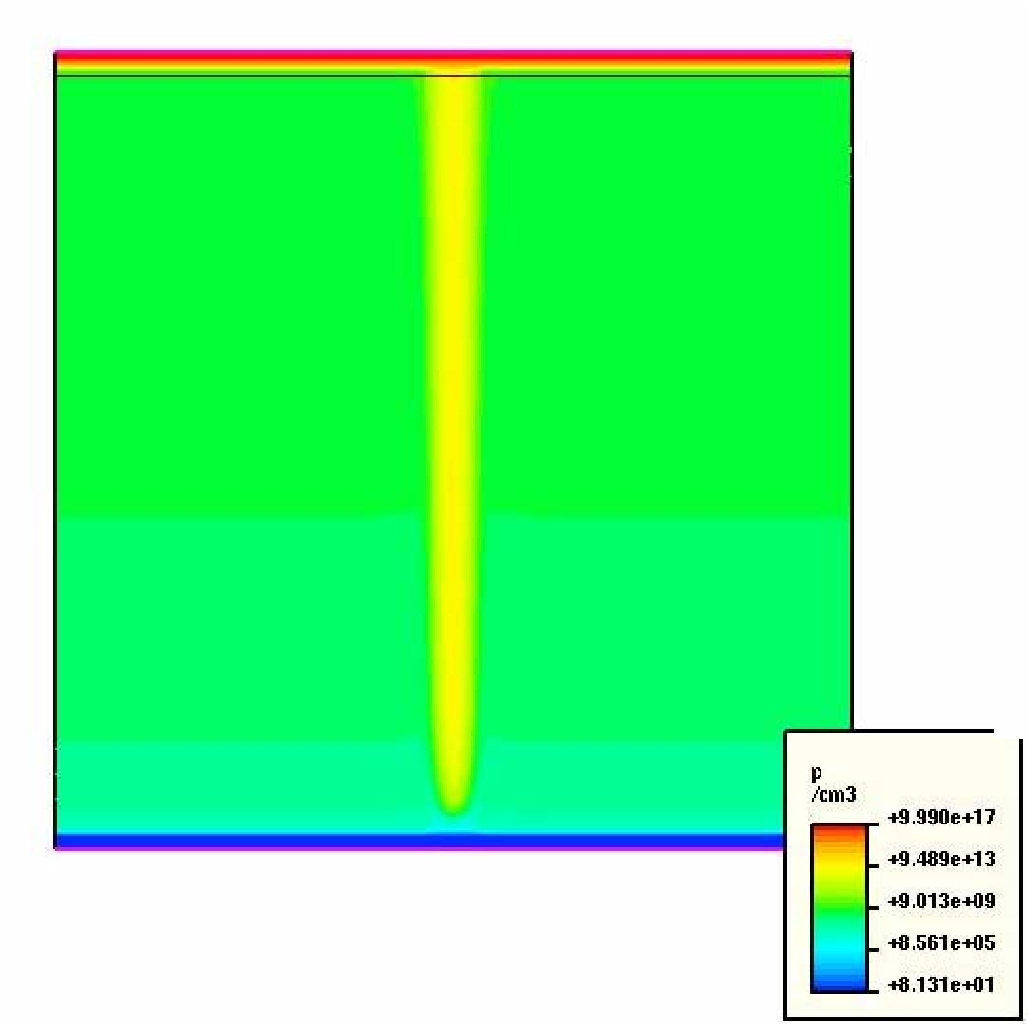

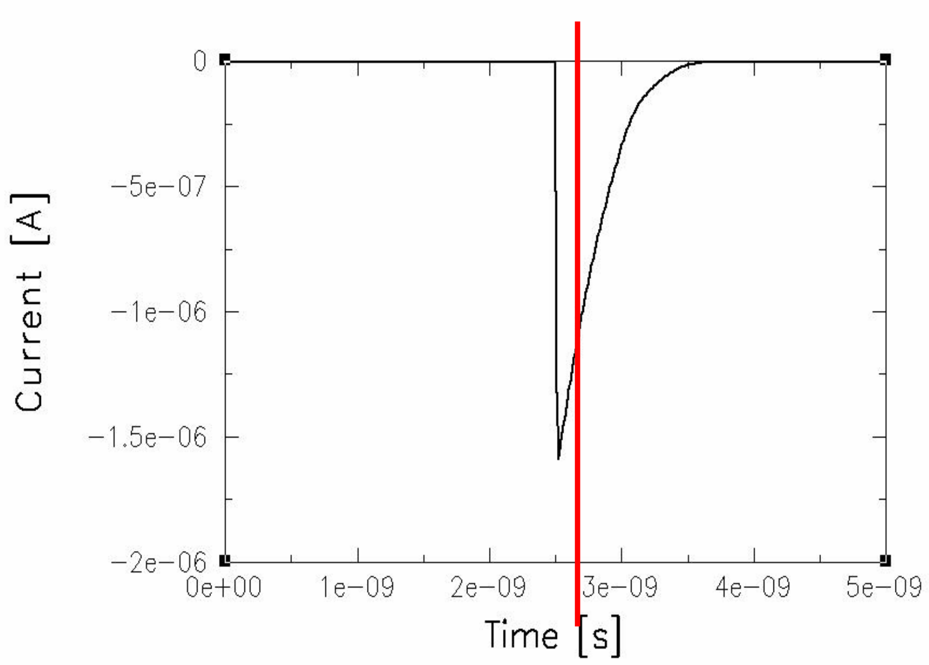

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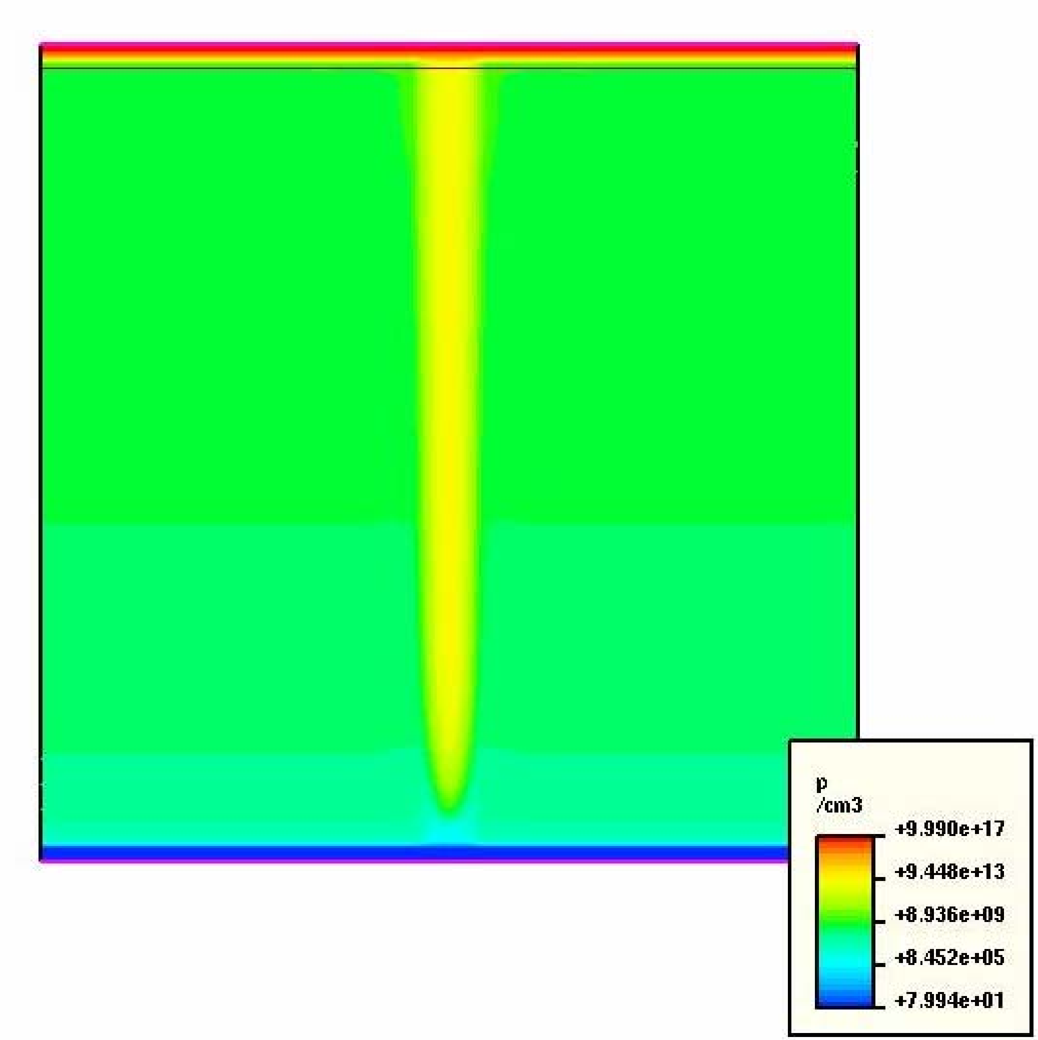

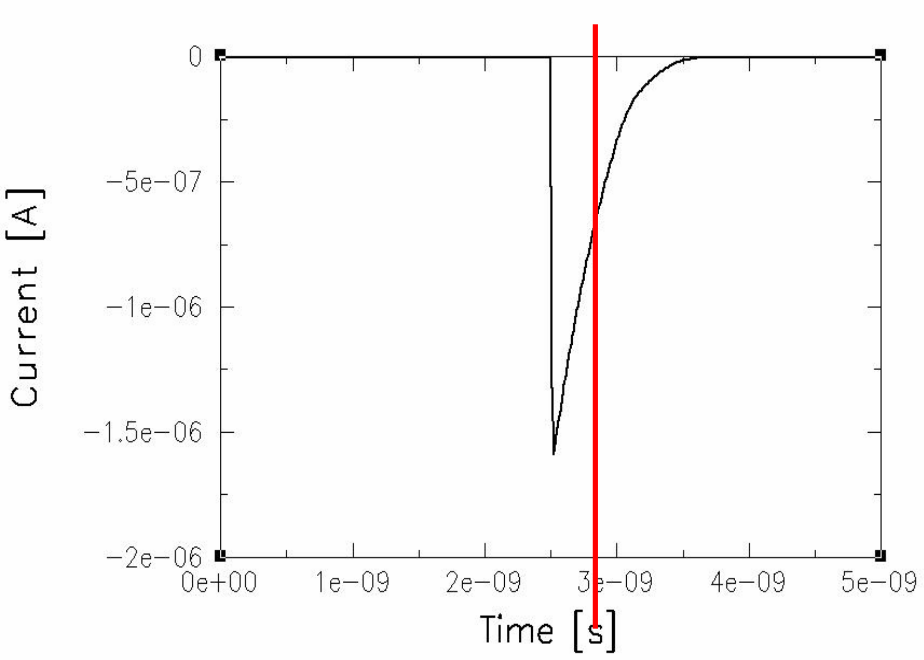

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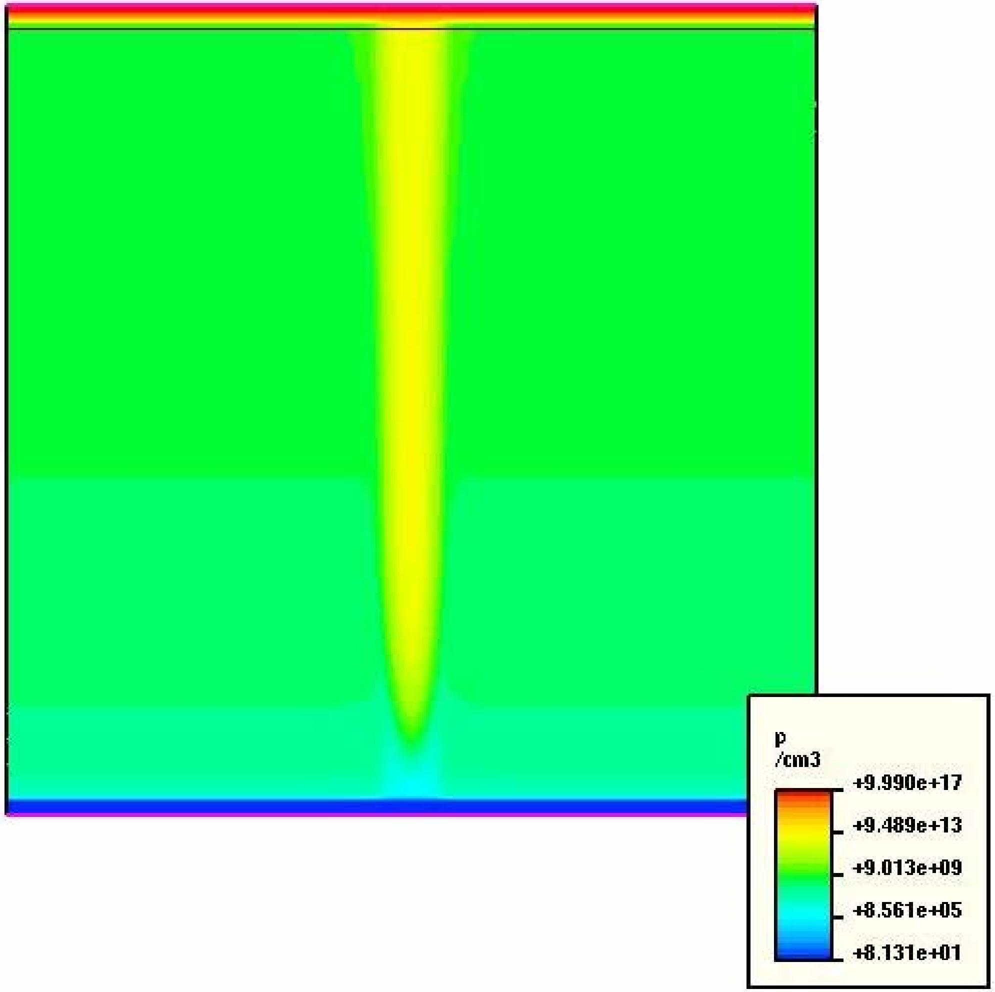

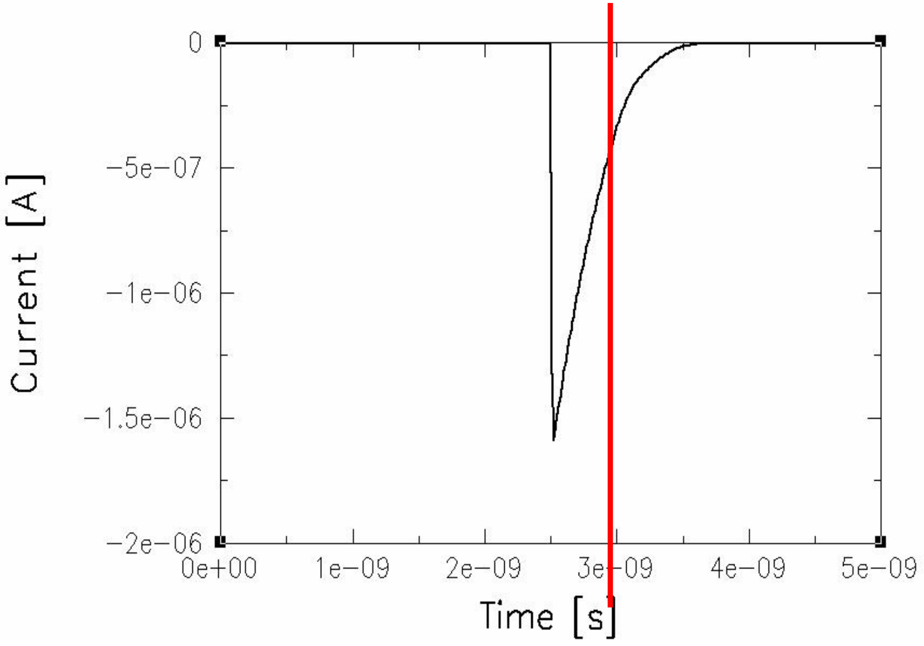

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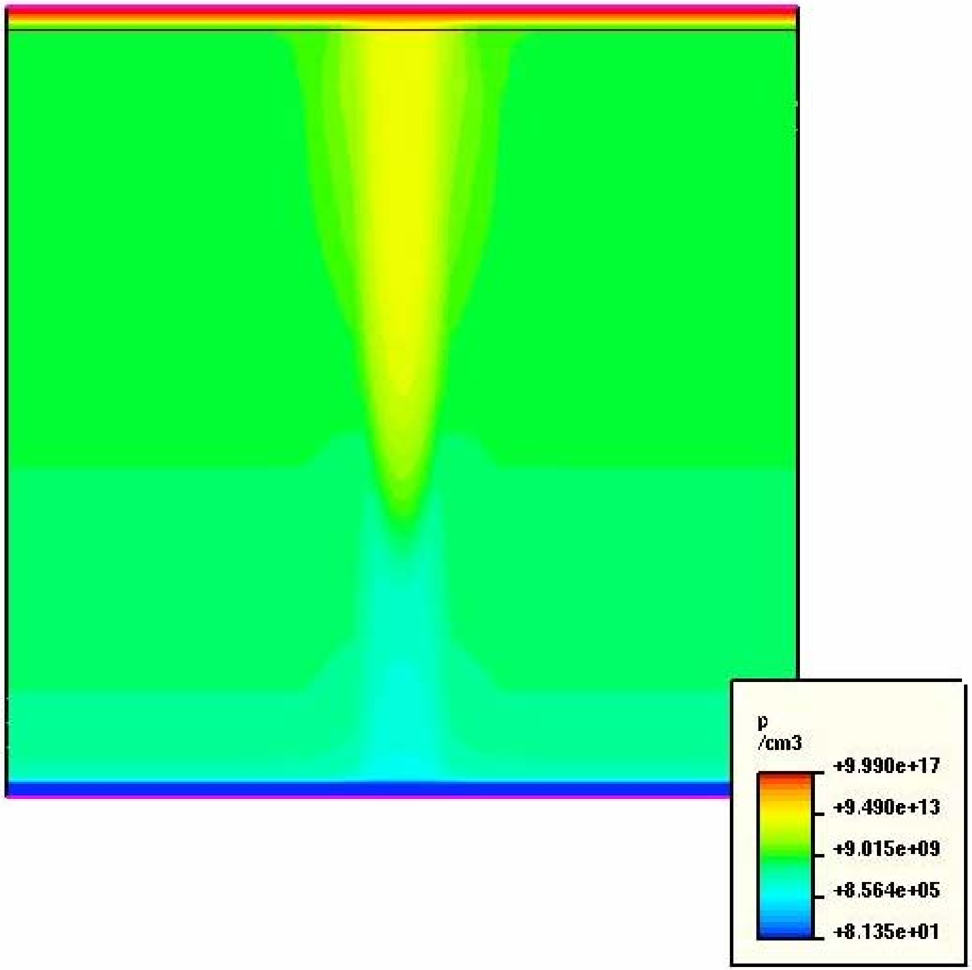

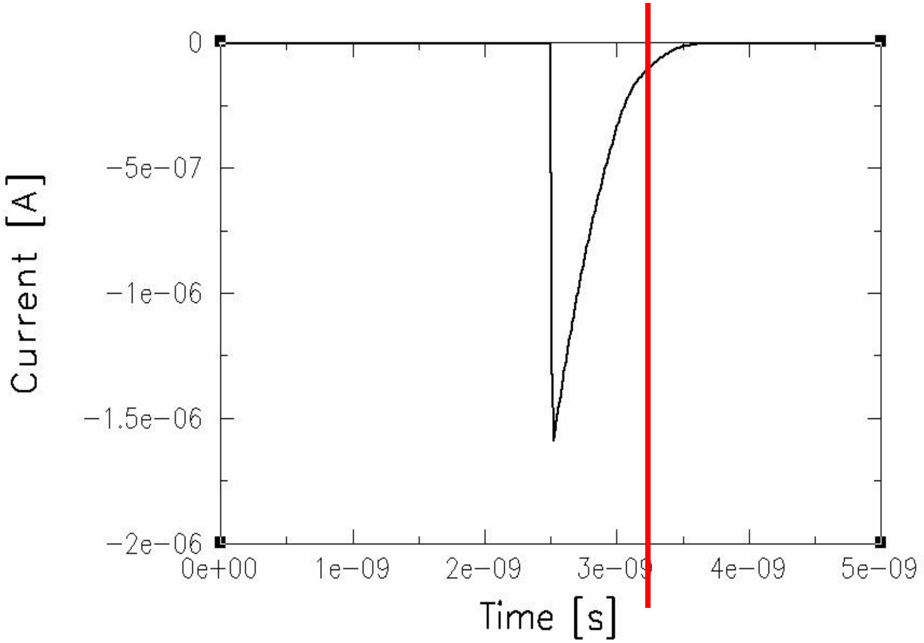

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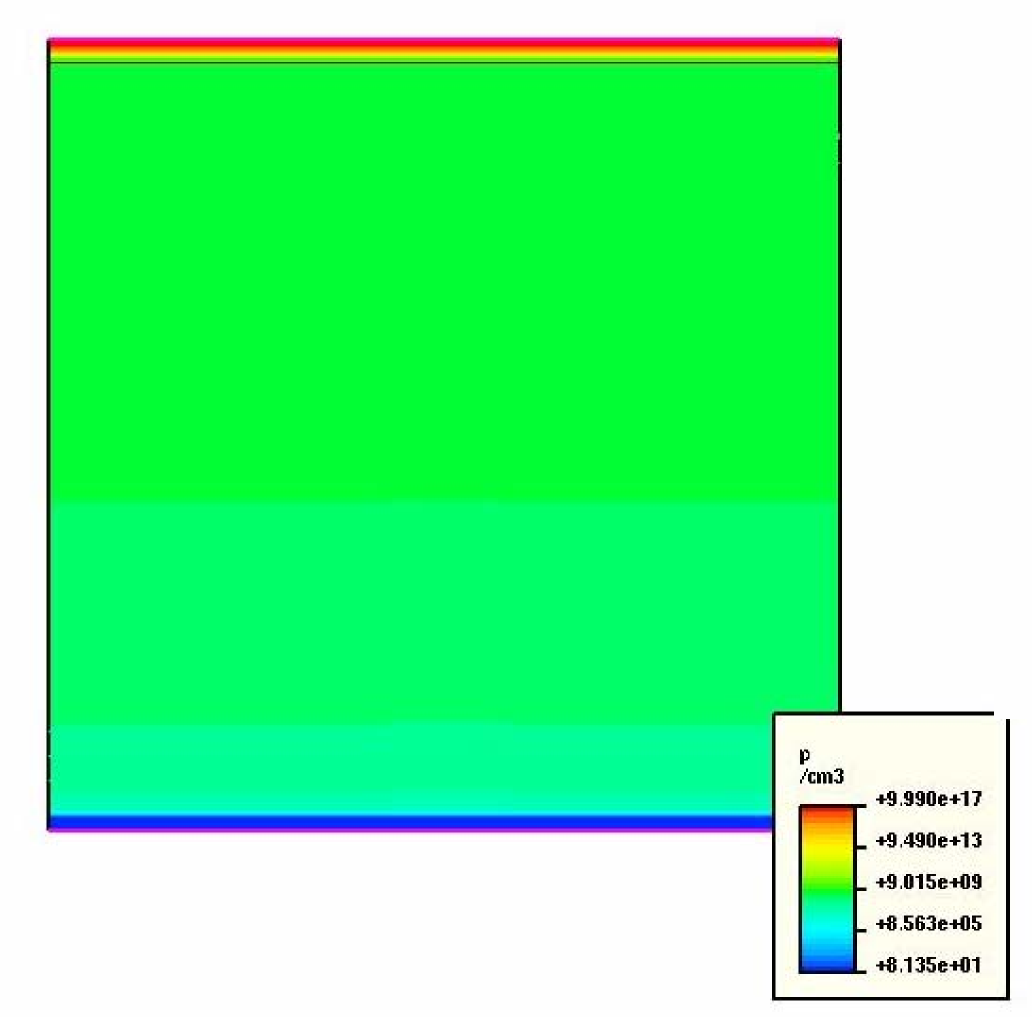
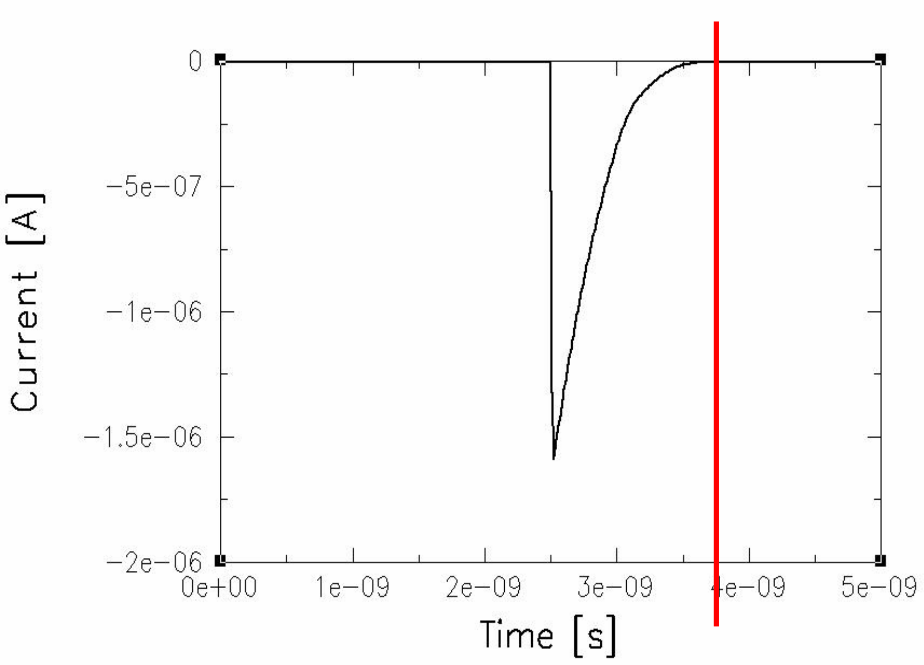
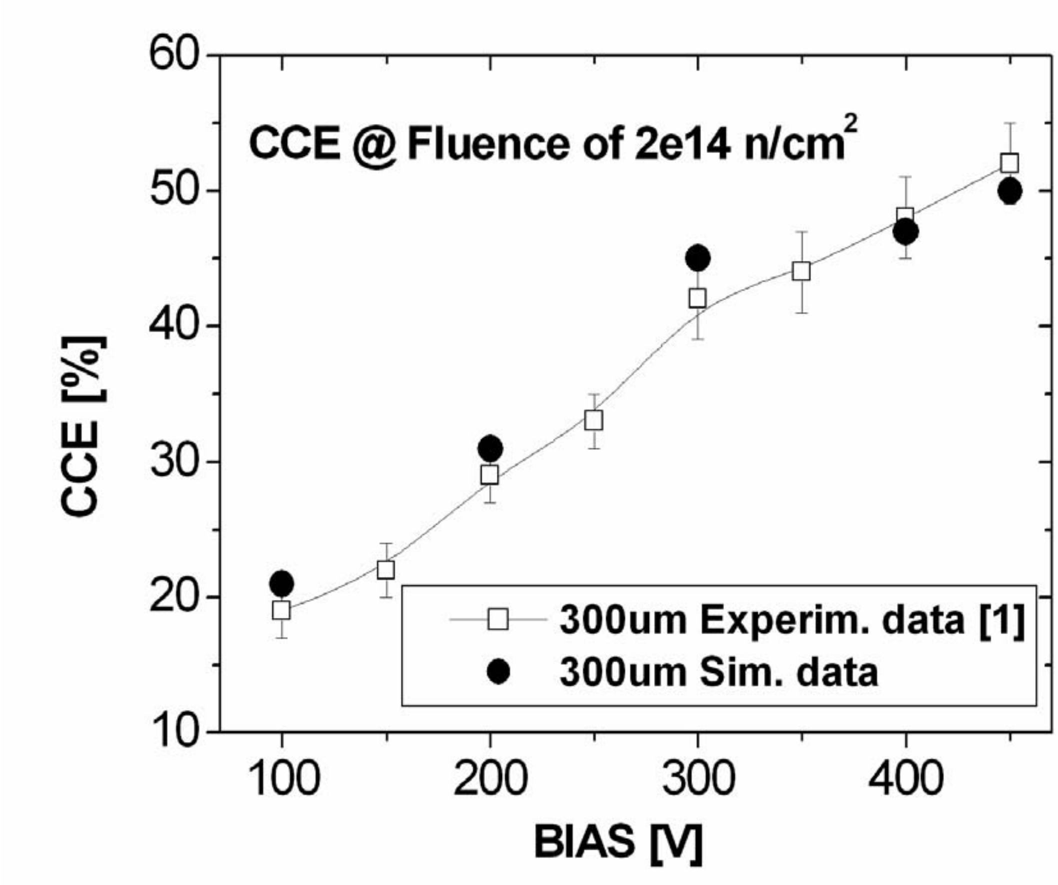




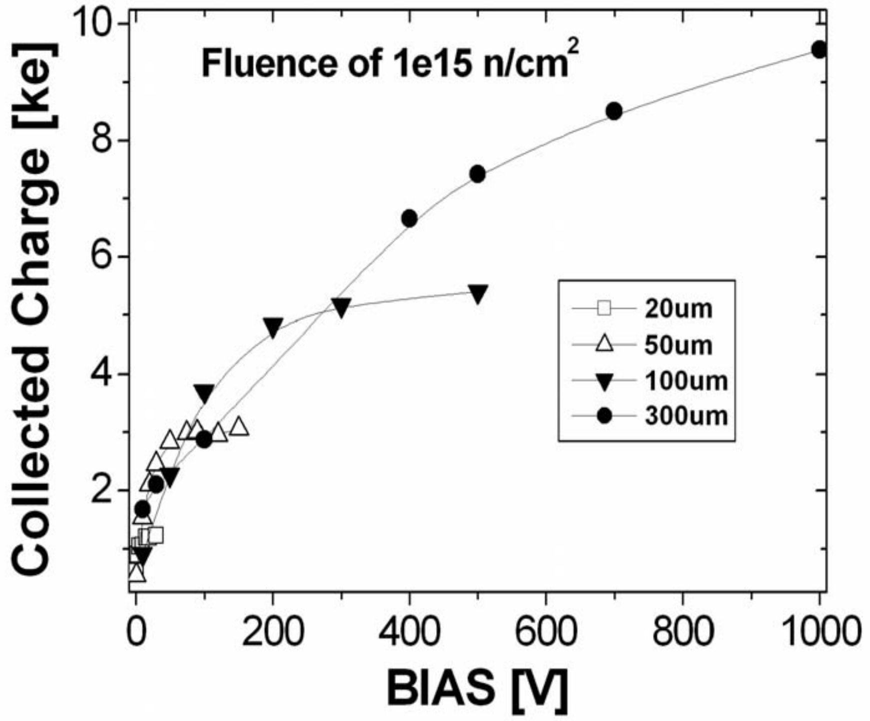
Simulated Collected Charge as a function of the applied Bias at 2×10^{14} n/cm^2 and Experimental data

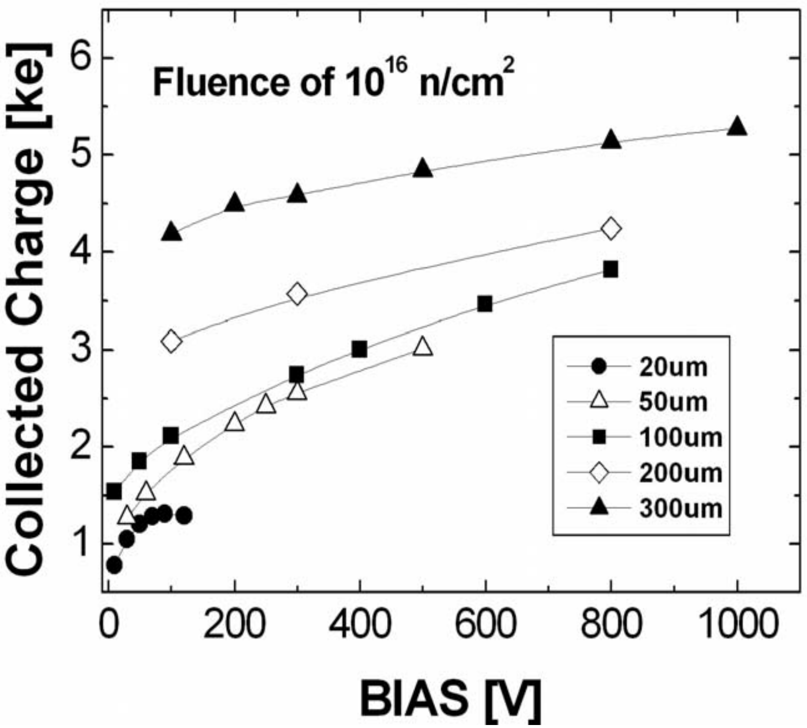


Simulated data at fluence of 10^{14} reproduce experimental results [1]

[1] M.Bruzzi et al./ Nucl.Phys.61B(98)

Simulated Collected Charge as a function of the applied Bias at 10^{15} and 10^{16} n/cm^2 Fluence

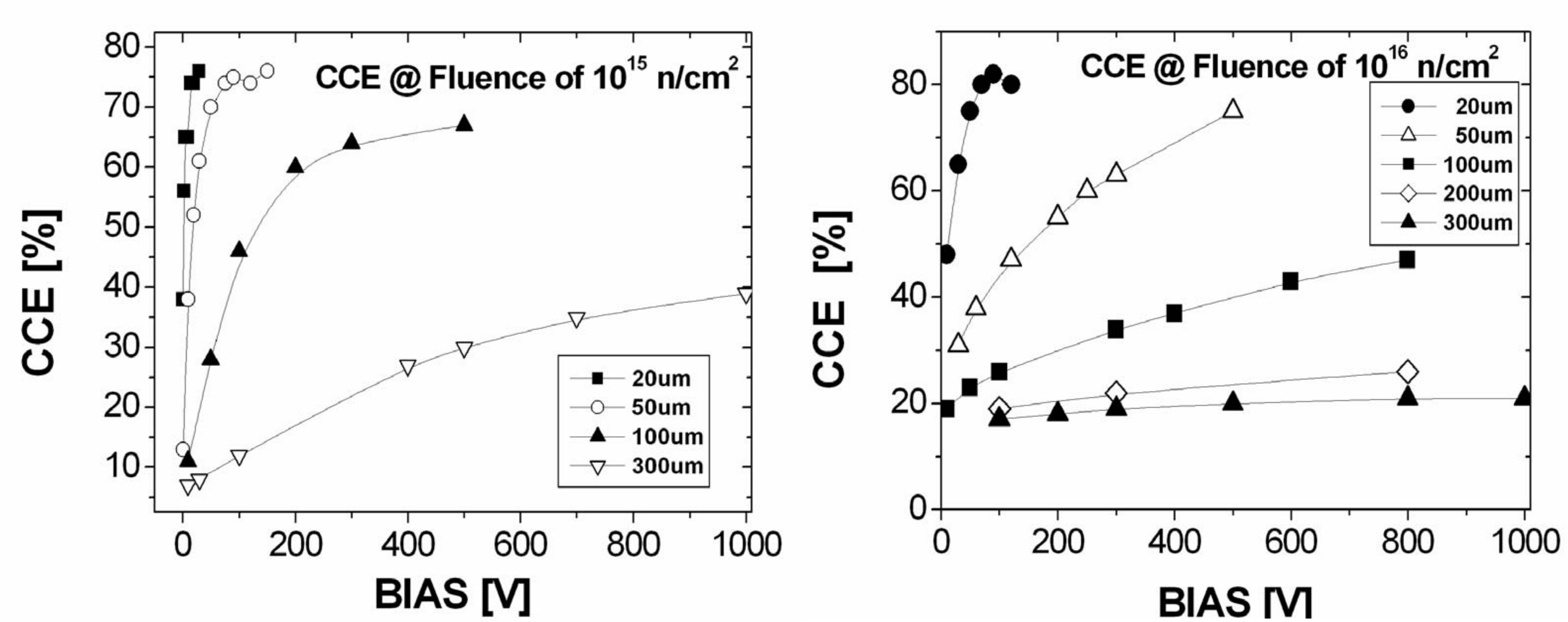




1. Simulated data at fluence of 10^{15} well reproduce experimental data [1,2]
2. The simulation of thinner structures (50-100µm) at higher fluence shows a saturation of the number of e-h pairs collected at the diode's electrode.

[2] L.Beattie et al./ NIM 412A (98)

Simulated CCE as a function of the applied Bias at Fluence of 10^{15} and 10^{16} n/cm^2



Simulated Charge Collection Efficiency

Conclusions

- Irradiated thin and thick diodes have been analyzed considering a three levels simulation model up to Φ=1e16 n/cm^2
- Thin features:
  - V_{dep} in thin structures is one order of magnitude lower
  - The results suggest that an optimum thickness exists (50-100 um) which can maximize detector radiation hardness and signal-to-noise ratio.
- Next steps are:
  - compare thin structures simulation data at higher fluences (1e16 n/cm^2) with irradiated diode measuring results (Bruzzi-Florence and Casse-Liverpool).