Cosmic Rays induced Single Event Effects in Power Semiconductor Devices

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ROBUSPIC SMARTER POWER

Naples June, 4th 2006

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Outline

- Introduction
  - Cosmic rays in Space
  - Cosmic rays at Sea Level
  - Radiation Effects
  - Single Event Tests
    - Irradiation Facilities
    - Particles beam to be used
- SEB in Power Diodes
- SEE in Power MOSFETs:
  - SEB
  - SEGR
- SEB in IGBTs
- Conclusions

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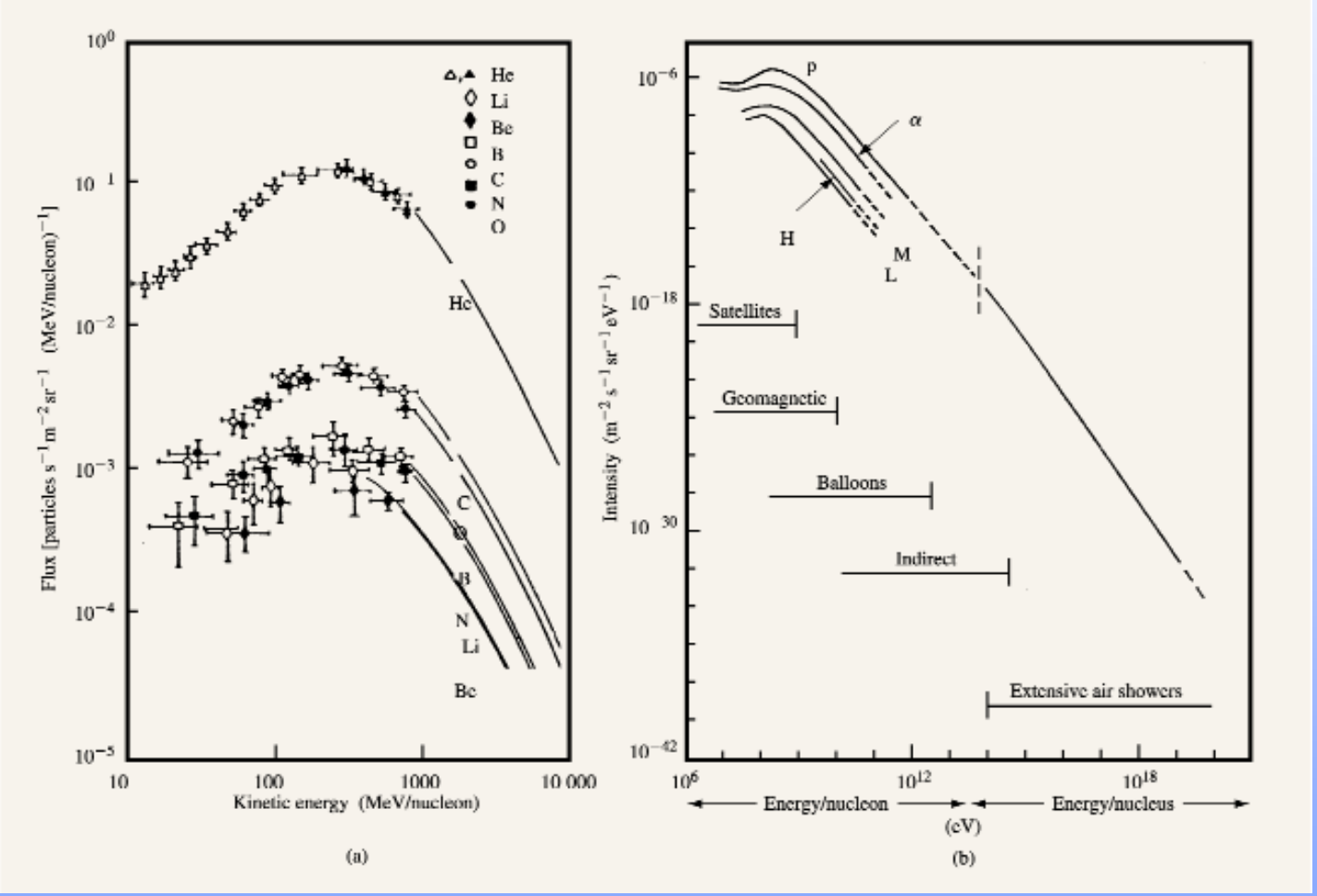
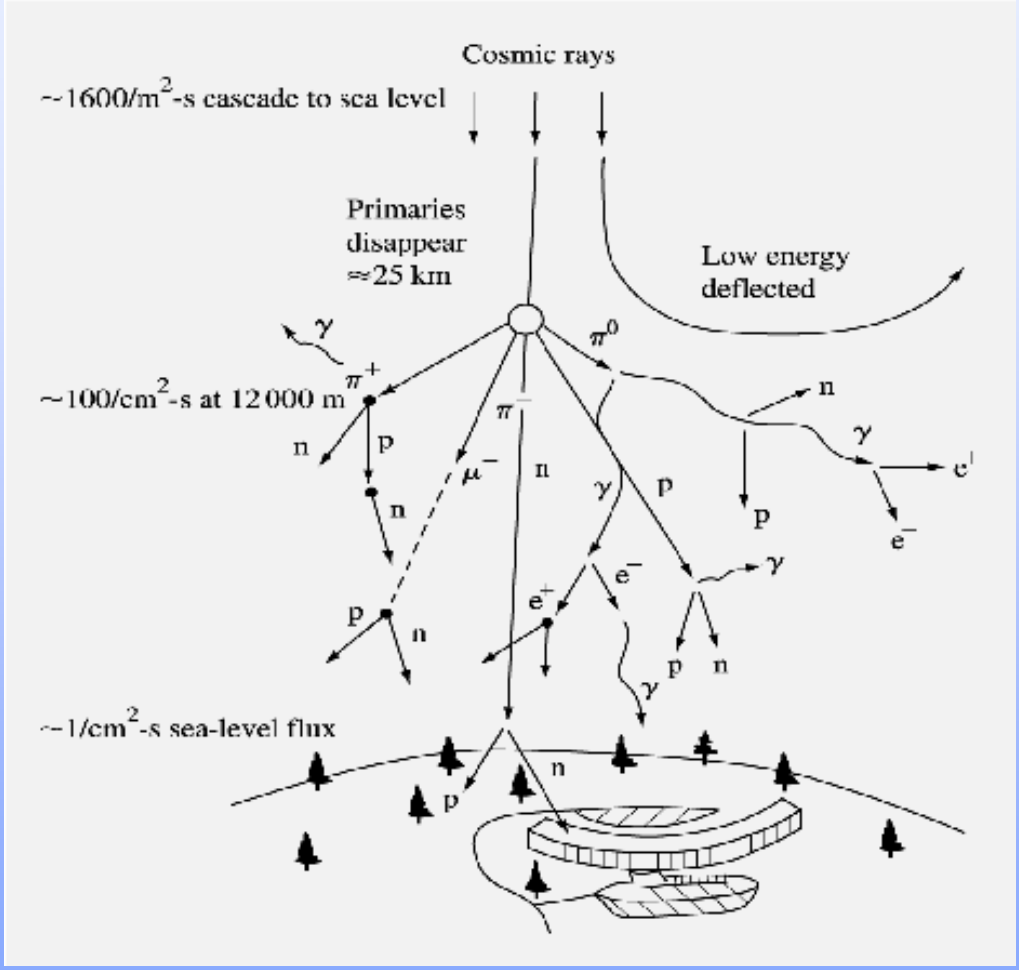
Flux of Cosmic Rays in Space



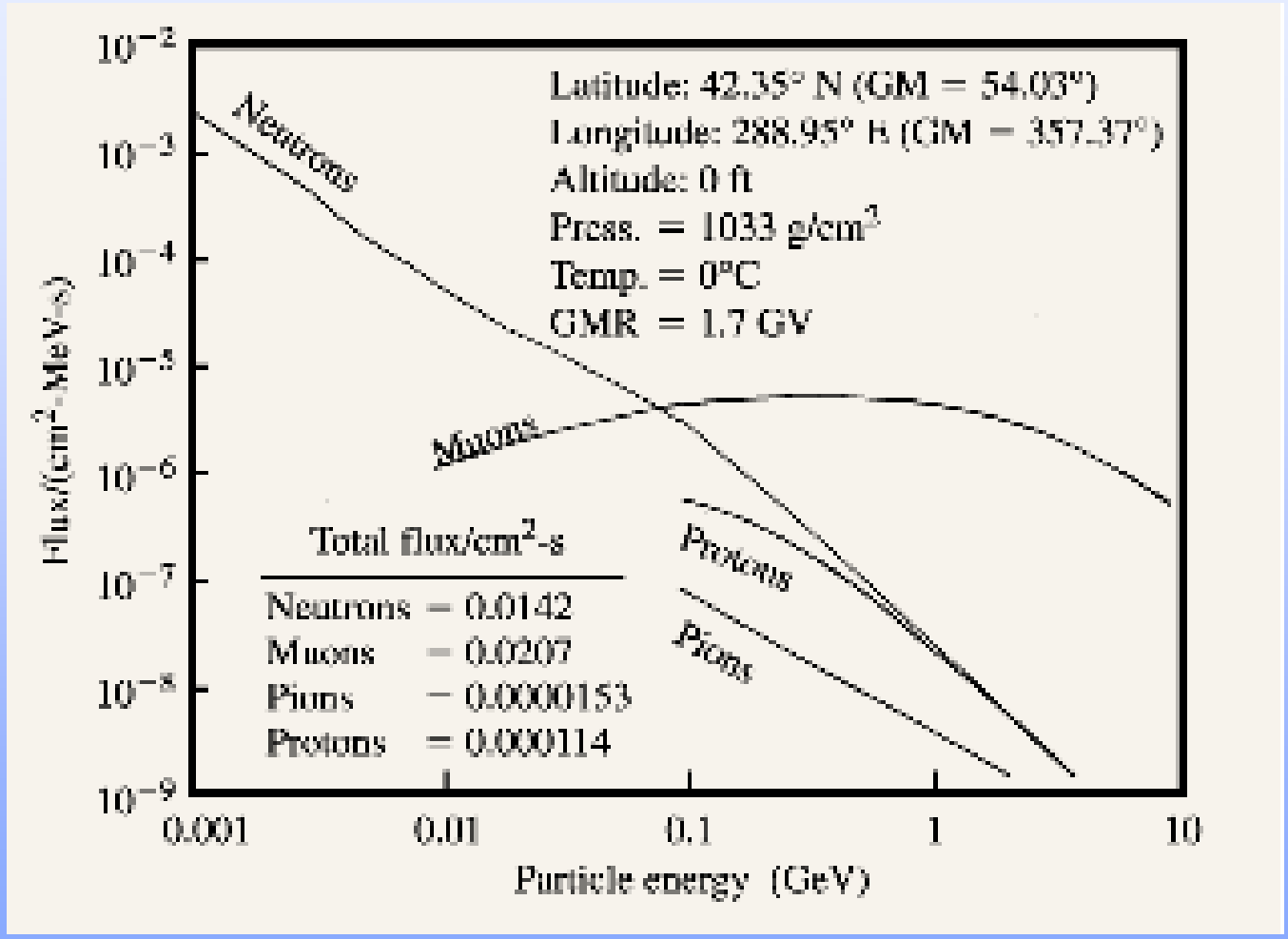
J. F. Ziegler, “Terrestrial cosmic rays intensities,” IBM Journal of R & D, Vol. 42, No. 1, pp. 117-140, 1998

Particles Cascade into the Atmosphere after the Impact of an Energetic Particle



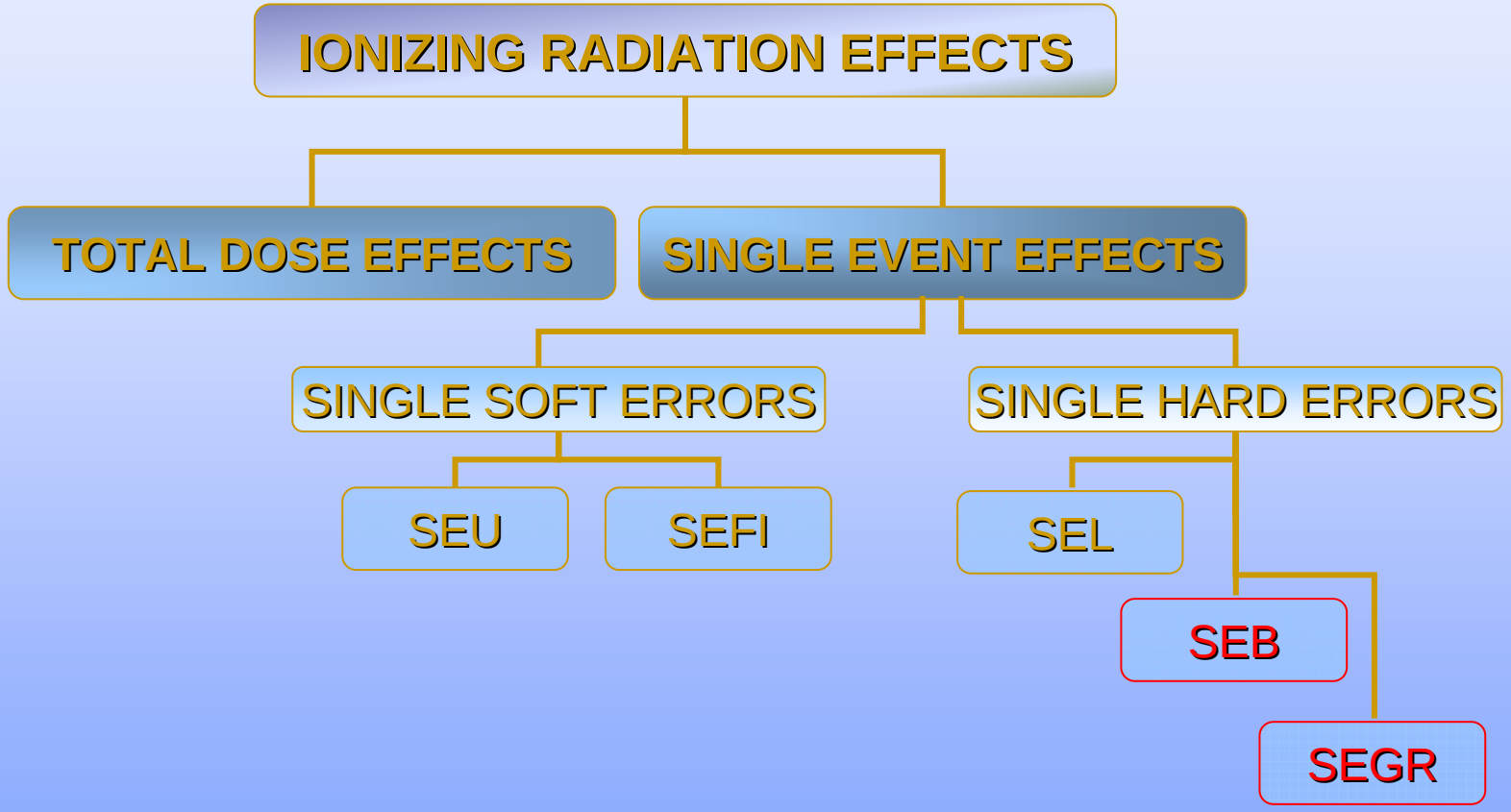
J. F. Ziegler et Al., "IBM experiments in soft fails in computer electronics," IBM Journal of R & D, Vol. 40, No. 1, pp. 3-18, 1996

Flux of Impacting Energetic Particles at the Sea Level



J. F. Ziegler, “Terrestrial cosmic rays intensities,” IBM Journal of R & D, Vol. 42, No. 1, pp. 117-140, 1998

Radiations Effects



SEE Tests

- In field experiments are too expensive
- Accelerators (LinAc or cyclotrons) are used to produce high energy particle beams
- Typical experiments are performed by using:
  - neutrons and protons
  - heavy ions (Ni, Br, I, ... Au)

Heavy Ions Irradiation Facilities

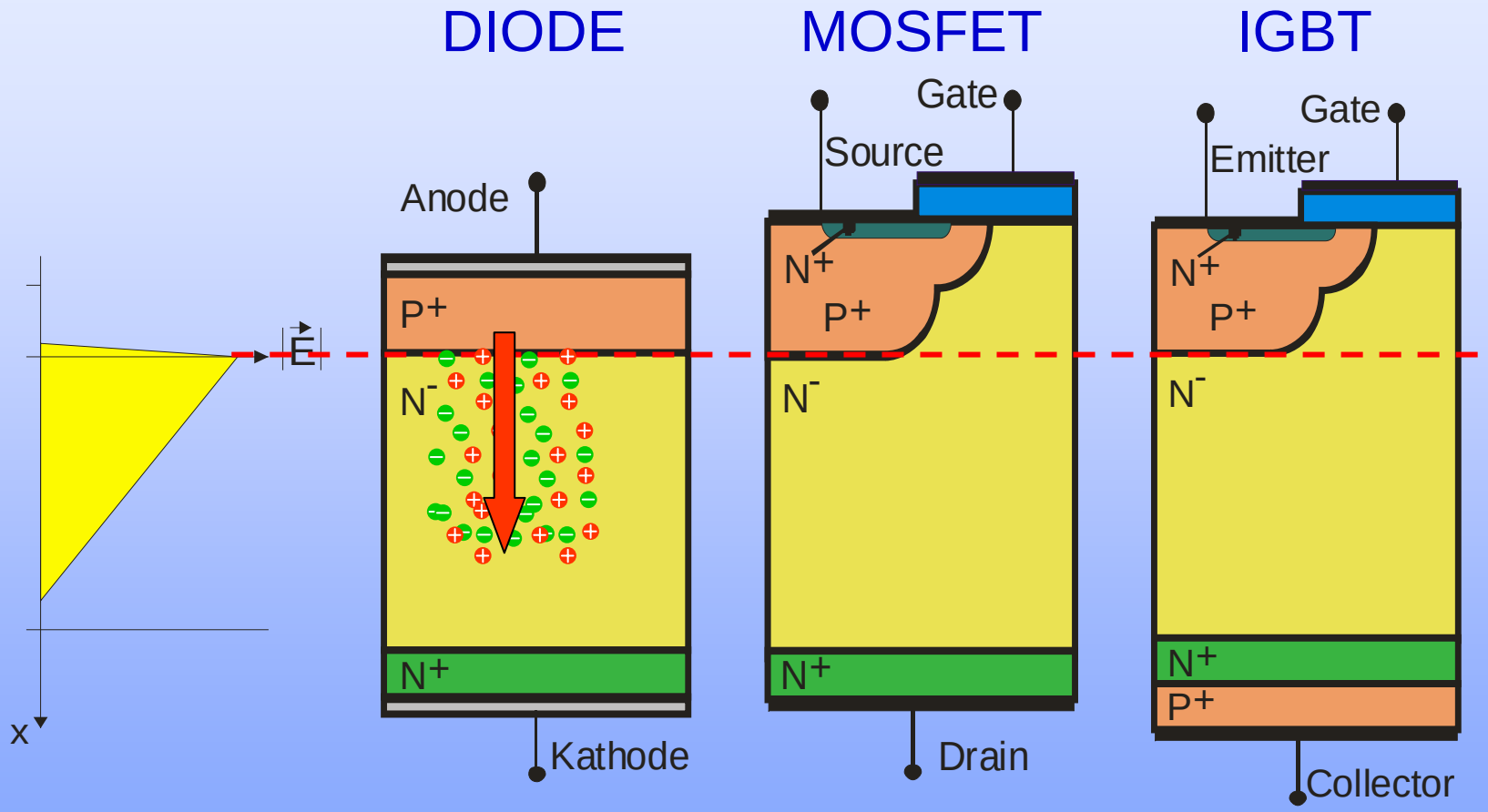
16MV TANDEM XTU

I.N.F.N. – L N L (PD)

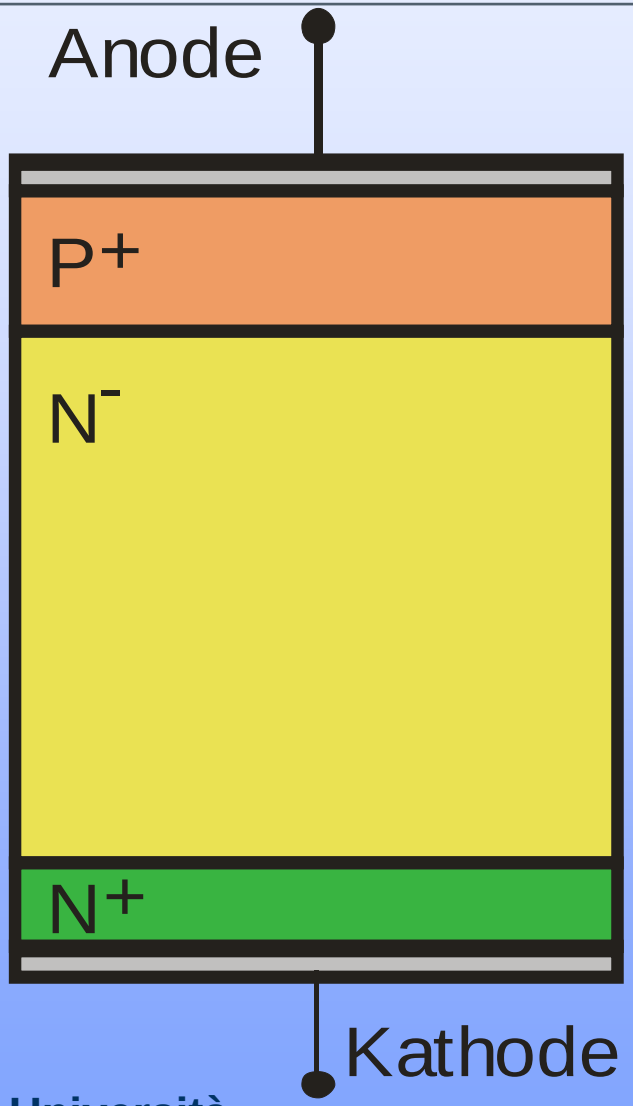
15MV TANDEM XTU

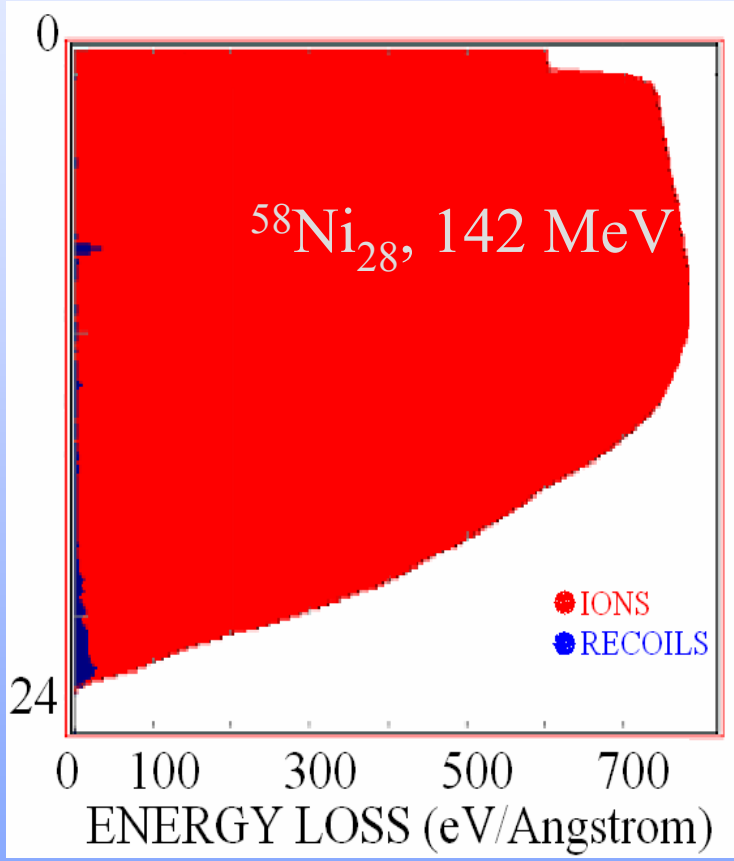
I.N.F.N. – L N S (CT)

Particle Impact on a Power Device

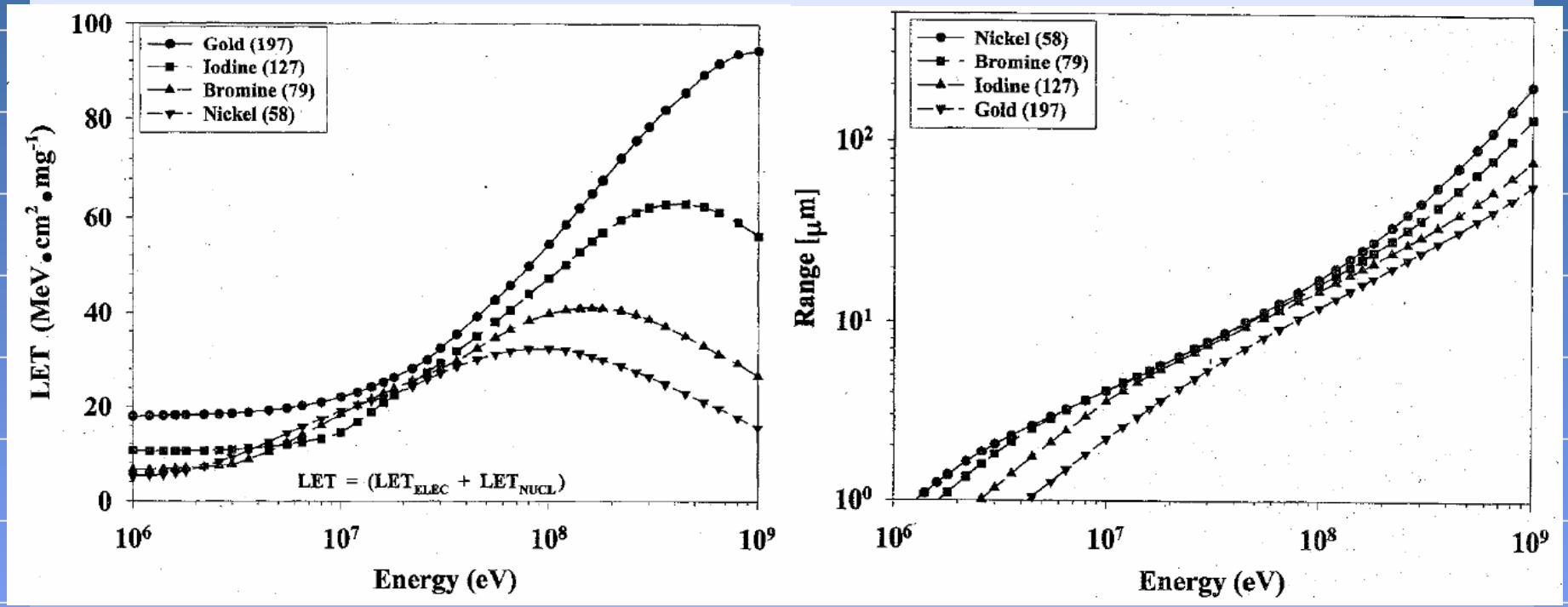


The Brag Diagram





The Choice of the Impacting Particle



Titus et al. "Experimental Studies of Single-Event Gate Rupture and Burnout in Vertical Power MOSFET's," IEEE Trans. on Nuclear Science, Vol. 43 n. 2, pp. 533-545, 1996

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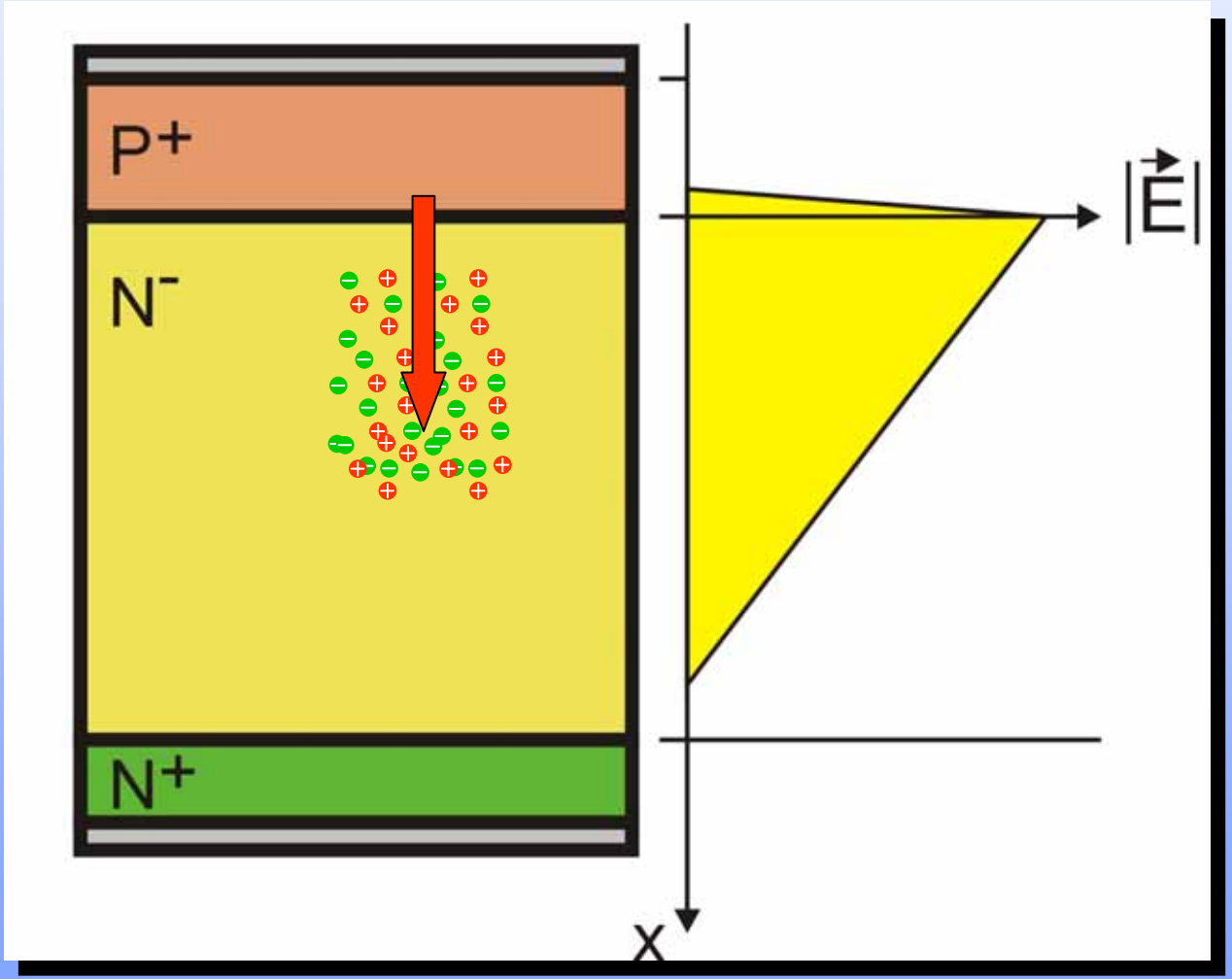
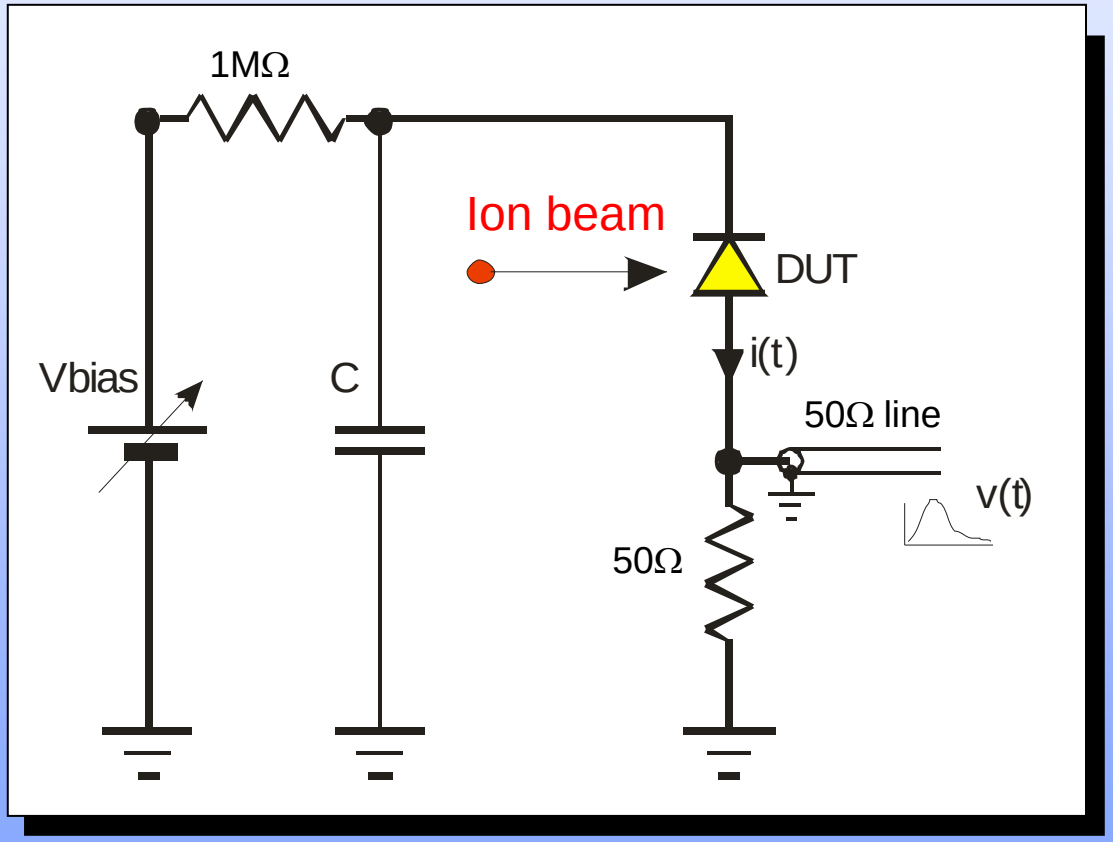
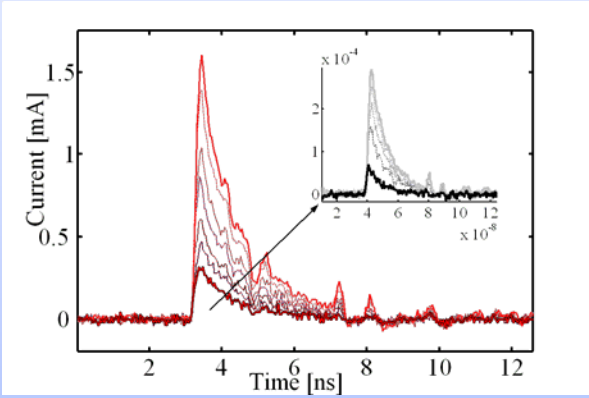
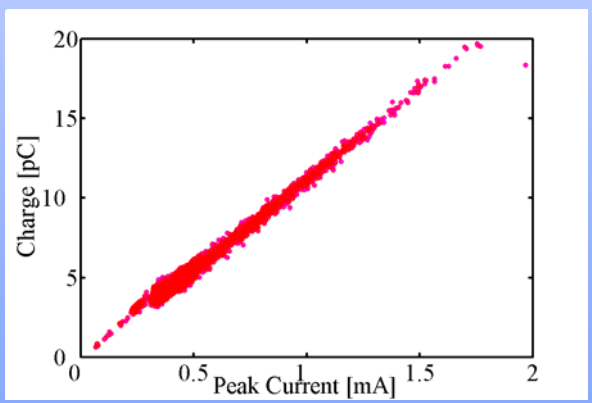
SEB of DIODES



Typical Test Circuit (Static Characterization)

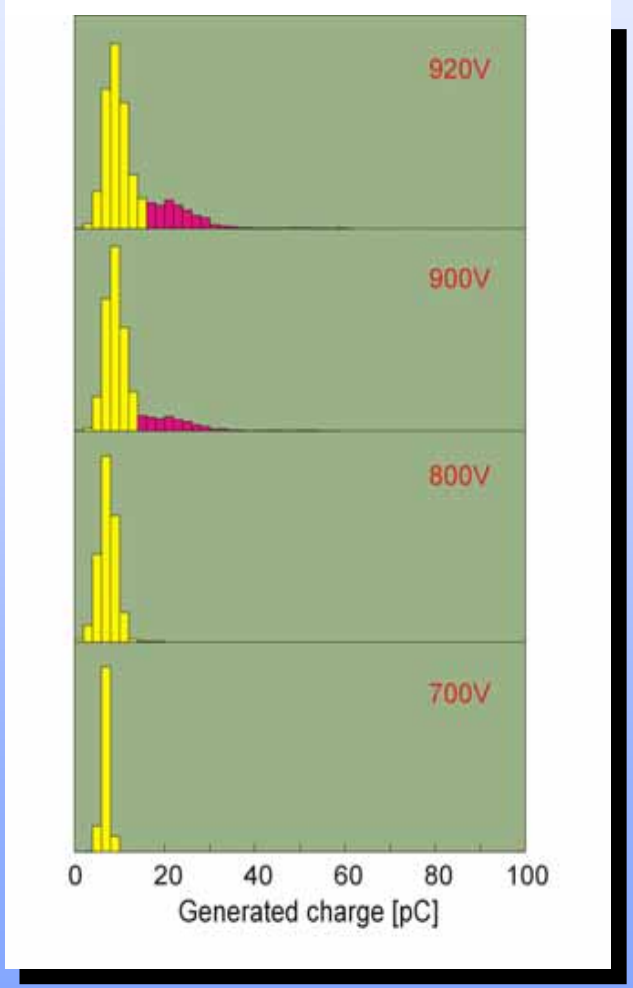


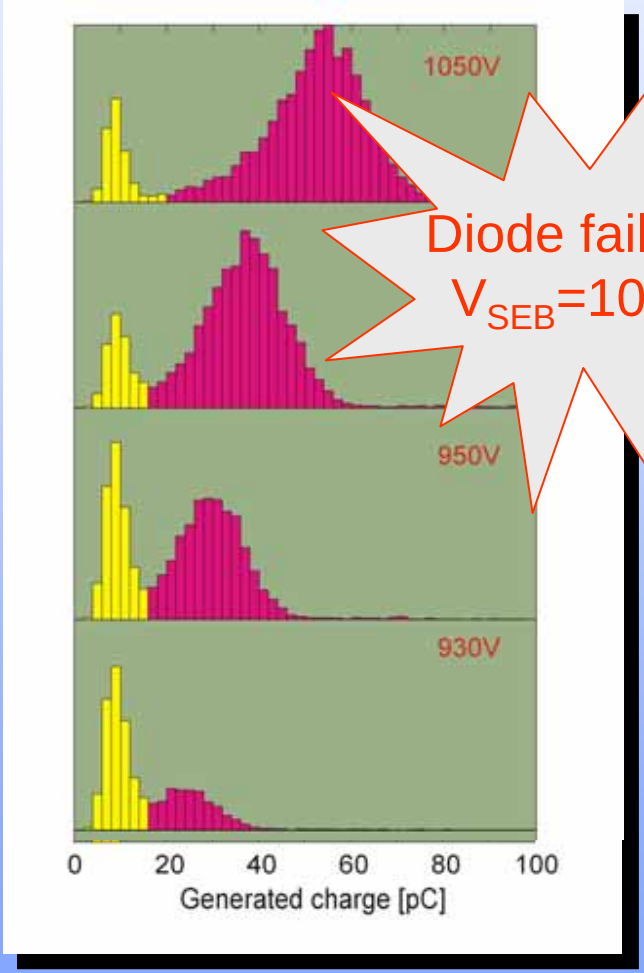




Generated Charge Histograms

1700V Diode

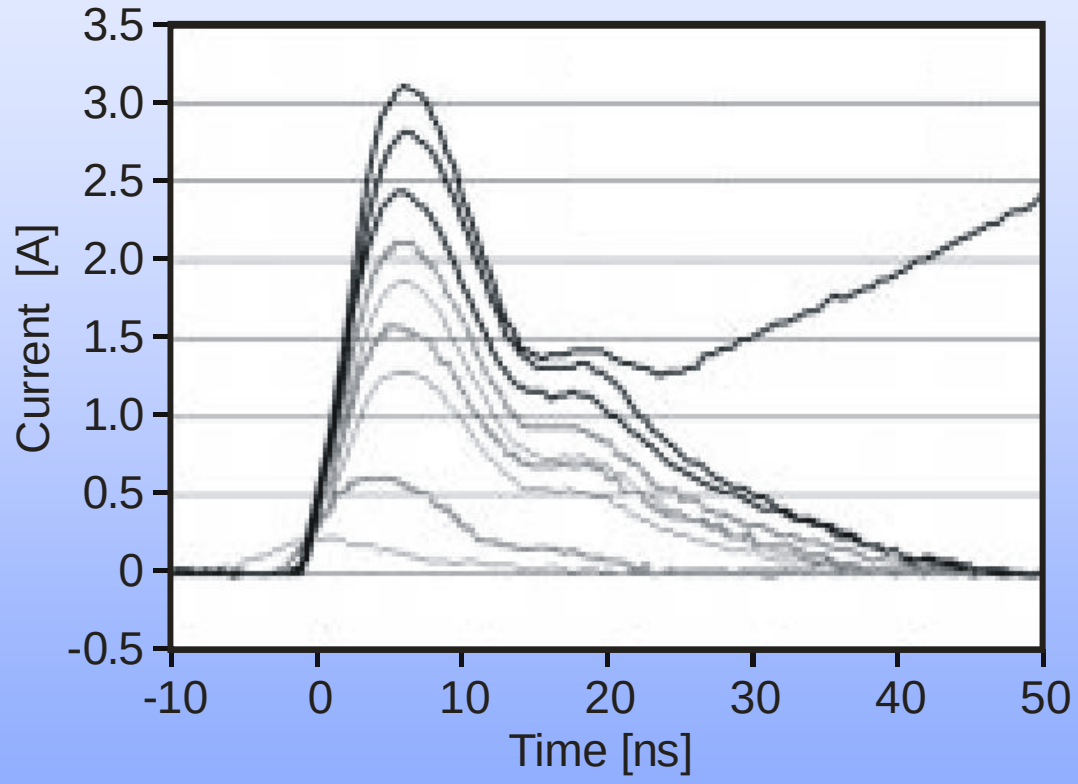




Diode failed at V_{SEB}=1060V

Charge Amplification (Measured Waveforms)

4000V Diode



Gerald Soelkner, et al., “Charge Carrier Avalanche Multiplication in High-Voltage Diodes Triggered by Ionizing Radiation” IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 47, NO. 6, pp. 2365-2372, Dec. 2000

Charge Amplification (2D Simulation)

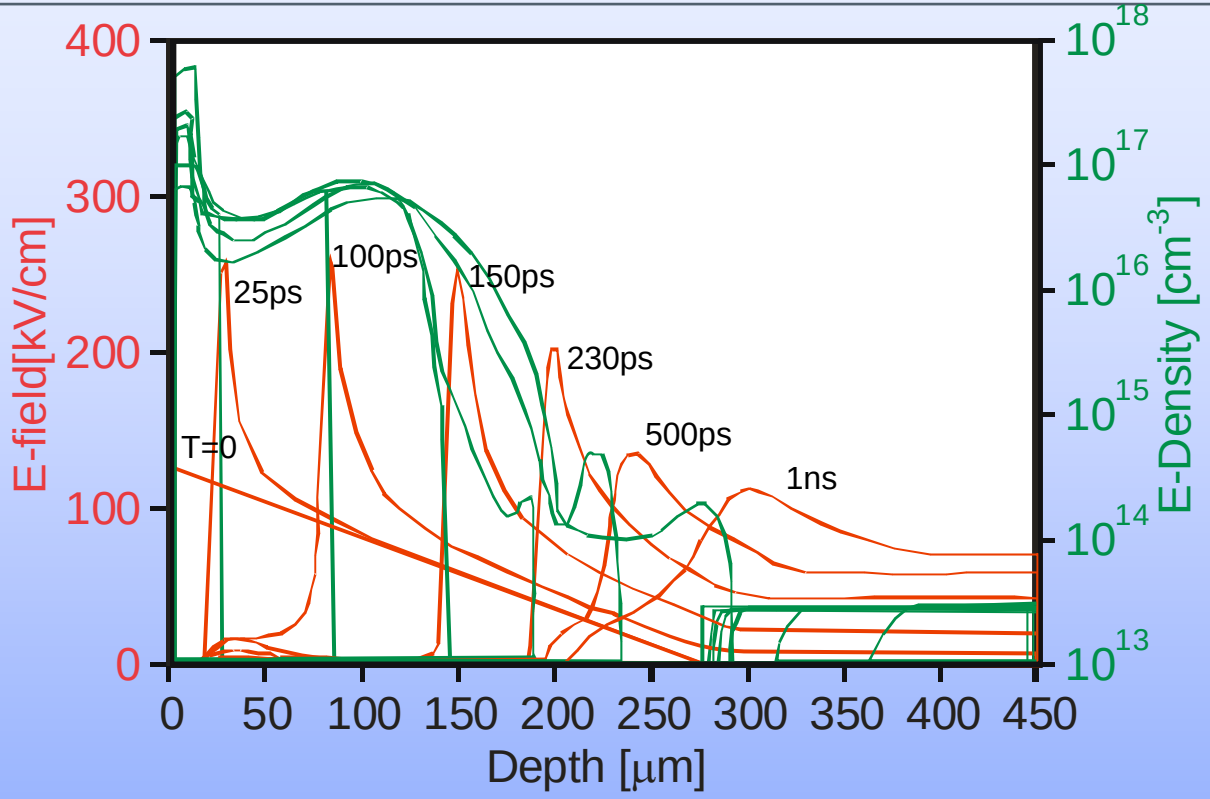
4kV Diode

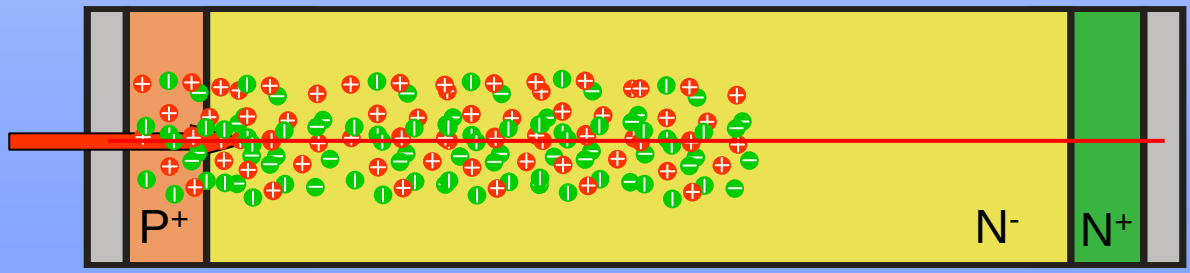
Bias Voltage: 1800V

Simulated Particle : ^{12}C (17MeV)

Energy Transfer Peak: 1.2 MeV/μm

Range: 17μm





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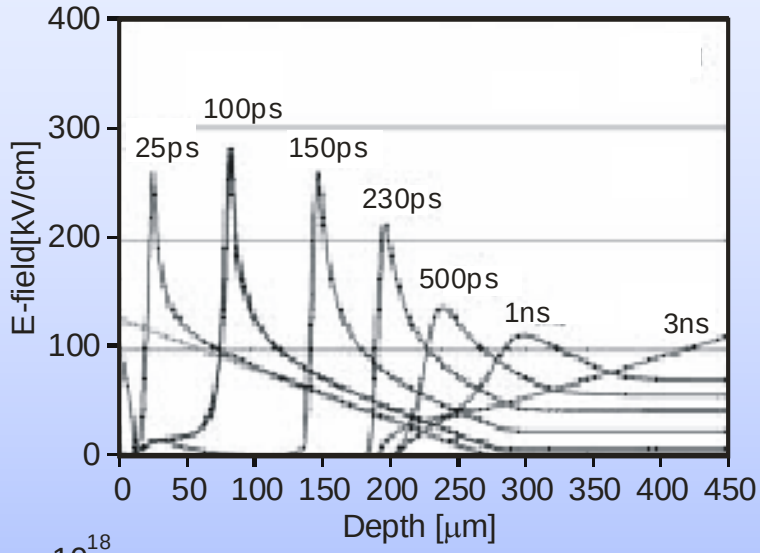
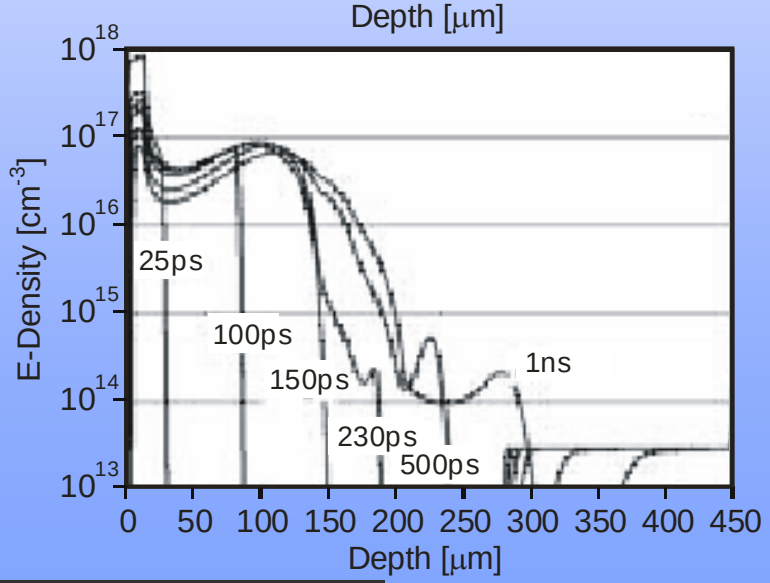
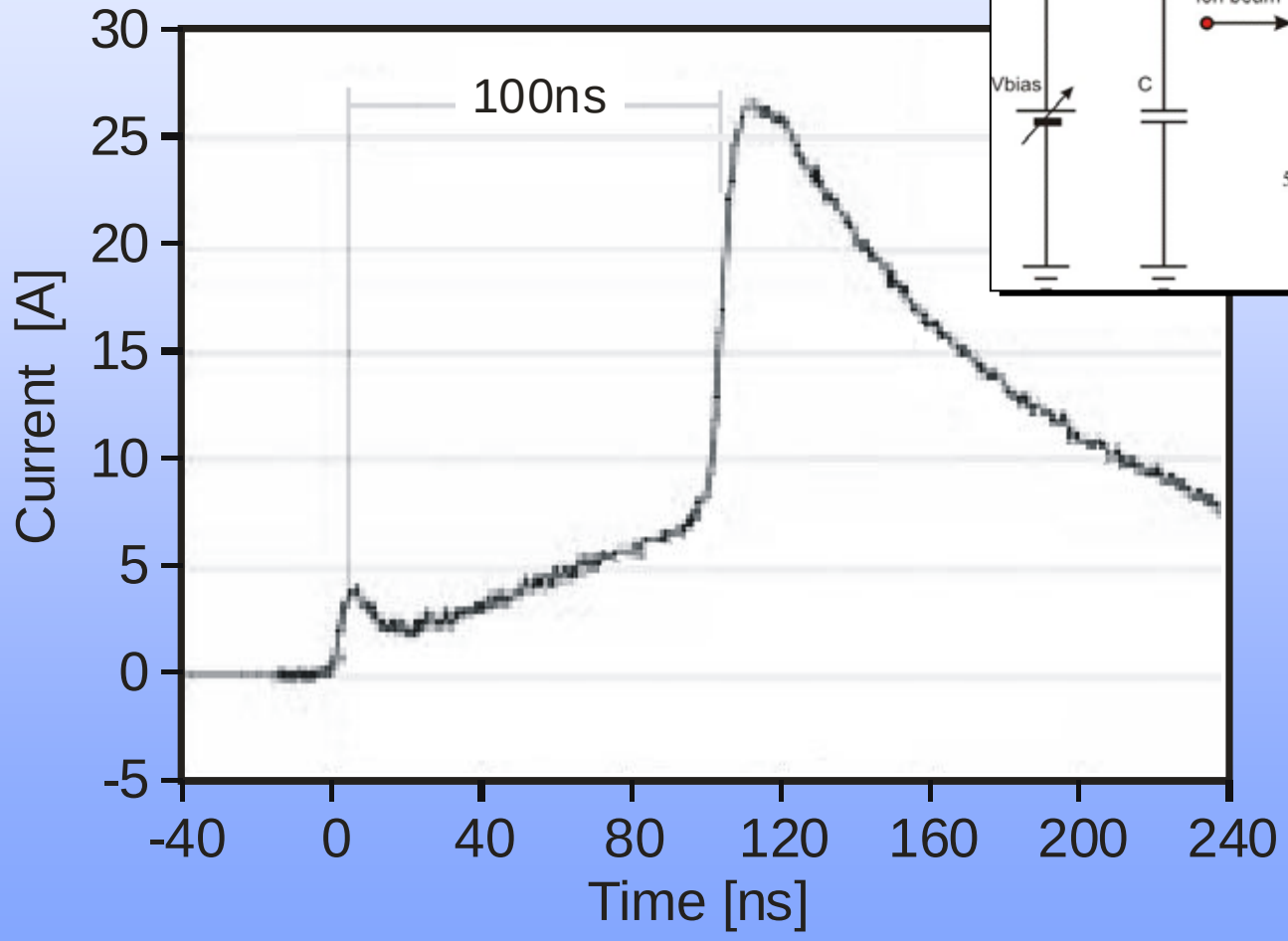
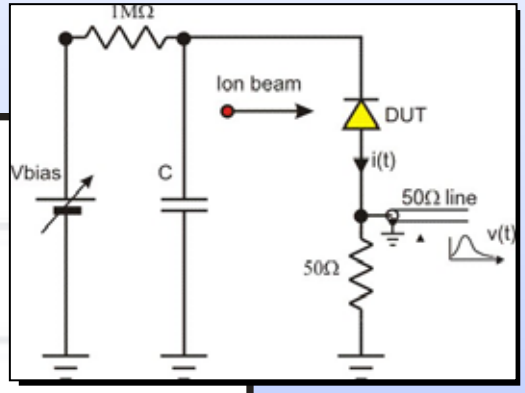




Diode Current during a Destructive Impact

Bias Voltage: 2200V





Simulation of a SEB

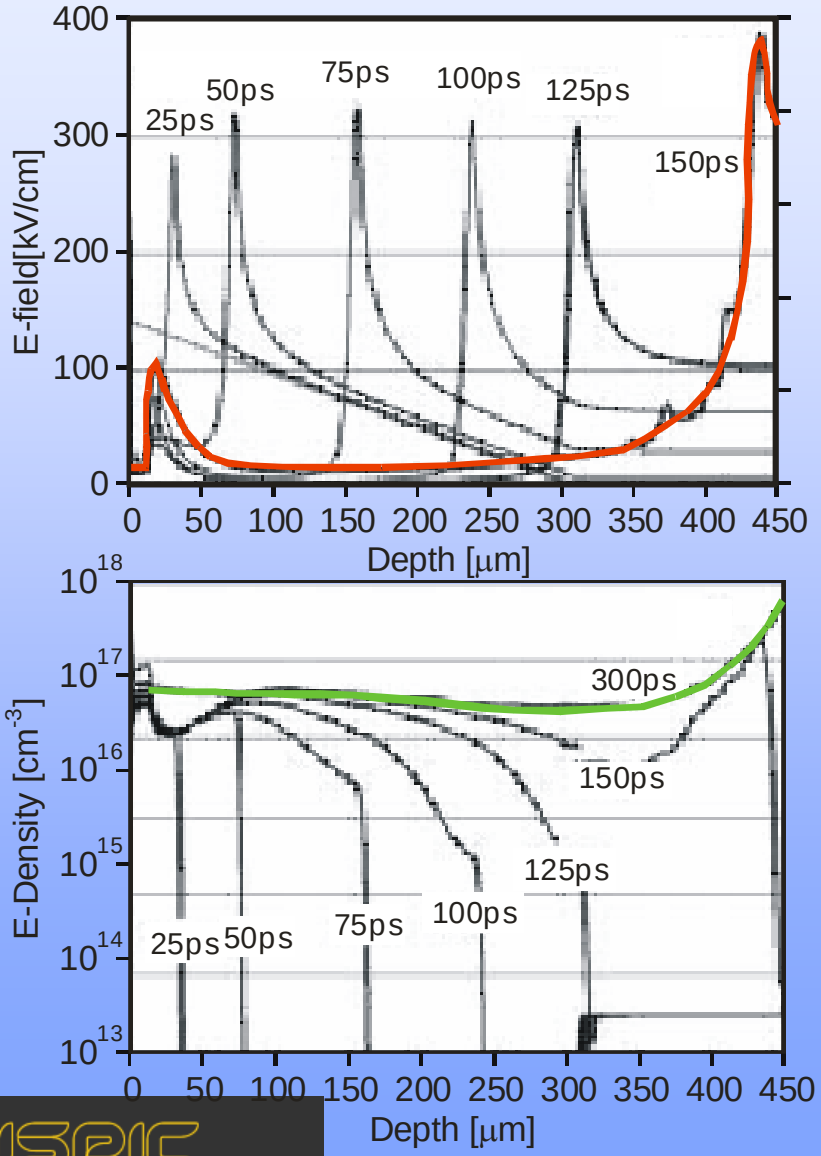
4kV Diode

Biasing Voltage: 2200V

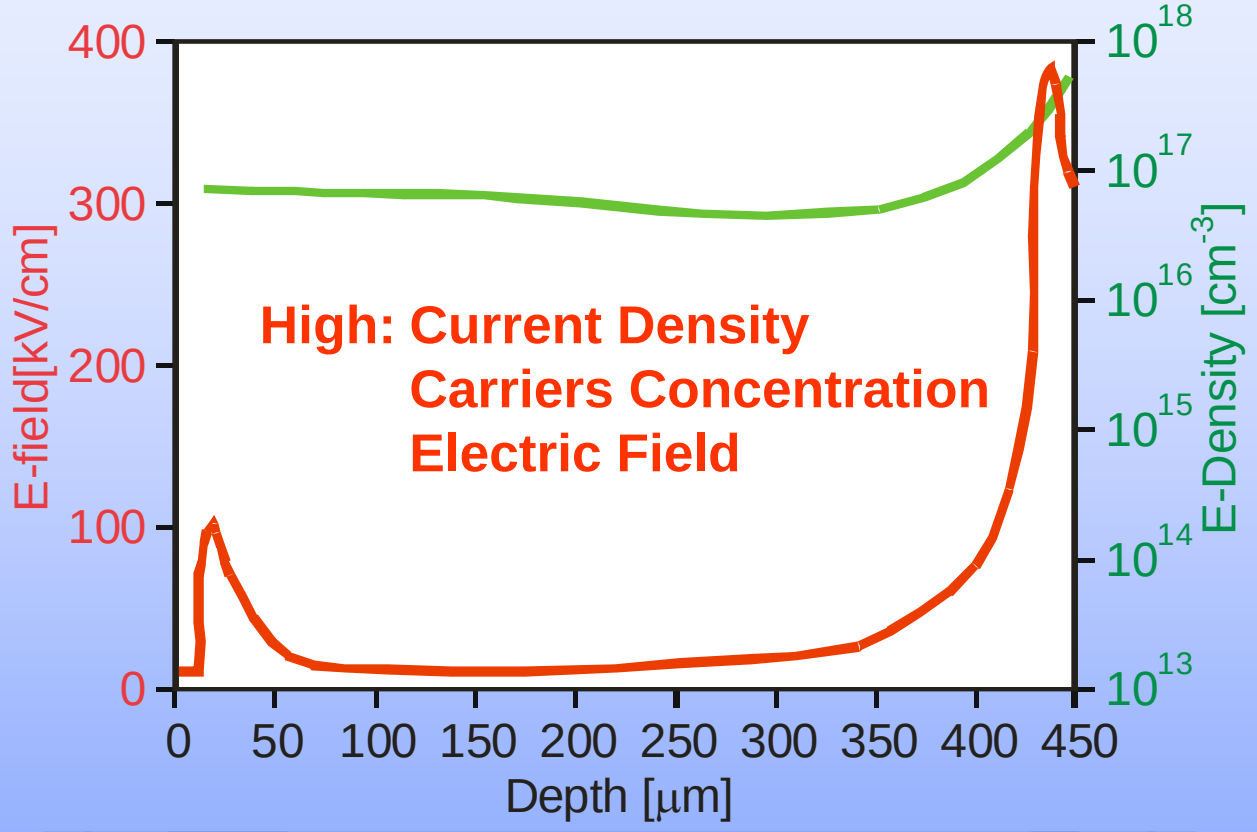
Simulated particles:
^{12}C (17MeV)

Energy Transfer
Peak: 1.2 MeV/μm

Range: 17μm



Double Injection Phenomenon



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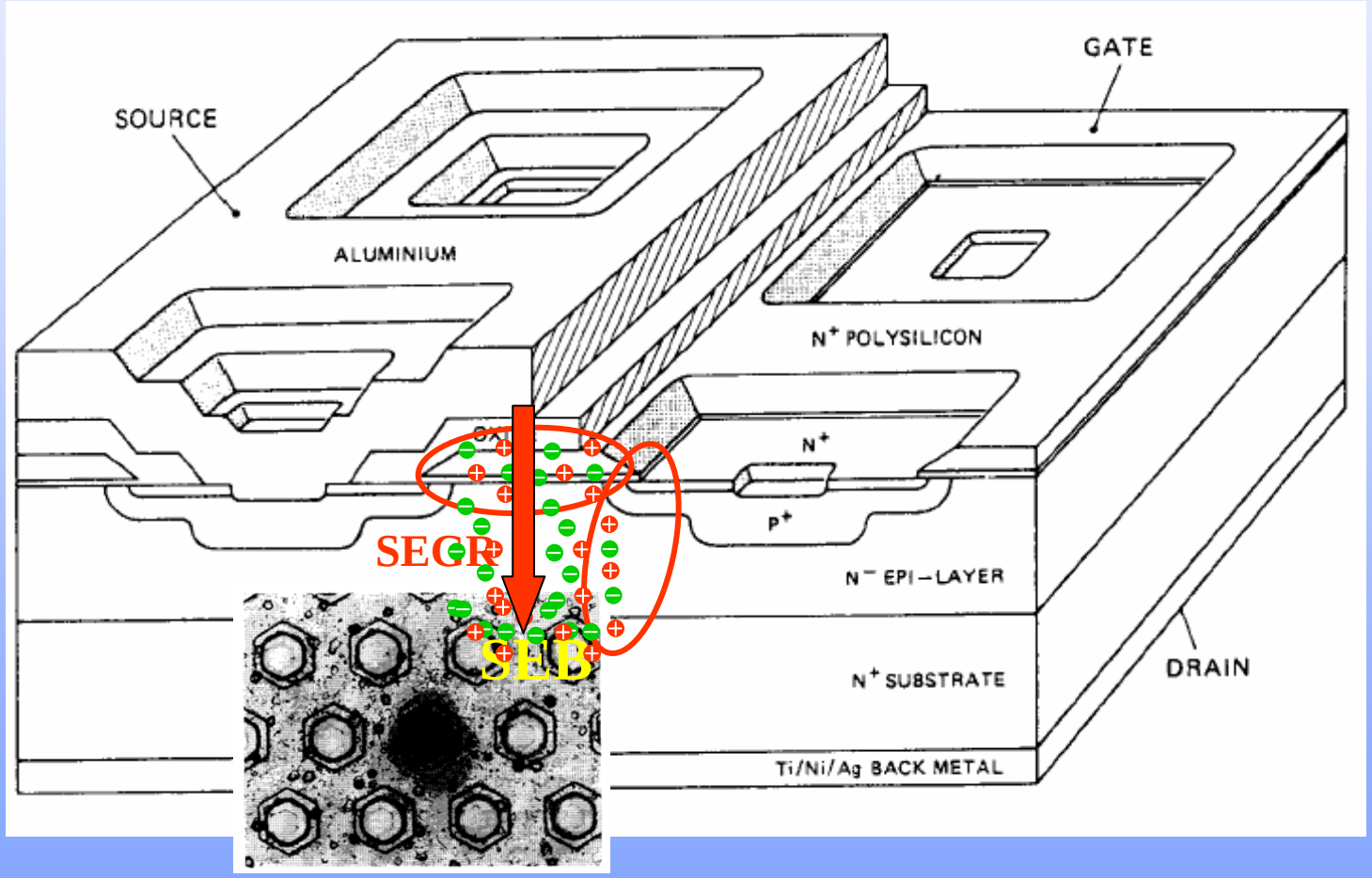
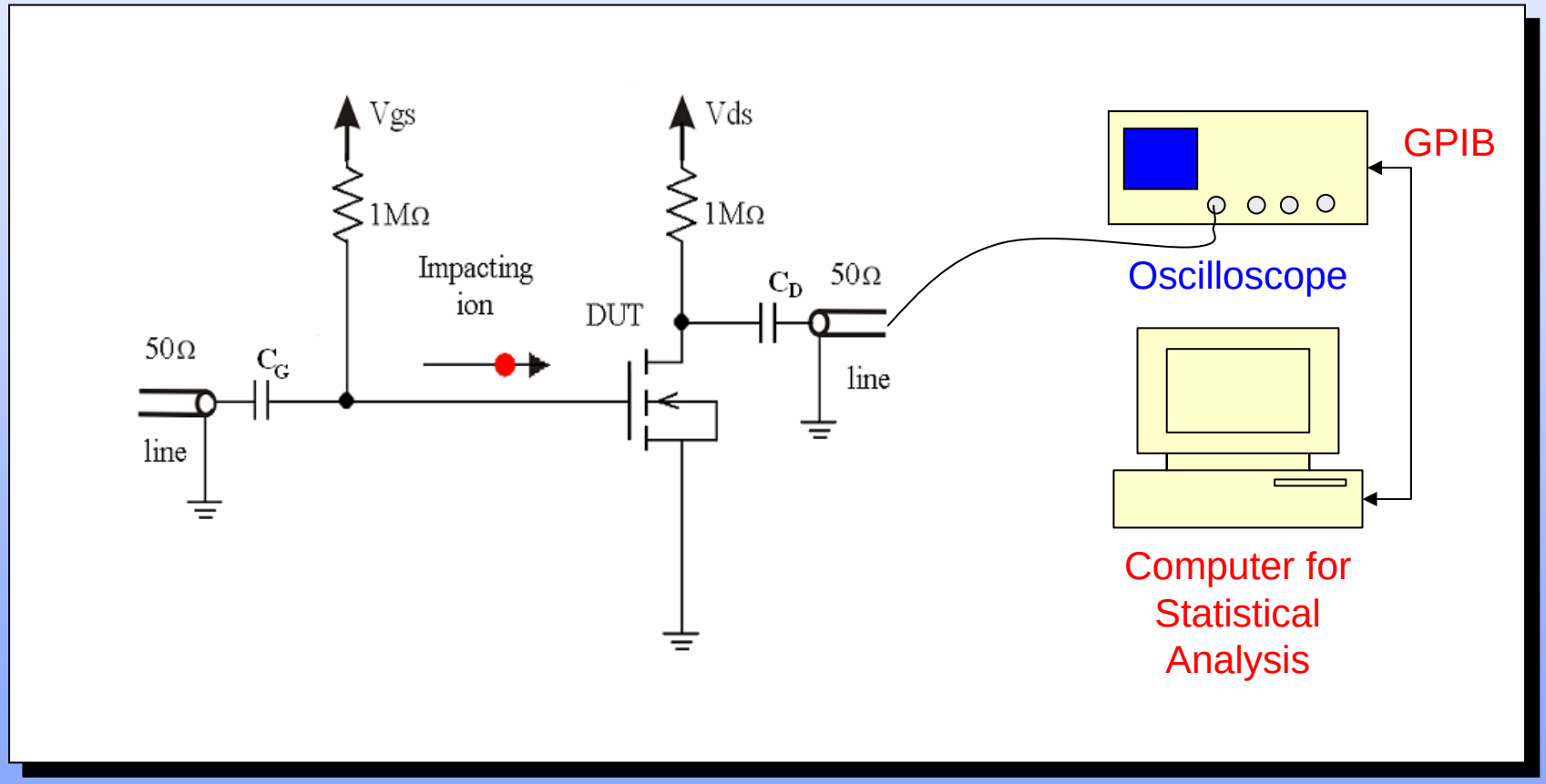
SEE in Power MOSFET

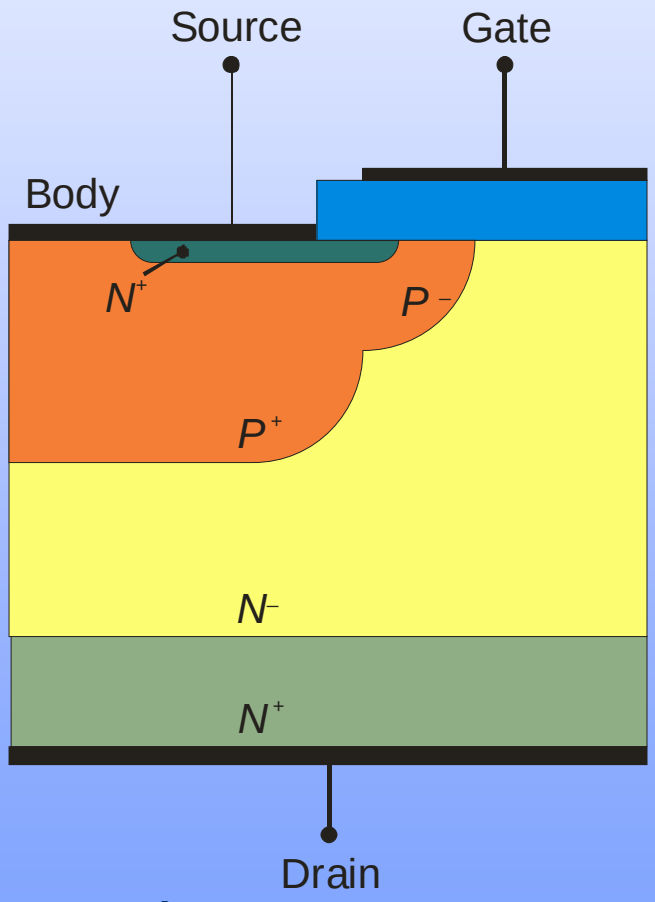


Test Circuit

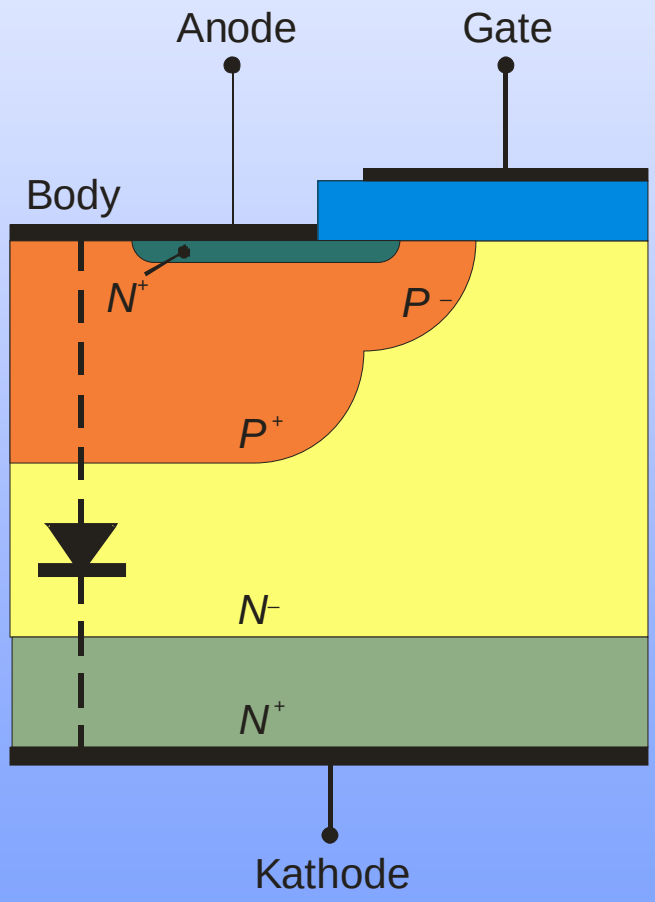


SEB in Power MOSFET
Studied Structures

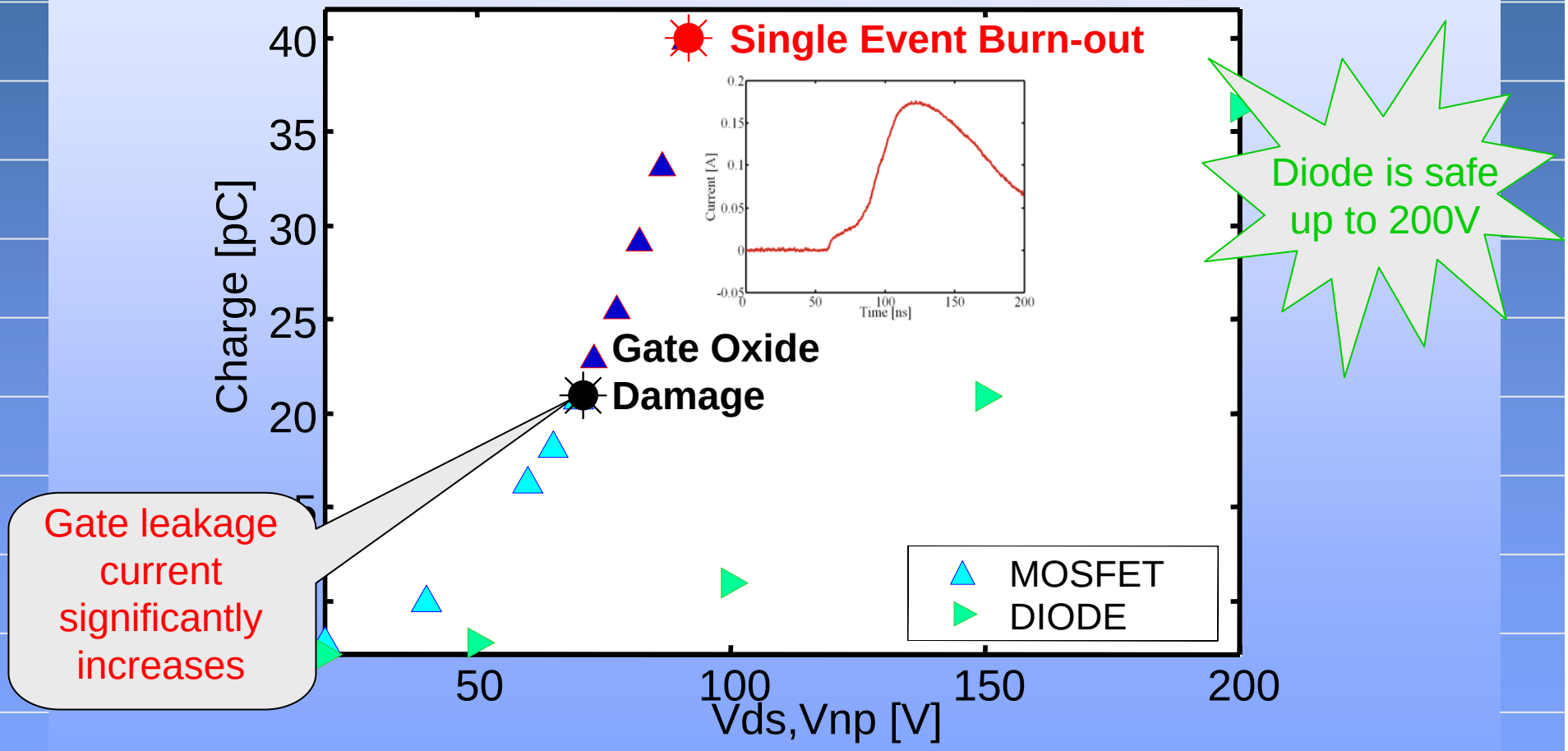
MOSFET



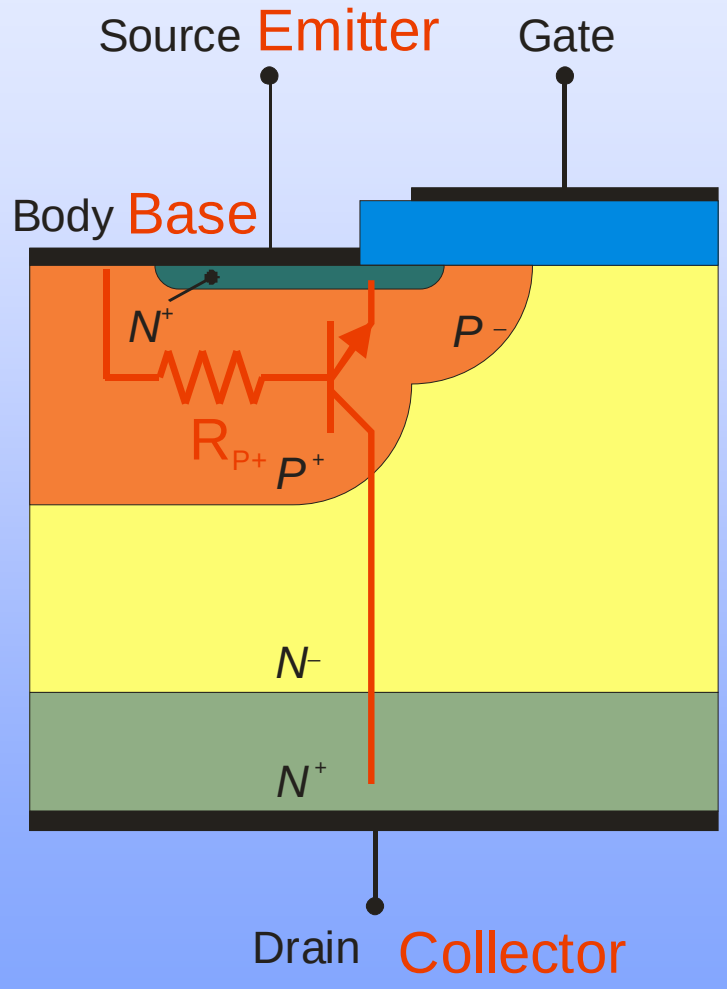
DIODE



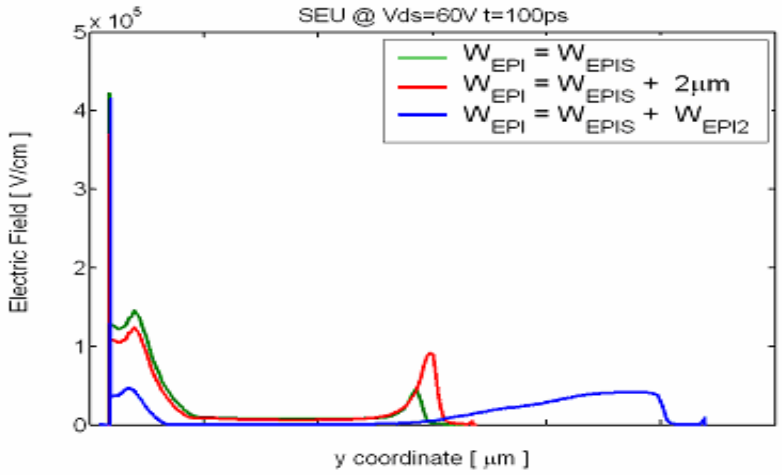
MOSFET Behaviour at increasing Voltage

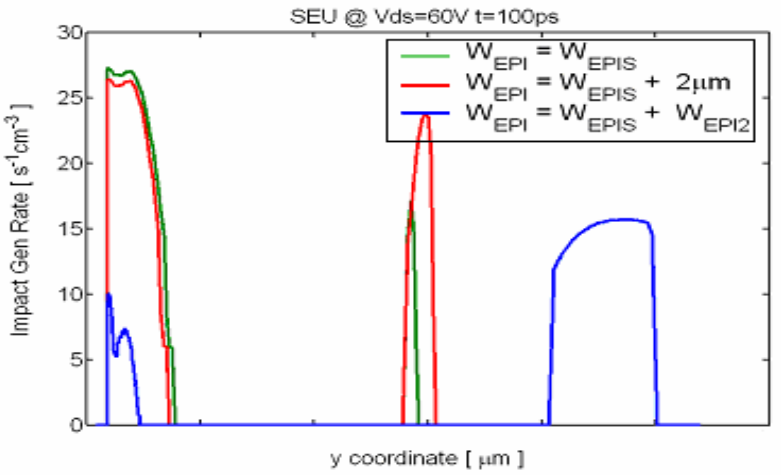


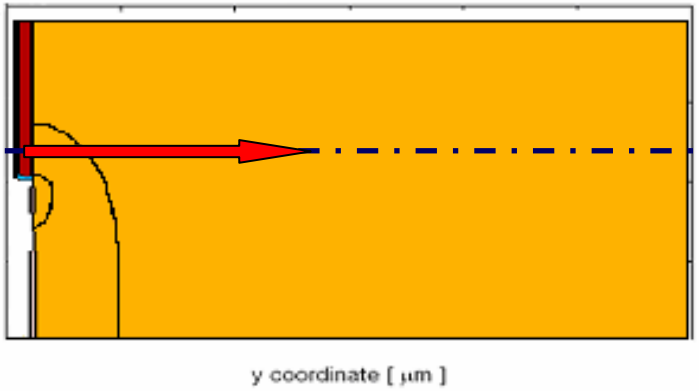
Parasitic BJT Activation

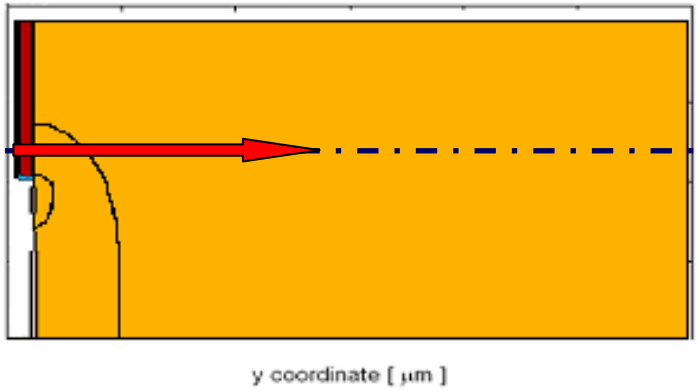


The effect of the epi-thickness on the BJT Activation

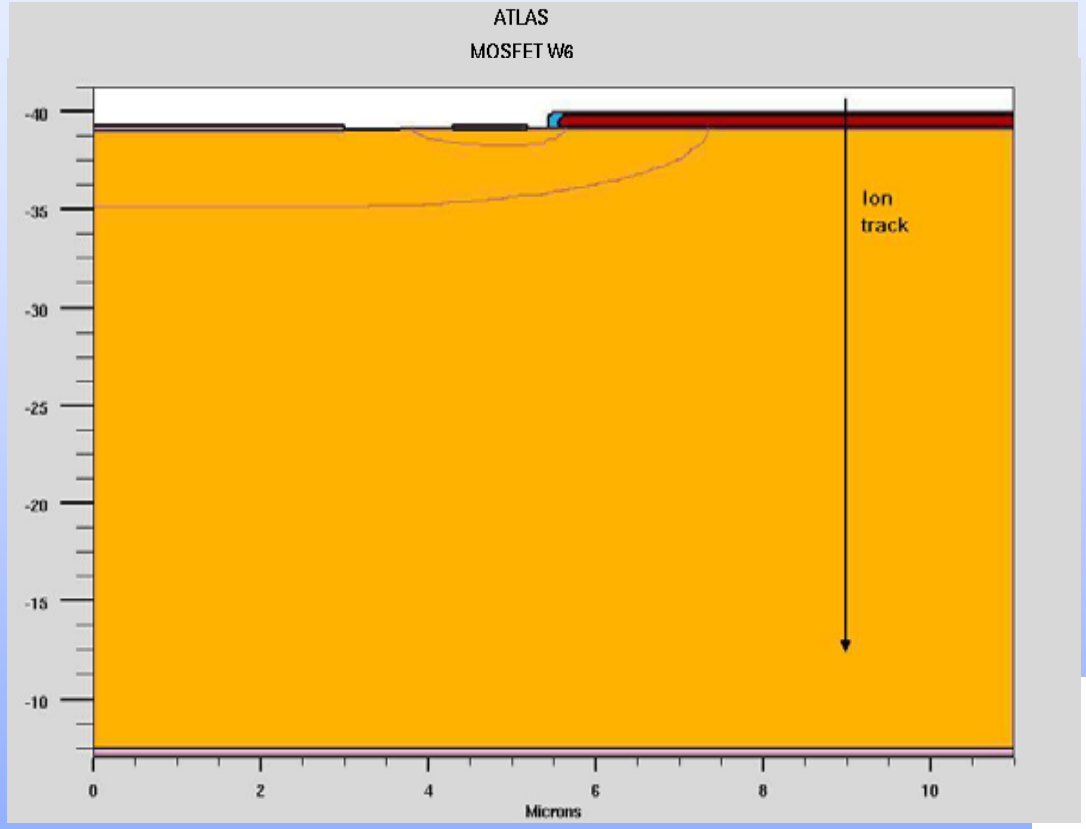








3D Simulation of Potentially Destructive Impact



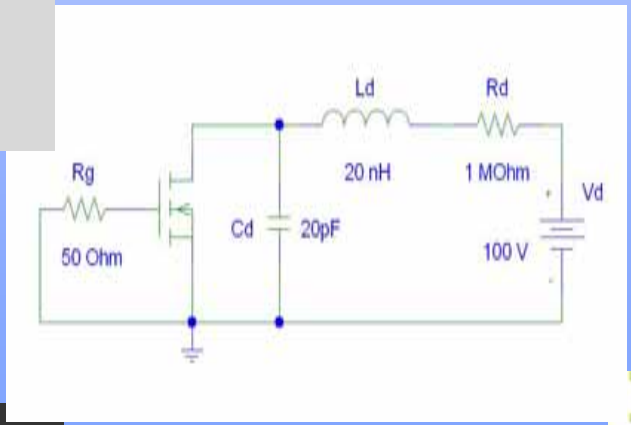
200V MOSFET

V_{DS} = 100V

V_{GS} = 0V

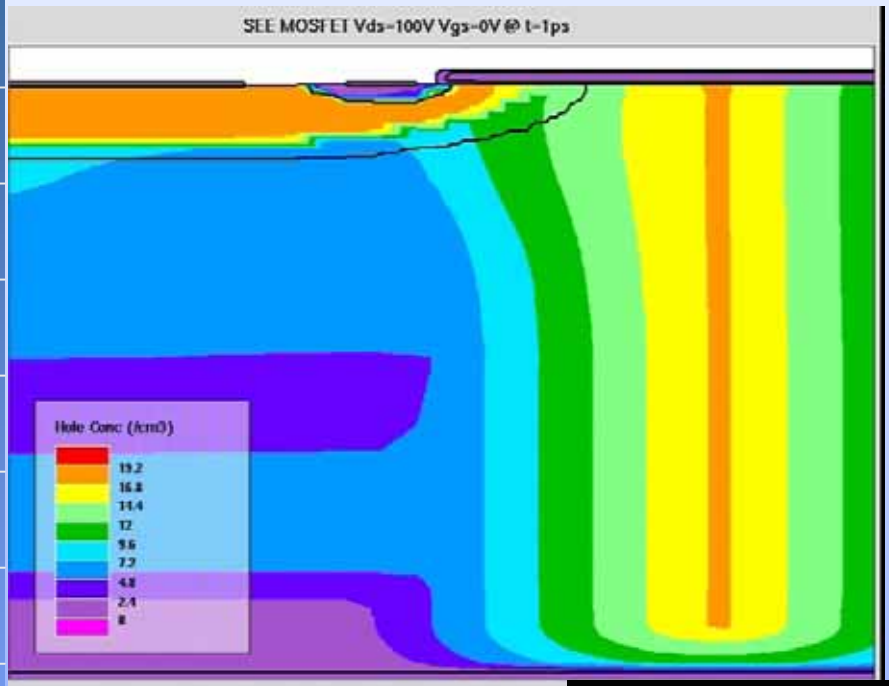
Simulated Particle:
^{79}Br (236MeV)

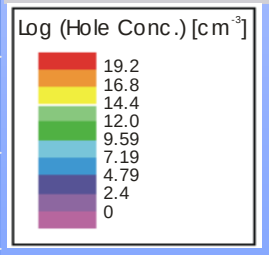
Range: 34μm



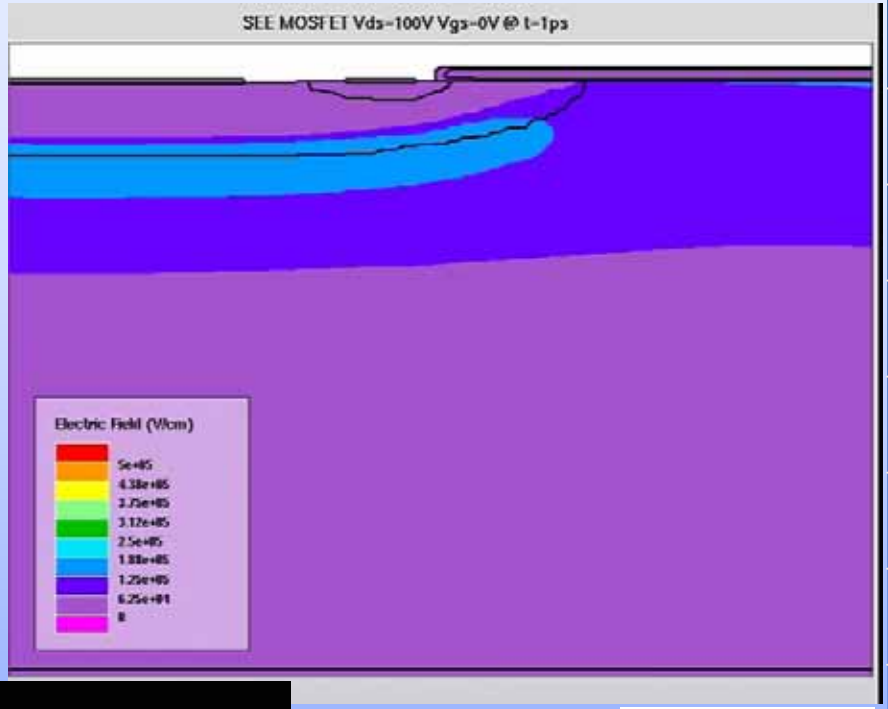
3D Simulation of Potentially Destructive Impact

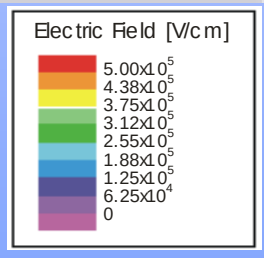
Holes Concentration

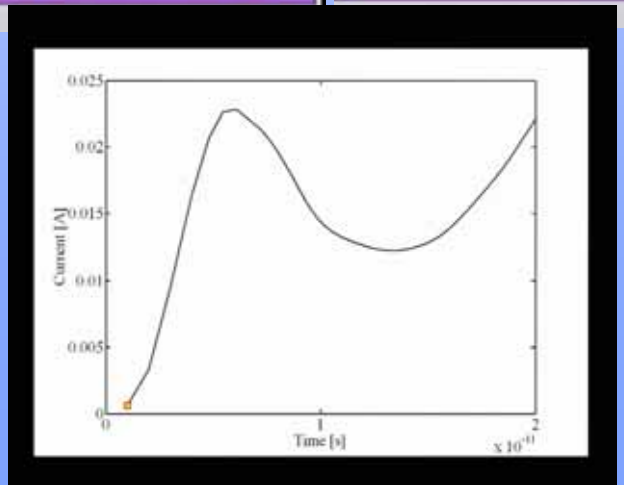




Electric Field







Drain Current

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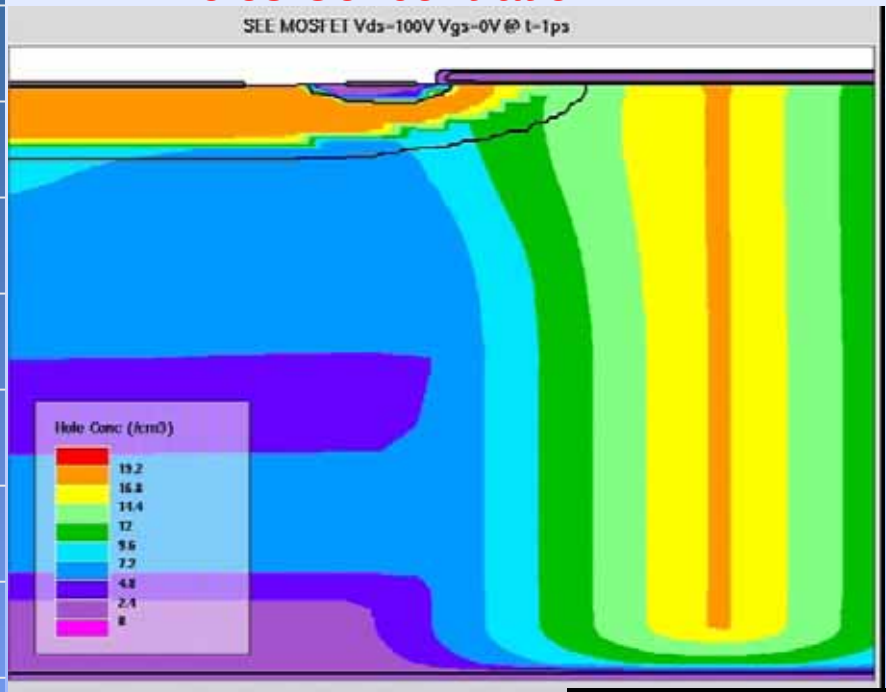
3D Simulation of Potentially Destructive Impact

Holes Concentration



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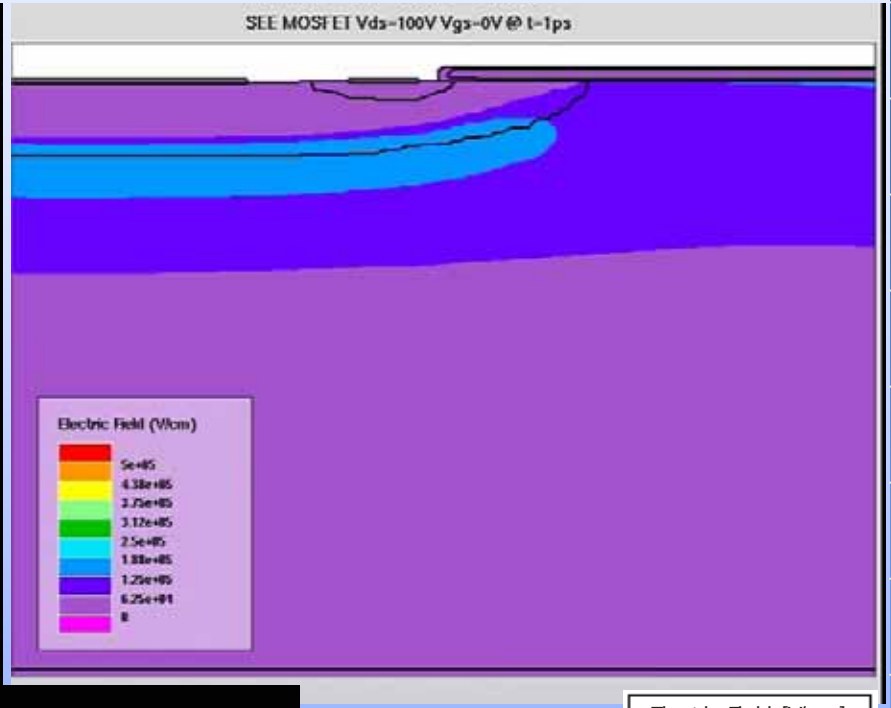
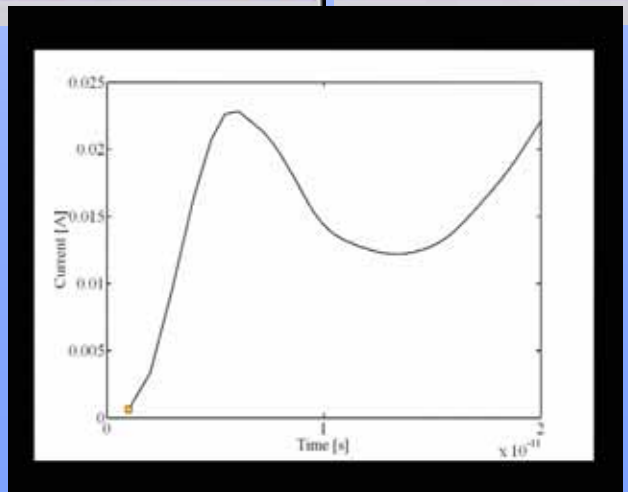


Log (Hole Conc.) [cm^{-3}]

19.2
16.8
14.4
12.0
9.59
7.19
4.79
2.4
0



Drain Current

Electric Field [V/cm]

5.00×10^5
4.38×10^5
3.75×10^5
3.12×10^5
2.55×10^5
1.88×10^5
1.25×10^5
6.25×10^4
0

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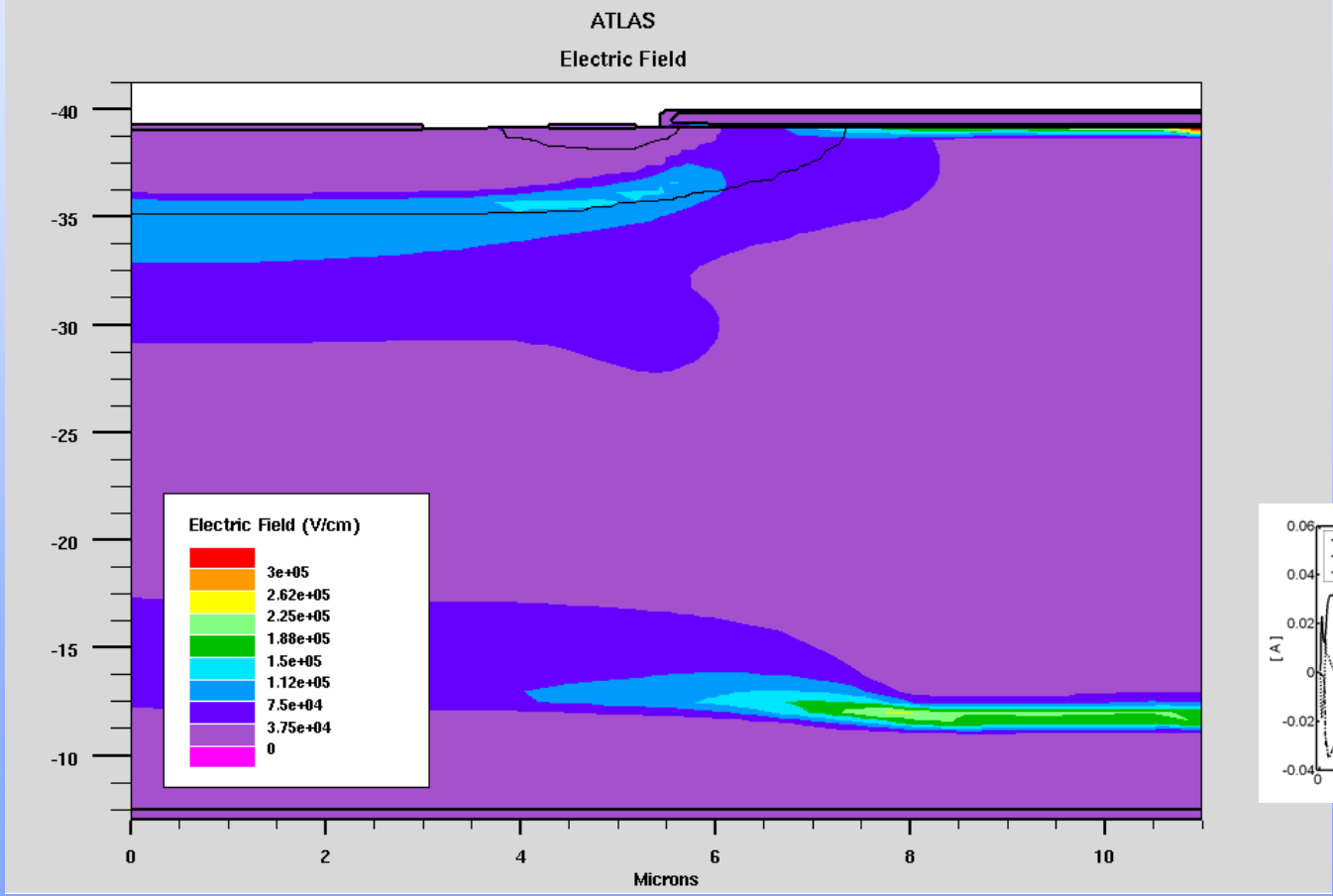
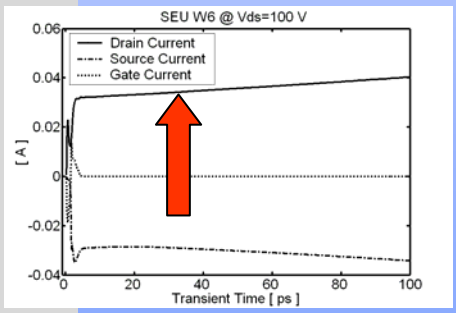
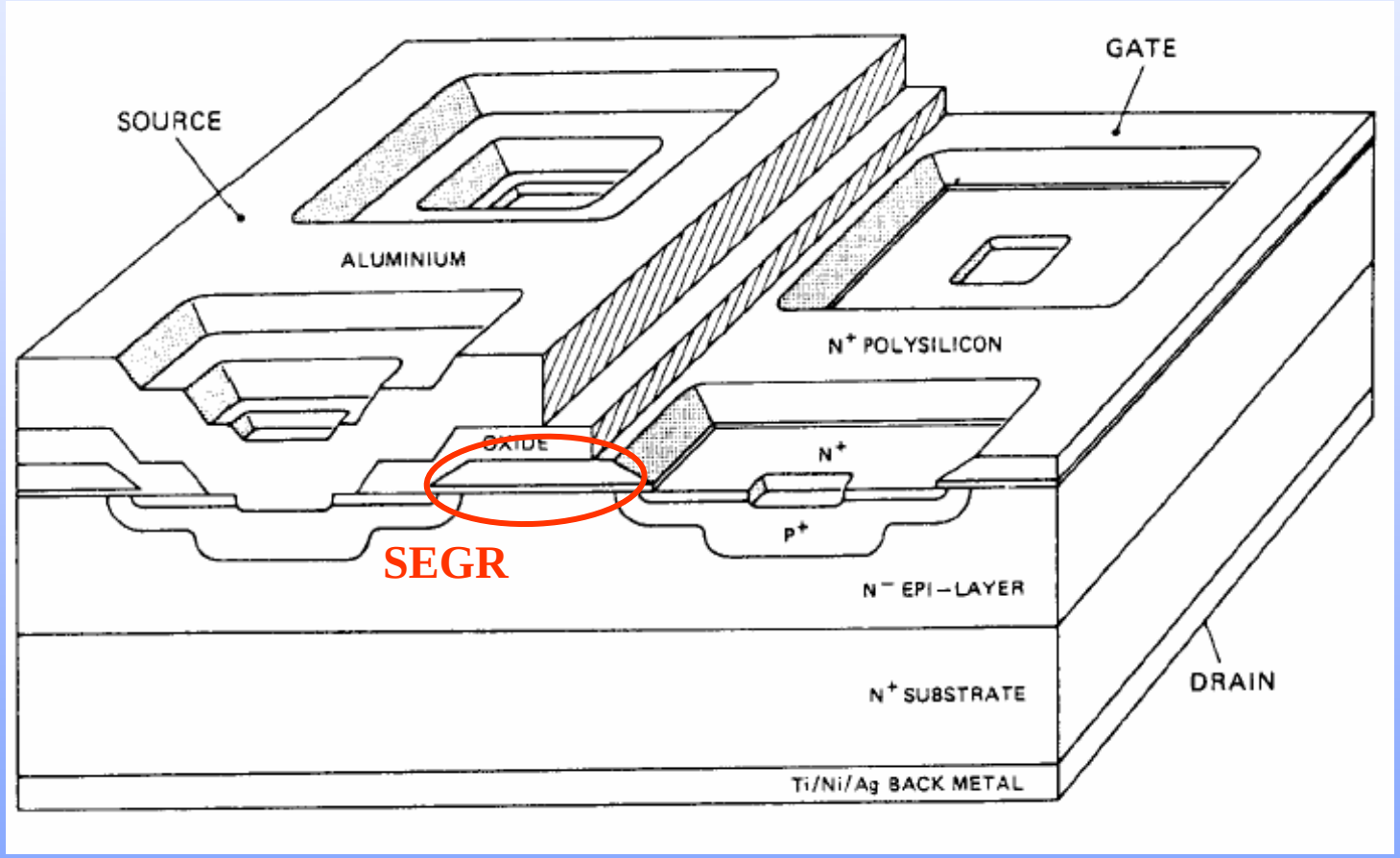
3D Simulation of Potentially Destructive Impact

Electric Field (35ps)



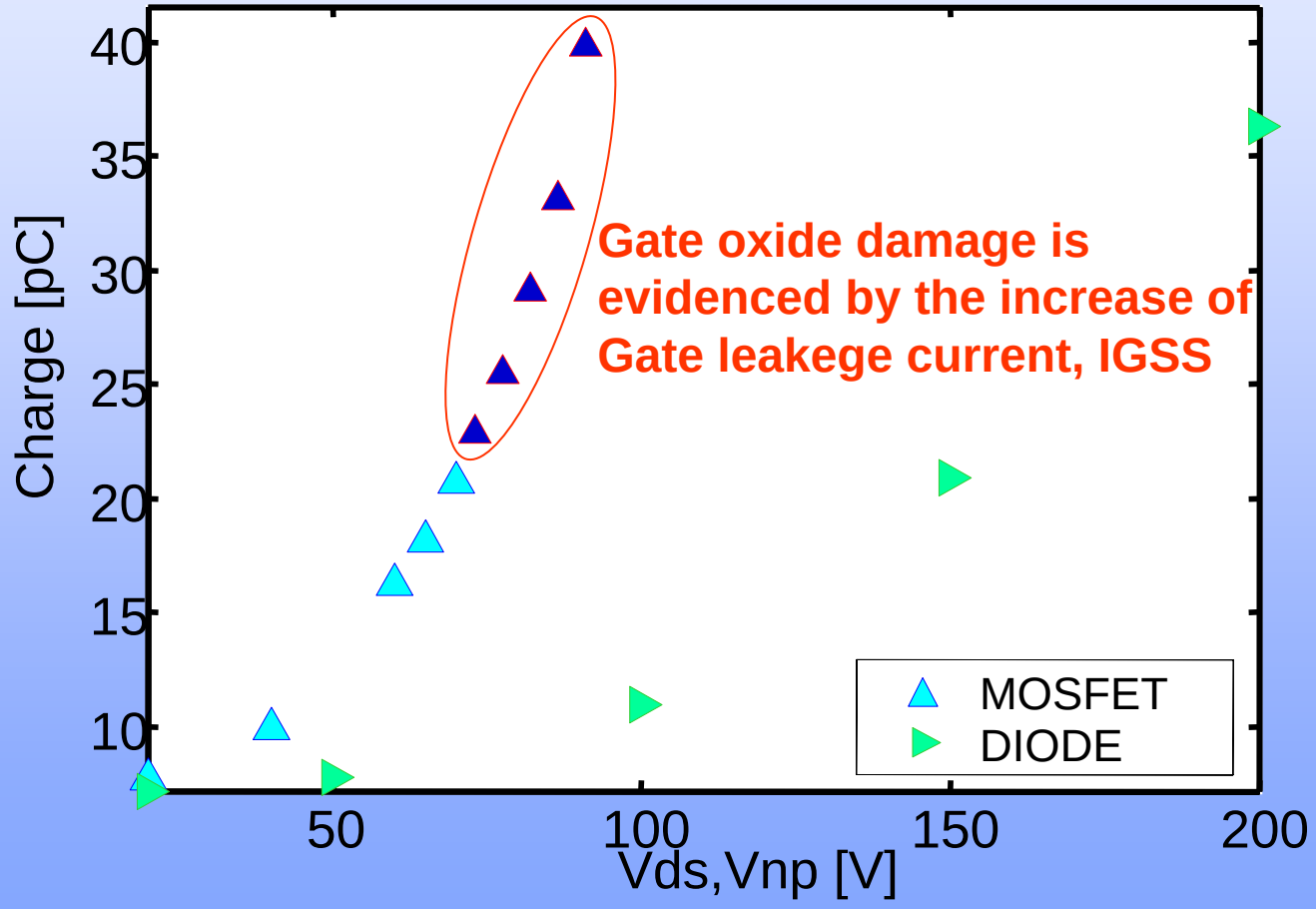


SEGR in Power MOSFET

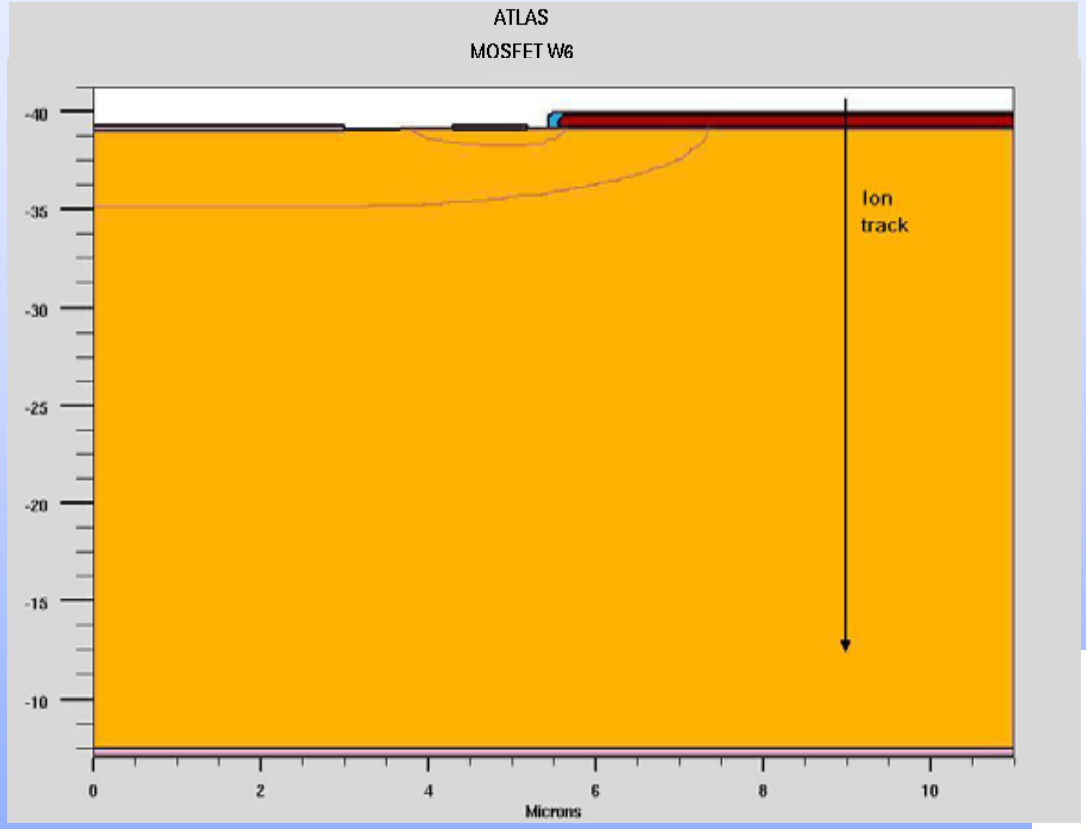


Mean Charge Generated in a 200V MOSFET and in Corresponding Diode

$V_{GS}=0$



3D Simulation of an Impact accompanied by Gate Damage



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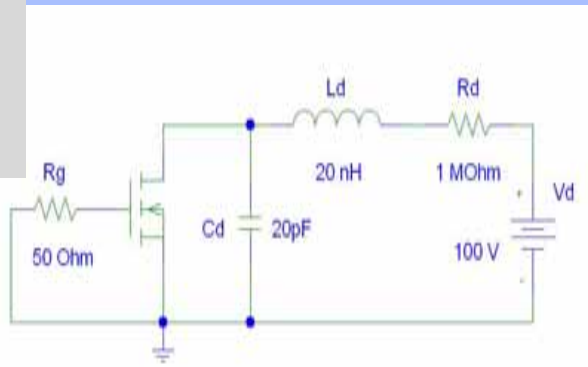
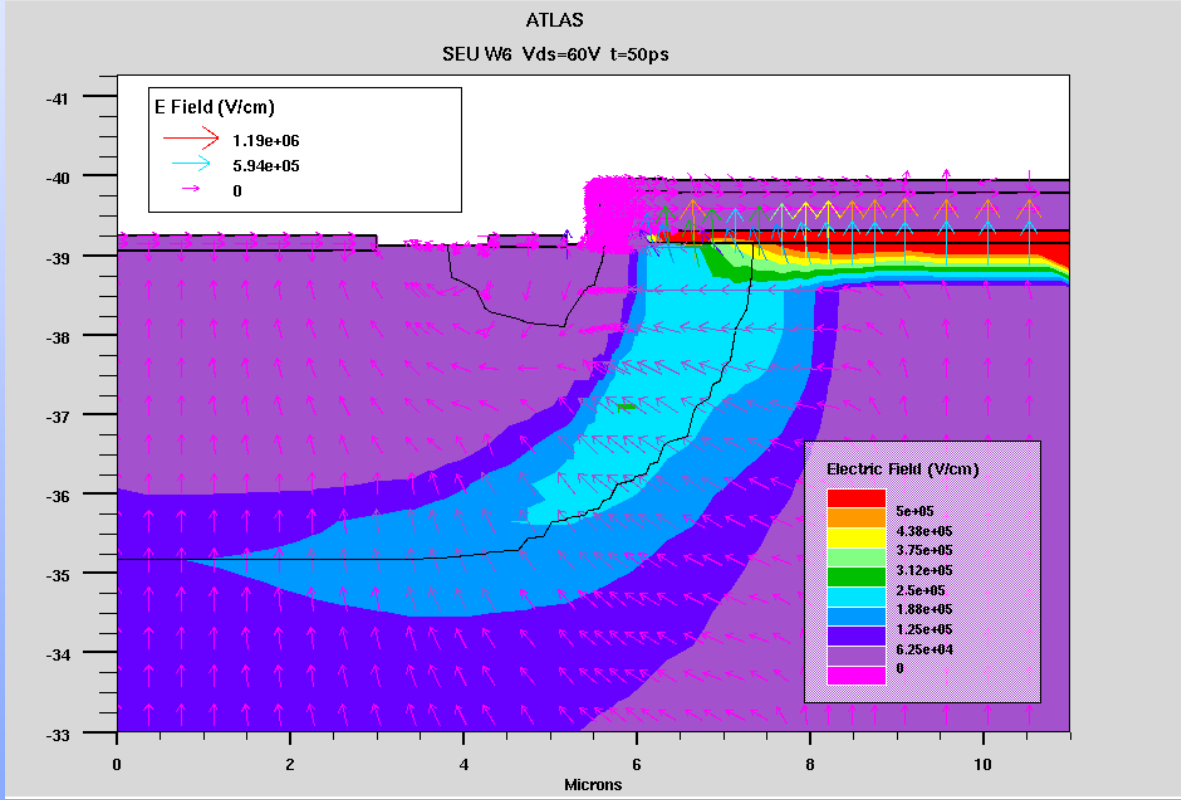


3D Simulation of an Impact accompanied by Gate Damage

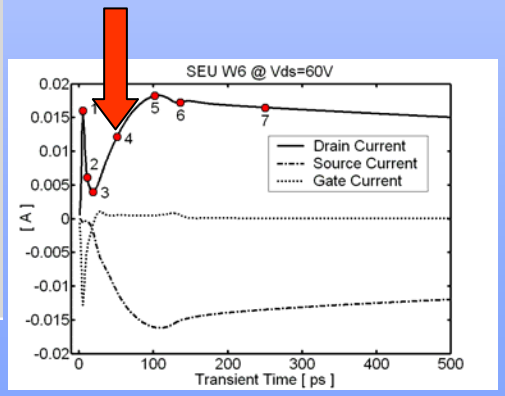
Electric Field



200V MOSFET

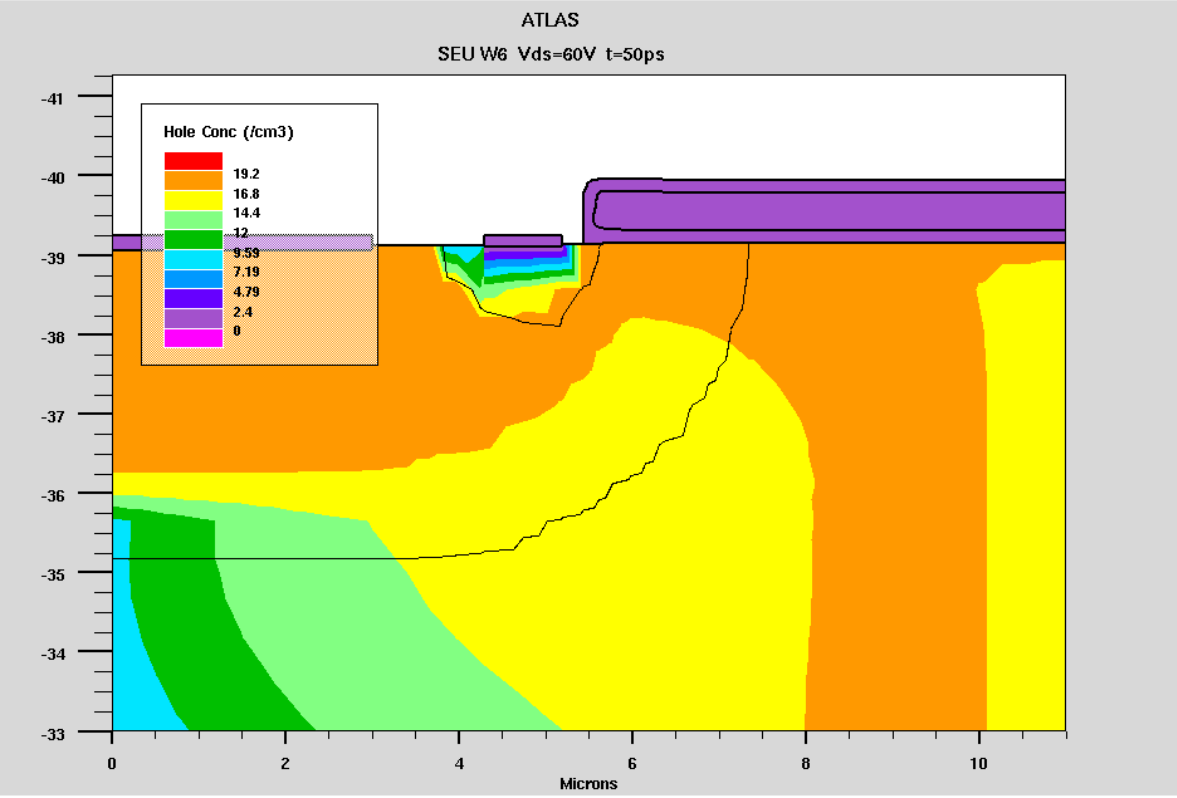
V_{DS} = 60V

V_{GS} = 0V



3D Simulation of an Impact accompanied by Gate Damage

Holes Concentration



200V MOSFET

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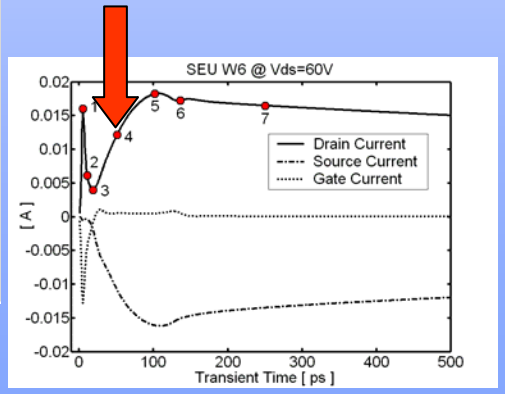
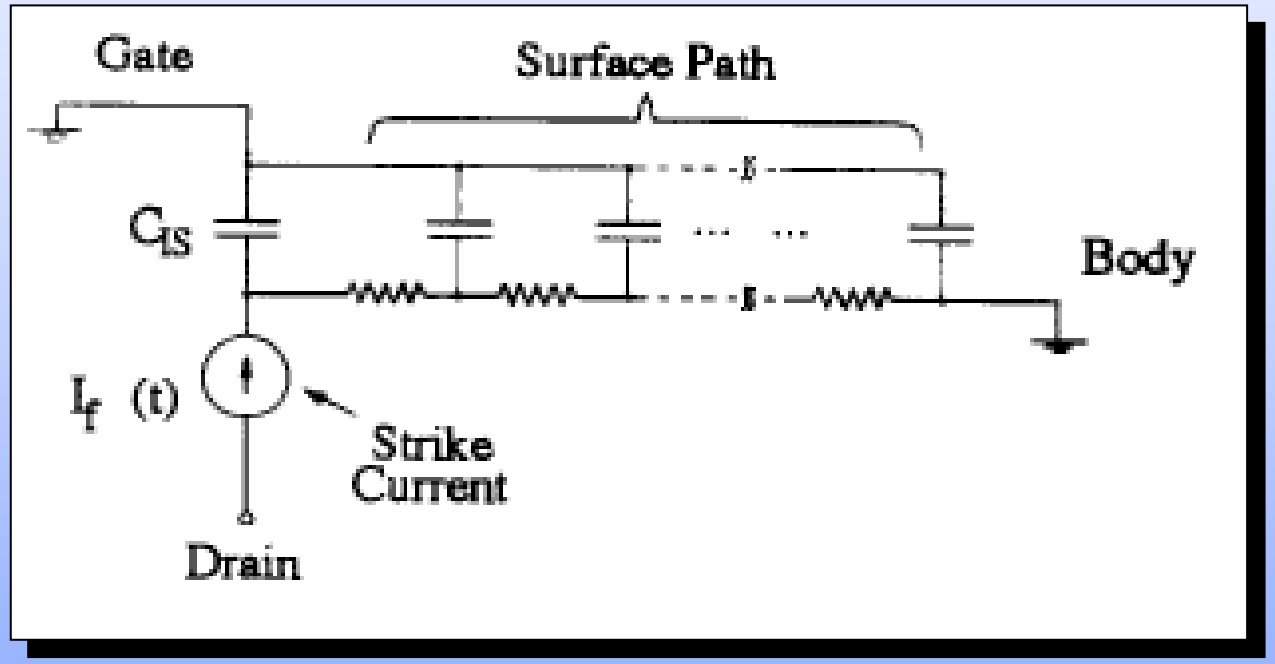


SEGR Conceptual Model

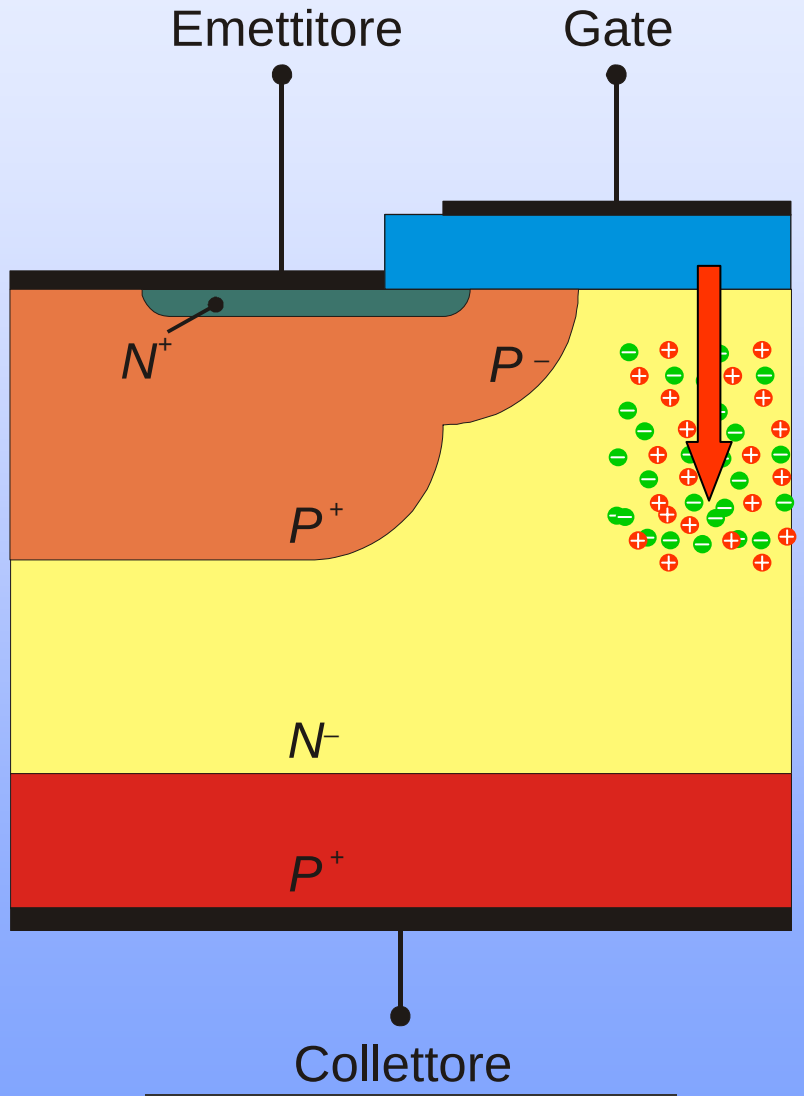


J. R. Brews, et. Al. “A Conceptual model for SEGR in Power MOSFET’s,” IEEE TRANS. ON NUCLEAR SCIENCE, VOL. 40, NO. 6, DECEMBER 1993

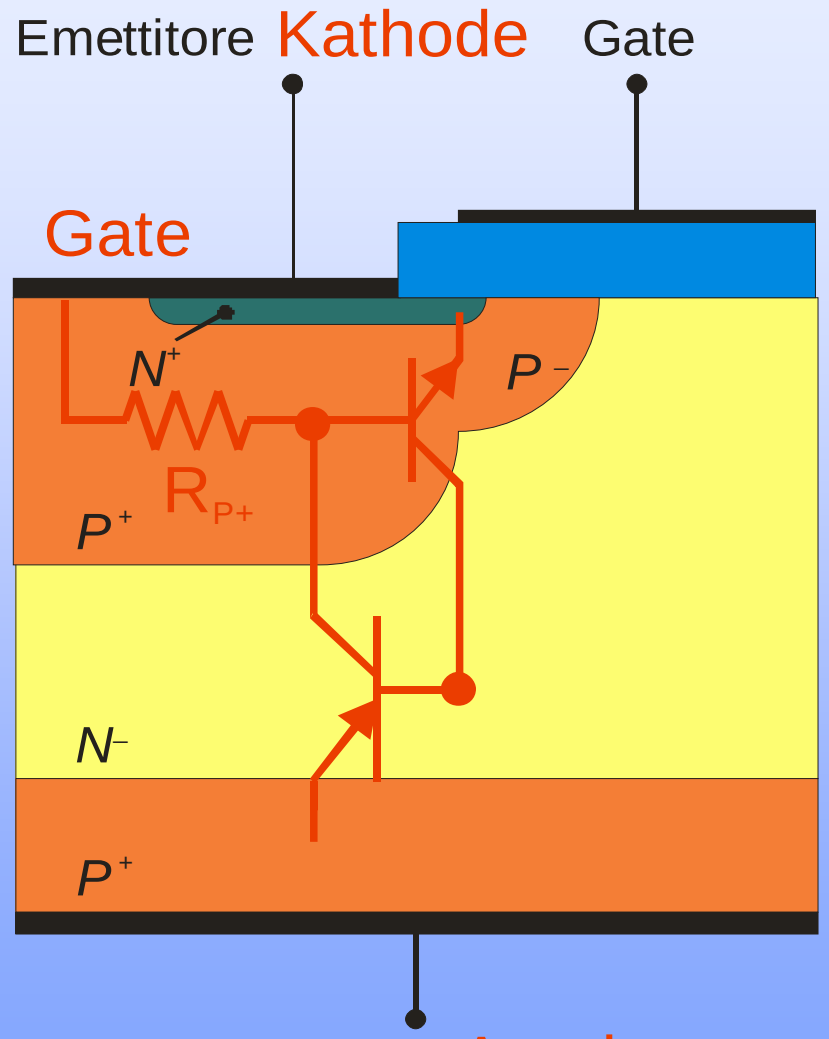
Outline

- Introduction
  - Cosmic rays in Space
  - Cosmic rays at Sea Level
  - Radiation Effects
  - Single Event Tests
    - Irradiation Facilities
    - Particles beam to be used
- SEB in Power Diodes
- SEE in Power MOSFETs:
  - SEB
  - SEGR
- SEB in IGBTs
- Conclusions

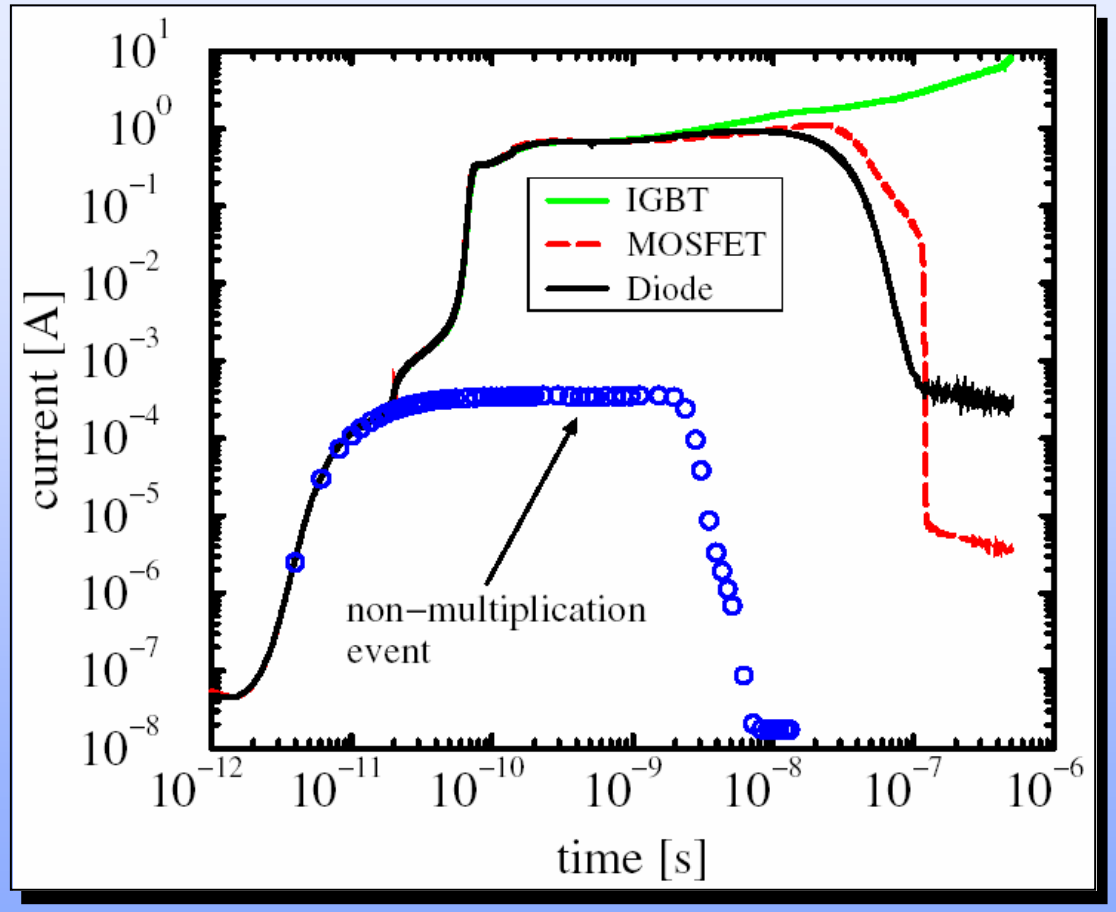
SEB in IGBTs



SEB in IGBTs



SEB in IGBTs (2D Simulation)



W. Kaindl, et. Al. “Cosmic Radiation-Induced Failure Mechanism of High Voltage IGBT,” Proc. of the 17th ISPSD, May 23-26, 2005, Santa Barbara, CA

Conclusions

- Main phenomena observed during the impact with energetic particles have been presented
- In SEB phenomena the interaction between Charge and Electric Field (double injection) plays a relevant role in triggering electrical instabilities
  - In MOSFET its effects are enhanced by parasitic BJT activation
  - In IGBT the presence of two parasitic BJT makes the device even more subject to SEB
- In SEGR phenomena charge motion during the impact causes the electric field across the oxide to increase and causes damages to it
  - more theoretical work must be developed to better understand the formation of the damages to the gate oxide

Thank you for your attention!