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Correlation of Sensitive Volumes Associated with Ion- and Laser-Induced Charge Collection in an Epitaxial Silicon Diode

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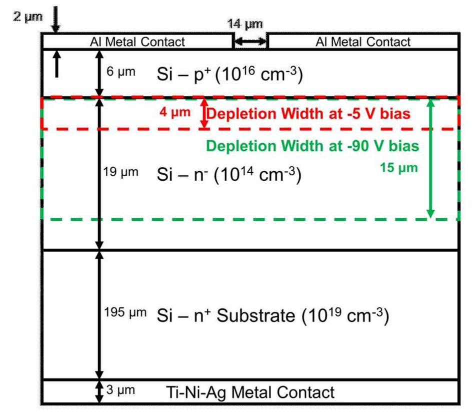
Abstract

Laser-induced collected charge is used to define a sensitive volume in a Si diode. This sensitive volume is inconsistent with heavy ion experiments when depletion region modulation is not truncated. An ion-based sensitive volume is developed and compared to the laser-based sensitive volume. These sensitive volumes differ at a small bias due to differences in potential modulation and are the same when the device is fully depleted due to truncation in potential modulation.

Experimental Details

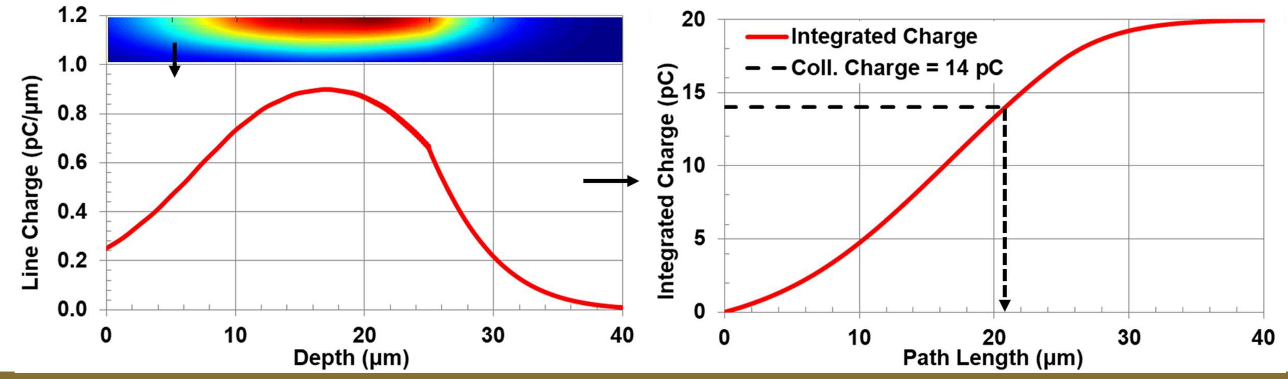
- Epitaxial Si diode test structure
- Heavy ion SET testing at LBNL 88" Cyclotron
- Pulse laser TPA SET testing at NRL
- High-speed transient capture
- Integrated SETs → collected charge



Sensitive Volumes

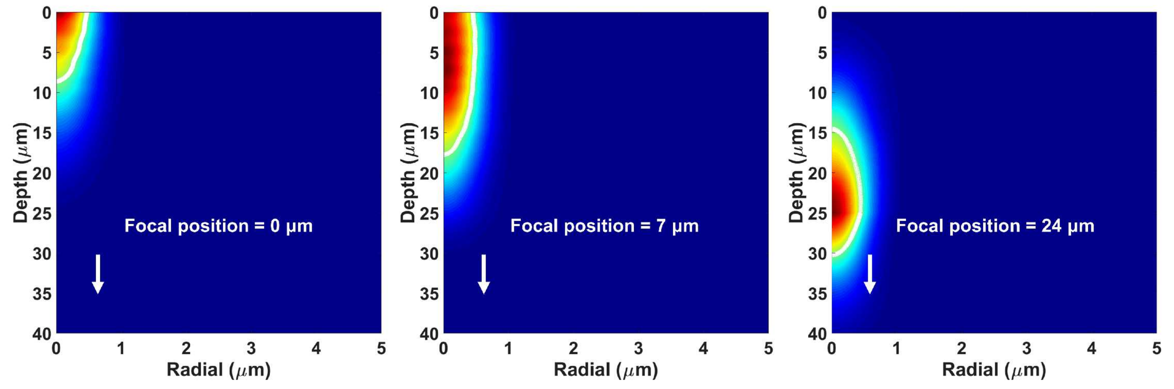
- Sensitive volume based on laser-induced collected charge:
  - One volume with 100% collection efficiency
  - Sensitive volume area is radially symmetric, spans entire device
  - Sensitive volume depth, SV_{laser}, begins at device surface

$$Q_{coll} = \iiint_{V=A\,SV_{laser}} \frac{dQ_{gen}}{dV}\,dV$$



Optical Simulations

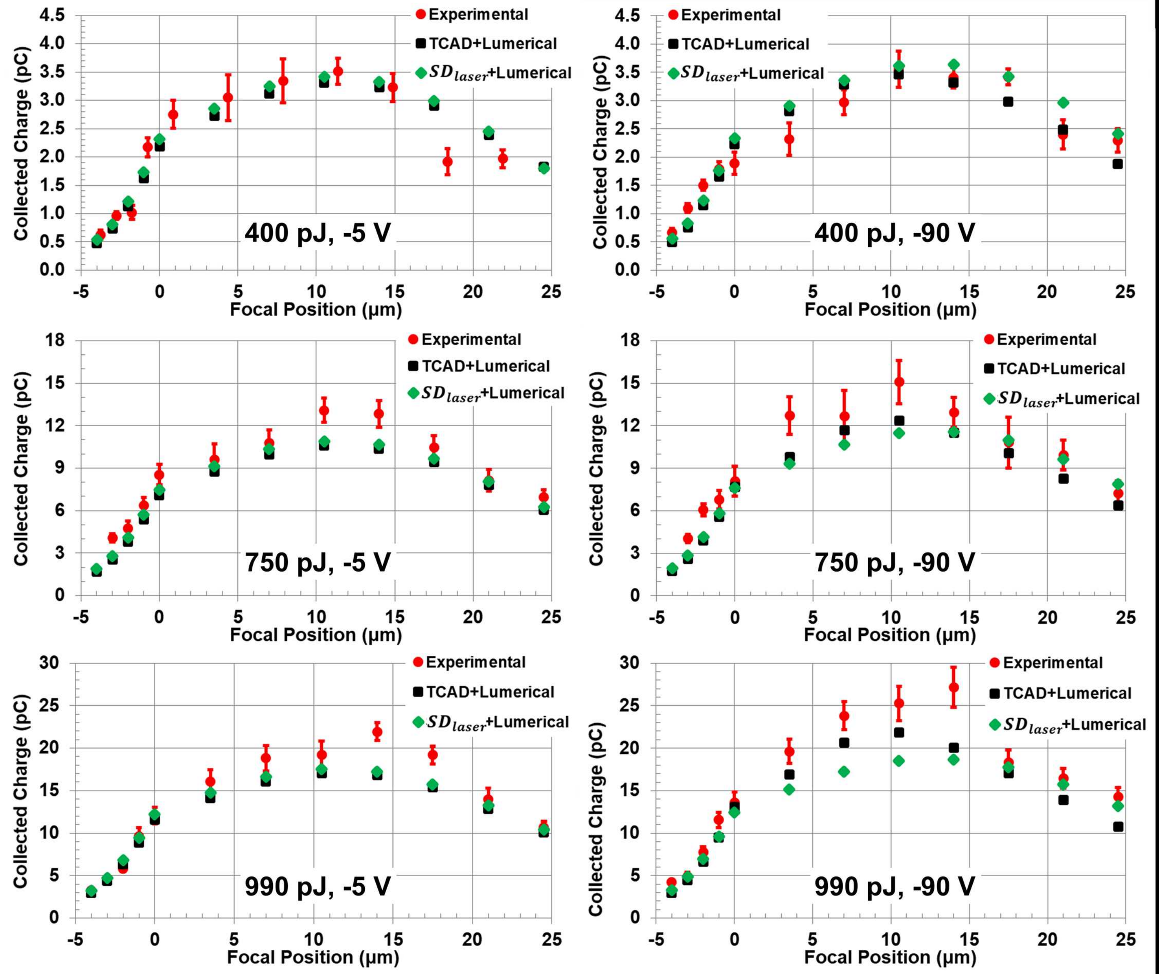
- Lumerical FDTD Solution – Nanophotonic optical simulation package
- Modified to account for charge generated by nonlinear effects
  - Intensity dependent refraction and absorption, optical generation of free carriers, free carrier refraction and absorption
- Outputs time integrated optically generated carrier distributions



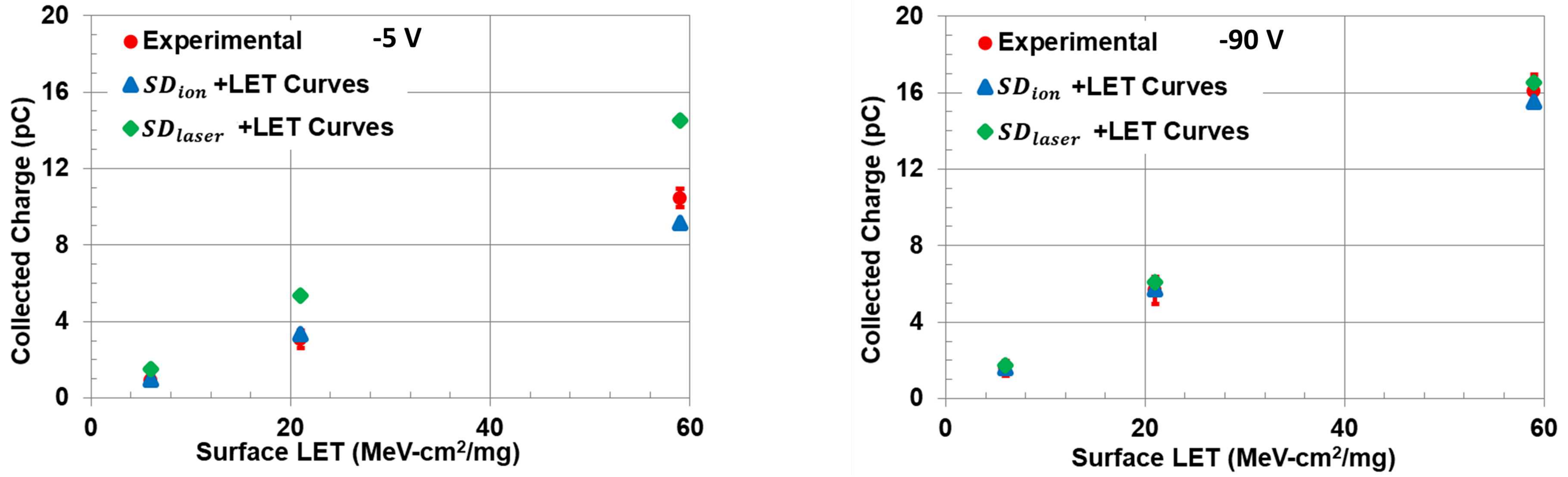
Laser Results

- Depth scan was performed (**Experimental**)
- Optical distributions were found for each focal position
- TCAD simulations were done using Lumerical as an input (**TCAD+Lumerical**)
- SD_{laser} found by integrating over Lumerical distribution at Focal Position = 24.5 µm
- SD_{laser} used to predict collected charge at other focal positions (***SD_{laser}+Lumerical***)

SD_{laser} = 23 µm (-5 V)
SD_{laser} = 26 µm (-90 V)



Heavy Ion Results



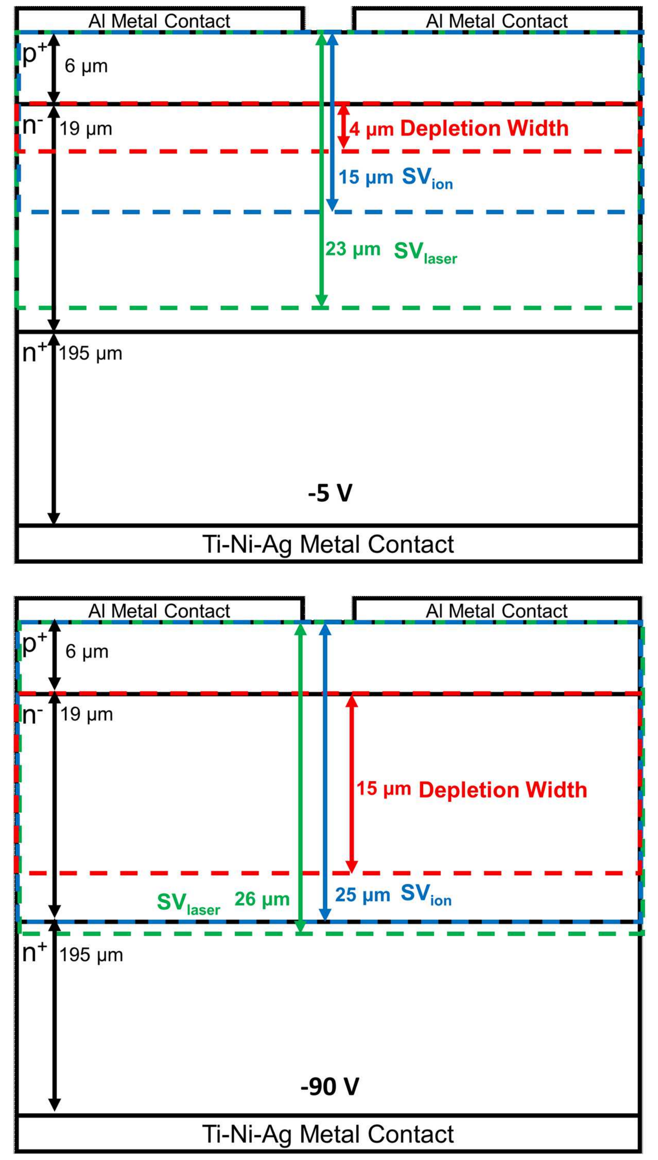
- 10,000 SETs recorded for each ion (**Experimental**)
- LET curves calculated with SRIM
- Collected charge predicted by integrating LET curves over SD_{laser} (***SD_{laser}+LET Curves***)
- SV_{ion} found by integrating over LET curves, averaging each ion

SD_{ion} = 15 µm (-5 V)
SD_{ion} = 25 µm (-90 V)

- Collected charge predicted by integrating over SD_{ion} (***SD_{ion}+LET Curves***)

Discussion

- At small biases, deeply penetrating laser-generated charge results in an increased potential modulation compared to linearly distributed ion-generated charge resulting in a larger sensitive volume
- At high biases, potential modulation is truncated by heavily doped substrate resulting in sensitive volumes of the same size
- The larger laser-based sensitive volume at -5 V results in an error rate twice as large as the ion-based sensitive volume in CRÈME96
  - 4.9x10^{-4} SEEs/bit/s vs 2.3x10^{-4} SEEs/bit/s
  - ISS orbit, solar minimum, quiet magnetosphere conditions
  - Critical charge of 0.5 pC



Conclusions

- A sensitive volume defined by laser-induced collected charge is defined and adequately represents multiple laser experimental results
- A different sensitive volume defined by ion-induced collected charge is defined and adequately represent multiple ion experimental results
- Ion- and laser-defined sensitive volumes are different at -5 V due to potential modulation differences
- Ion- and laser-defined sensitive volumes are the same at -90 V due to truncation of potential modulation

Acknowledgment

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