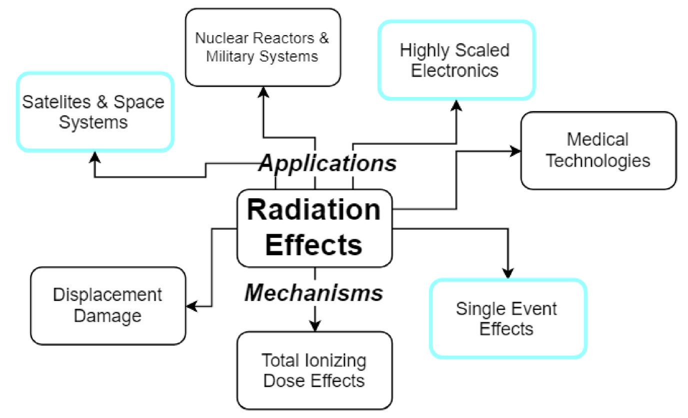
Heavy Ion Strikes on Diodes: Effects of Surface Recombination on Charge Collection

Rebecca Mendez[1], Andrew Tonigan[2], Dr. Ronald Schrimpf[2]

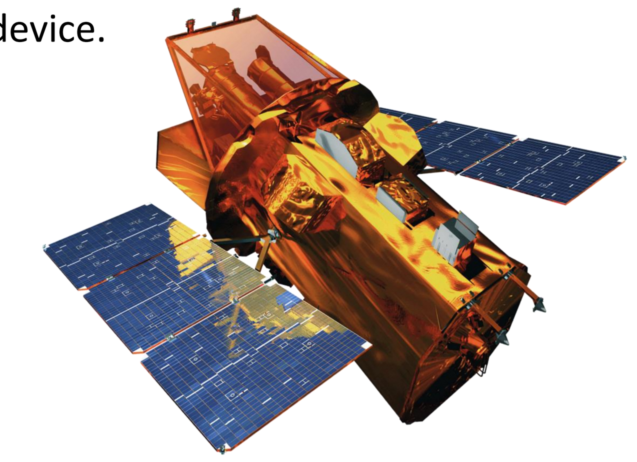
1 Northeastern University, Electrical and Computer Engineering, Boston MA

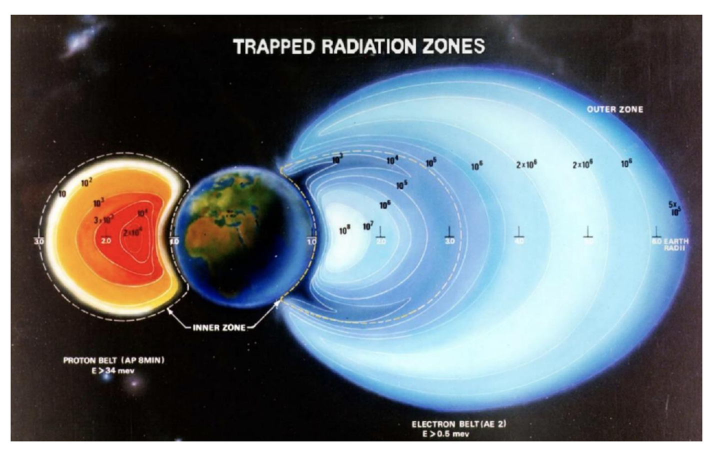
2 Radiation Effects and Reliability Group, Electrical and Computer Engineering, Vanderbilt University, Nashville TN

WHY RADIATION EFFECTS?



Radiation's ability to interfere with electronic devices has long been known. As device sizes shrink, radiation particles can cause more damage due to their size relative to the device.





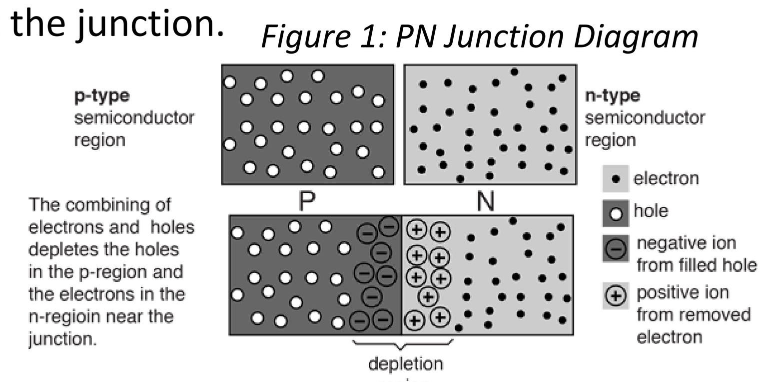
[2] Barth, Janet L. IEEE 466-482

Radiation found in space from energetic solar events (e.g. solar flares, corona mass ejections) and in the Van Allen Belt regions are a concern for satellites, probes, and shuttles– technologies which rely on electronic devices in their computers and sensors. This project focuses on Single Event Effects caused by Solar Radiation: Heavy Ion and Alpha Particle strikes. We investigated the effects of these on Silicon and Germanium diodes respectively through simulation and experimentation.

BACKGROUND

Diodes are a class of electronic device that favor current flow in one direction. A Diode consists of a PN Junction (a P-Type semiconductor in contact with a N-Type semiconductor). When a voltage bias is applied across the PN Junction, an electric field is produced at the junction.

Figure 1: PN Junction Diagram



[3] HyperPhysics

Charge carrier recombination is a phenomenon in semiconductor materials in which an electron in the conduction band falls down in energy to the valence band, recombining with a hole. We consider Shockley-Read-Hall (SRH) Recombination which is a type of recombination mediated by defects in the semiconductor lattice.

SRH Bulk Recombination Equation:

$$R_{SRH} = \frac{p_s n_s - n_i^2}{\tau_p \left(n + n_i e^{\frac{E_t}{kT}}\right) - \tau_n \left(p + n_i e^{\frac{-E_t}{KT}}\right)}$$

p_s / n_s - electron and hole conc.
n_i - intrinsic carrier conc. (equilibrium)
T – Sample Temperature
K – Boltzmann constant
E_t - Energy level of trap in Si band gap

Most diodes have insulation made of a non-conducting material such as Silicon Dioxide (SiO_2). At the interface of the semiconductor and the insulator, the semiconductor's lattice is incomplete and has defects. Recombination is especially high on this surface. Surface Recombination Equation:

$$R_S = \frac{(p_s n_s - n_i^2)}{[p_s + n_s + 2n_i \cosh(\frac{E_{st} - E_i}{kT})]} \cdot D_{it} v_{th} \sigma_s$$

D_{it} - density of interface traps
σ_s- carrier capture cross - section
E_i - center of Si band gap

Heavy Ion and Alpha Particle Strikes can disrupt operation of semiconductor devices. When radiation strikes the bulk of a semiconductor material, excess charges are created and therefore disturb the equilibrium carrier concentrations. We aim to see how Surface Recombination Velocity (SRV) -- a component of Surface Recombination -- affects the device Current vs. Time transient. We also investigate how the dimensions and doping profiles of diodes affect whether SRV will have an effect on the transient.

METHOD

Heavy Ion Strike Simulation

- Synopsys TCAD was used to run Finite Element Analysis using the device physics equations.
- Figure 2 shows one of the Silicon diodes that were modeled with features labeled.
- Figure 3 shows the Heavy Ion Strike that was simulated.

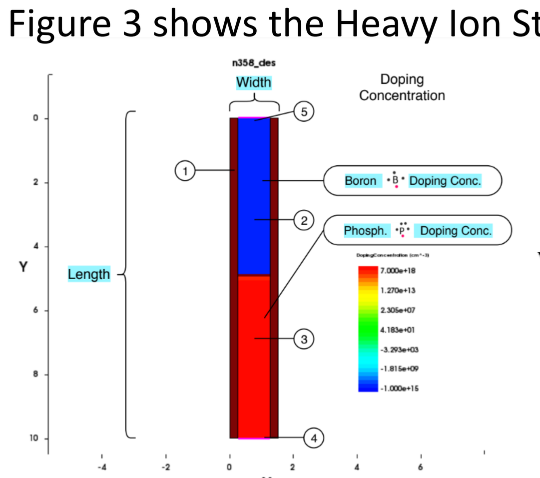


Figure 2: Doping Concentration Plot

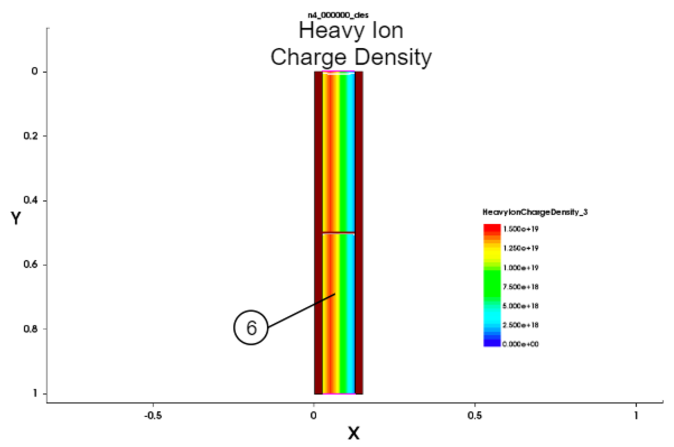


Figure 3: Heavy Ion Charge Density Plot

Key	
	Item
1	SiO2 Insulation
2	P-Type Si (B Doped)
3	N-Type Si (P Doped)
4	N Contact
5	P Contact
6	Heavy Ion Strike Path
	Parameters

- Parametric analysis of length to width ratios, doping ratios of diodes, and Surface Recombination Velocities was performed. Figure 4 shows organization of simulation parameters.

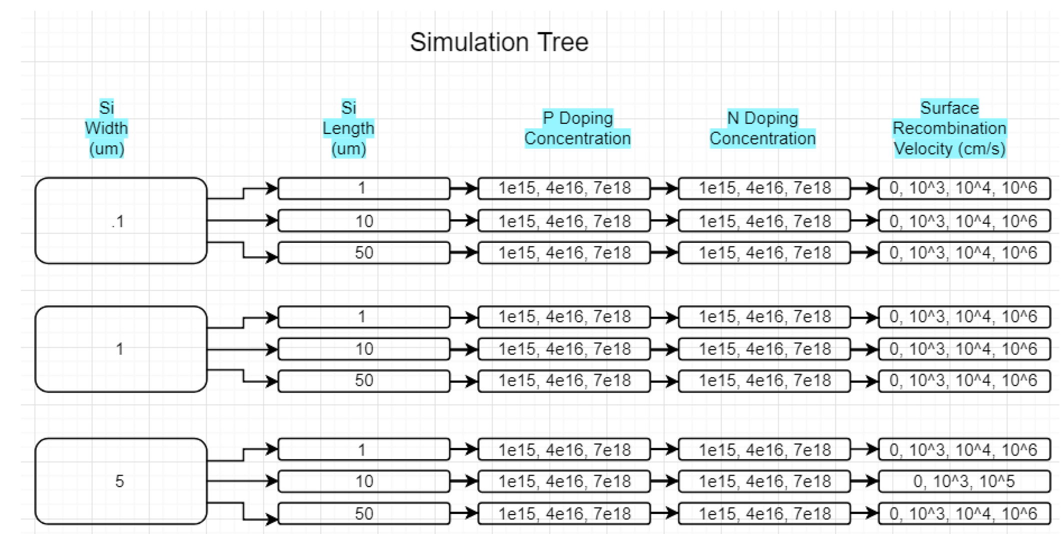


Figure 4: Simulation Tree

Alpha Particle Strike Experiment

- Diode dipped in melted wax to leave only desired portion of glass casing exposed.
- In VINSE Cleanroom, Hydrofluoric Acid (HF) Buffered (Ammonium) solution used to etch exposed glass of diode.
- Etching duration: ~12 hours.

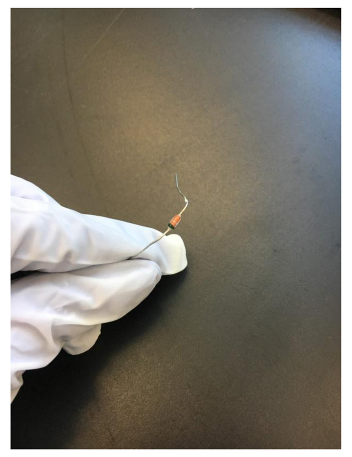


Figure 5: Ge Diode with Wax Coating

Figure 6: Mentor Andrew Tonigan and Professor Alice Leach at HF hood in Cleanroom

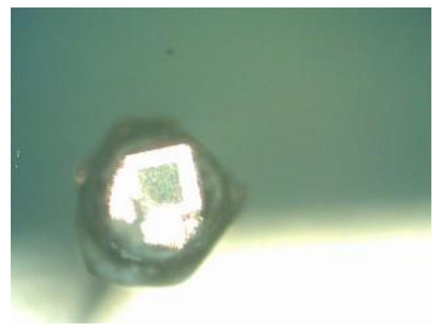


Figure 7: Cross Section Ge Diode

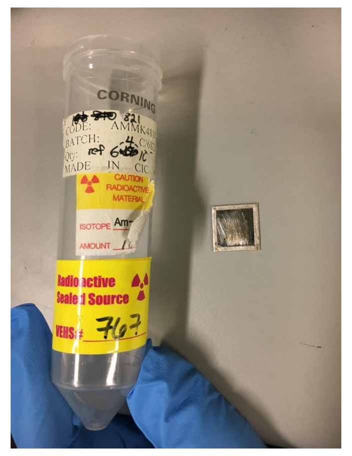


Figure 8: Americium-241 Alpha Particle Source

- Americium-241 is used as Alpha Particle source to irradiate a Germanium diode and measure transient using a Bias Tee - Oscilloscope setup (Figure 9 & 10).

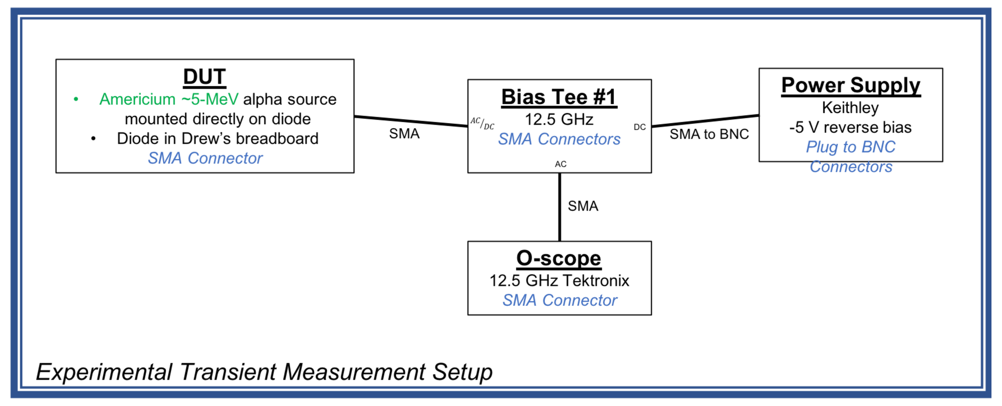


Figure 9: Alpha Particle Radiation Experiment Setup Diagram

Figure 10: Alpha Particle Experimental Setup Photo

- Diode is placed in bias tee setup with Americium-241 placed over exposed area of diode.
- Current vs. Time transient is measured and read out on the oscilloscope.

RESULTS

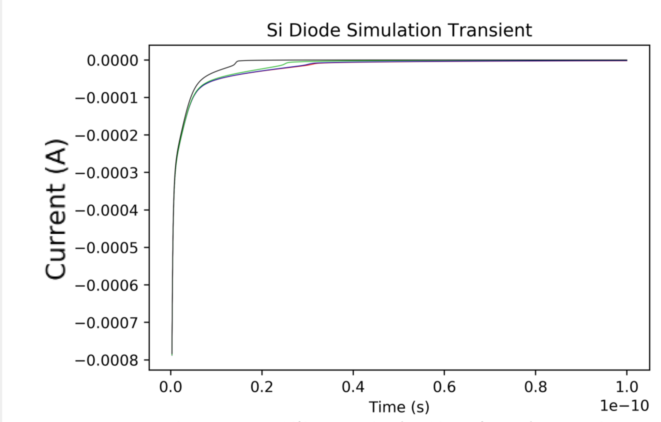


Figure 11: Silicon Diode Simulated Transient

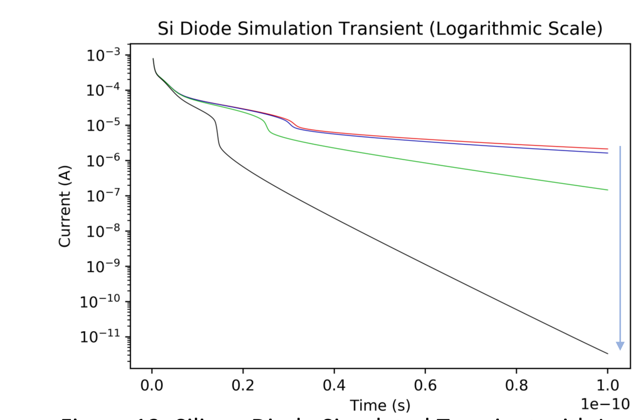


Figure 12: Silicon Diode Simulated Transient with Log Y Axis

Legend (Figures X-X)
Red – SRV = 0 cm/s
Blue – SRV = 1000cm/s
Green – SRV = 10^4 cm/s
Black – SRV = 10^6 cm/s

Figures 11, 12, 17, 18
Si Width: .1 um
Si Length: 1 um
P-Doping Conc.: 1e15 cm^-3
N-Doping Conc.: 7e18 cm^-3

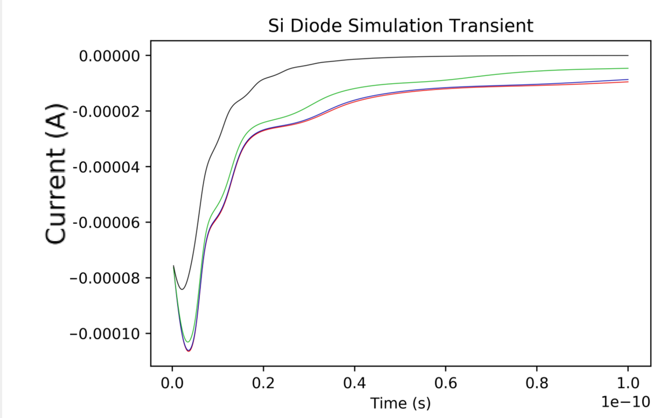


Figure 13: Silicon Diode Simulated Transient

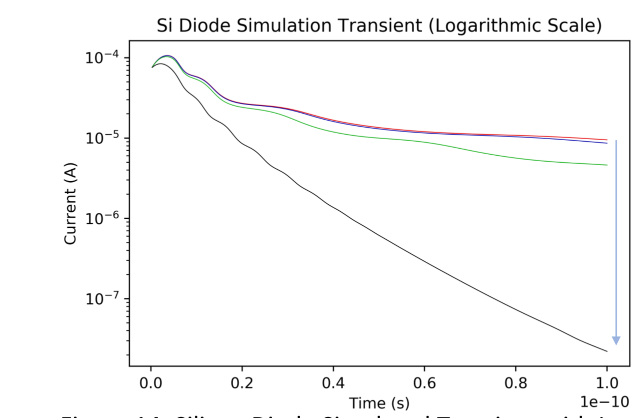


Figure 14: Silicon Diode Simulated Transient with Log Y Axis

Figures 13 & 14:
Si Width: .1 um
Si Length: 10 um
P-Doping Conc.: 1e15 cm^-3
N-Doping Conc.: 7e18 cm^-3

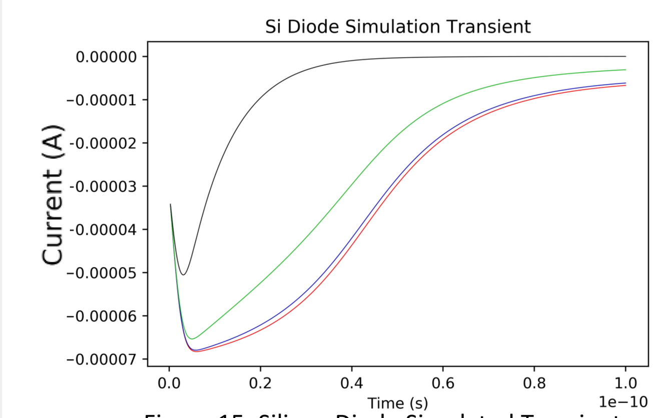


Figure 15: Silicon Diode Simulated Transient

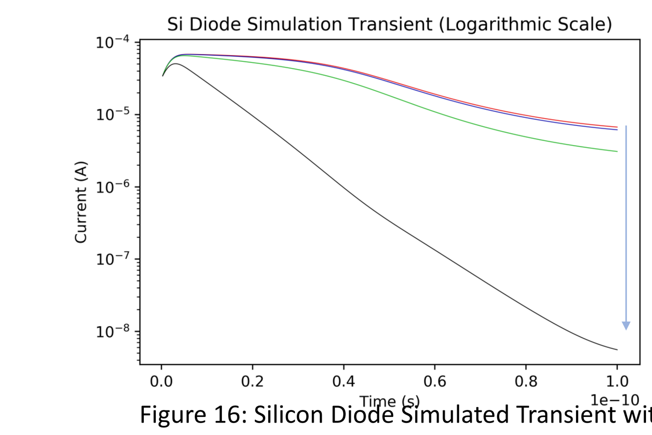


Figure 16: Silicon Diode Simulated Transient with Logarithmic Y Axis

Figures 15 & 16:
Si Width: .1 um
Si Length: 50 um
P-Doping Conc.: 1e15 cm^-3
N-Doping Conc.: 1e15 cm^-3

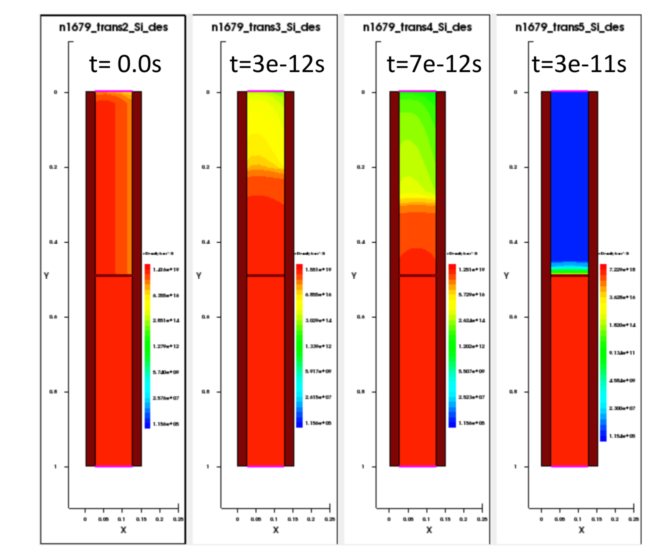


Figure 17: Silicon Diode Electron Density Plot at Four Times

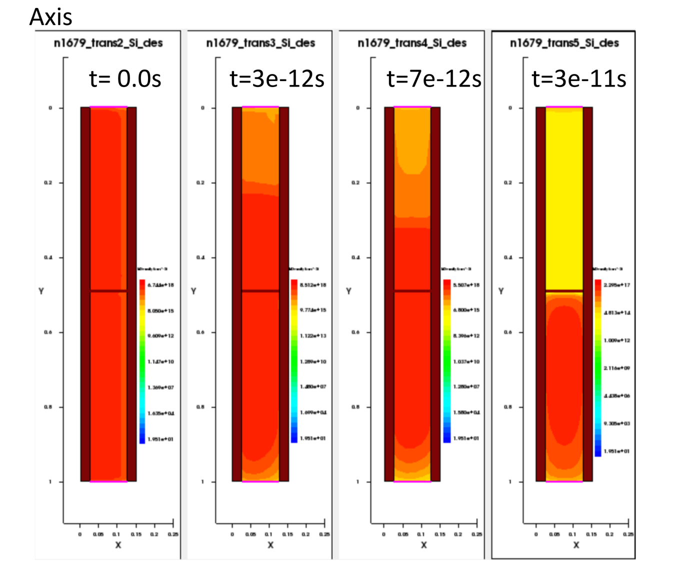


Figure 18: Silicon Diode Electron Density Plot at Four Times

CONCLUSION

- TCAD simulations show that in long and thin diodes (width of .1um and length >1um), the Surface Recombination Velocity affected the Current vs. Time transients of the device. As SRV increased, the current collected decreased.
- The alpha particle strike experiments did not result in a transient that seemed characteristic of an alpha particle strike. This was likely due to problems with the etching process and the placement of the alpha source on the diode.
- **Future Work:** Monte Carlo simulations with MRED will inform the probability of heavy ion strikes simulated in TCAD to be compared with the number and relative magnitude of transients observed in the alpha particle experiment.

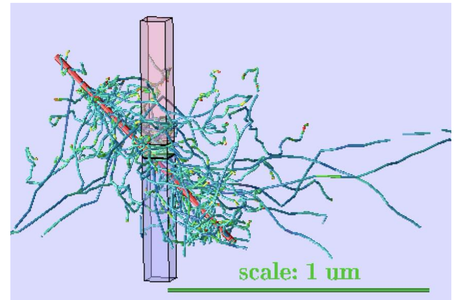


Figure 19: Silicon diode heavy ion strike in MRED Simulation

ACKNOWLEDGEMENTS

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2. Barth, Janet L., C. S. Dyer, and E. G. Stassinopoulos. "Space, atmospheric, and terrestrial radiation environments." *IEEE Transactions on Nuclear Science* 50.3 (2003): 466-482.
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