Mechanisms of Heavy Ion-, Focused X-Ray-, and Pulsed Laser-Induced Single Event Transients in an Epitaxial Silicon Diode

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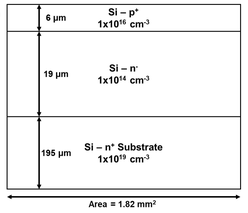
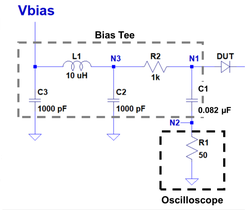
Abstract

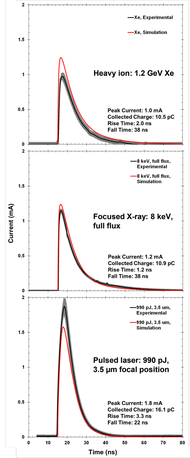
Heavy ion-, focused X ray-, and pulsed laser induced single event effects in an epitaxial silicon diode were simulated using Sentaurus Technology Computer Aided Design (TCAD). The variation of the potential with time in simulation agrees with previous experimental data, which suggests that the different radiation sources result in different amounts of potential modulation. The charge generation spatial profile strongly affects the potential modulation. The longitudinal range and starting location of generated charge most strongly impacts the amount of potential modulation, while the radial width has a slight effect, and the temporal duration of charge injection has negligible impact on potential modulation.

Sentaurus Technology Computer Aided Design (TCAD)

- Sentaurus TCAD simulations used to model device response
- Full diode structure with measured doping profiles
- Mixed mode circuit capture parasitic circuit components, bias tees
- Distinct charge generation models:
  - Built-in TCAD models used for heavy ions
  - Beer's law used to model focused X-rays
  - Lumerical FDTD simulations used for pulsed laser
- Good agreement between simulations and experiments
- Results shown at -5 V bias
  - SETs shown were caused by 15 pC of generated charge in diode's active region by each source
  - -90 V bias included in full paper







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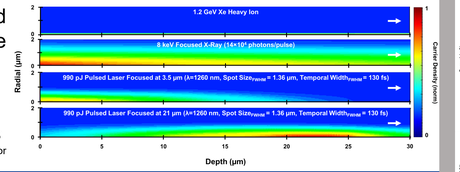
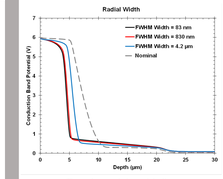
Charge Generation Distributions

- Heavy ions, focused X-rays, and pulsed lasers* have distinctive charge generation profiles
  - Radial width : ions < laser ≈ X-rays
  - Longitudinal range : ions ≈ X-rays > laser
  - Charge localization: ions = X-rays ≠ lasers

*Gaussian pulsed lasers were used in this work. Results would be different for Quasi-Bessel beam pulsed laser



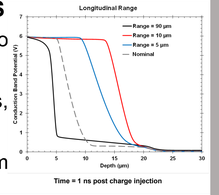
Radial Widths Simulations



- FWHM radial width varied over several orders of magnitude
- Increasing radial width causes slight decrease in amount of potential modulation
  - Larger width = smaller charge density
- Some differences between ions, X-rays, and lasers due to differences in width

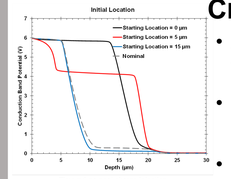
Longitudinal Range Simulations

- Changed longitudinal range from long (passes through epi) to short (stops in epi).
- Long range charge track causes potential modulation like ions, X-rays; short range charge track modulates potential like laser
- Most differences between ions/X-rays and Gaussian lasers from differences in range

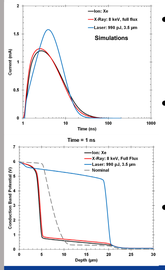


Charge Localization Simulations

- A 10 µm long packet of charge was set at different locations within the diode
- Magnitude and direction of potential modulation changes with starting location
- Emulates Gaussian pulsed laser changing focal positions



Experiment-Based Simulations

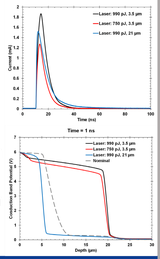


- Transient shapes differed between heavy ions, pulsed lasers, and focused X-rays even when similar amounts of charge were generated in active region (15 pC shown in figure)
- Simulations show different amounts of potential modulation over time
  - Potential modulation trends match those in transient shape
  - Pulsed laser results in more potential modulation and larger transients than heavy ions and focused X-rays, which result in similar device responses
- Distinctive charge generation profiles result in different device responses

Comparison of Experimental Pulsed Laser Focal Positions

- Gaussian pulsed laser transients are dependent on focal position (top)

Laser Pulse	Charge Generated (pC)	Collected Charge (pC)	Peak Current (mA)	Rise Time (ns)	Fall Time (ns)
990 pJ, 3.5 µm	15.0	16.1	1.79	3.34	21.9
990 pJ, 21 µm	15.0	13.9	1.54	1.82	33.0
750 pJ, 3.5 µm	9.3	9.59	1.21	2.74	21.5



- Simulations show potential modulation is more affected by focal position than amount of charge generated in active region (bottom)
  - Differences in transient shape result of variations in potential modulation from changes in location of generated charge

Conclusions

- Heavy ions, pulsed lasers, and focused X-rays result in different transient shapes due to variations in potential modulation
- Potential modulation variations result from differences in charge generation profiles
- From the simulations, disparities in longitudinal range and localization of charge generation explain most of the potential modulation variations
  - Quasi-Bessel beam pulsed laser would likely produce results similar to focused X-rays
  - SOI and highly scaled technologies likely to be less affected by differences in charge generation profiles