Coupled Electro-Thermal Simulations of Single Event Burnout in Power Diodes

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Abstract

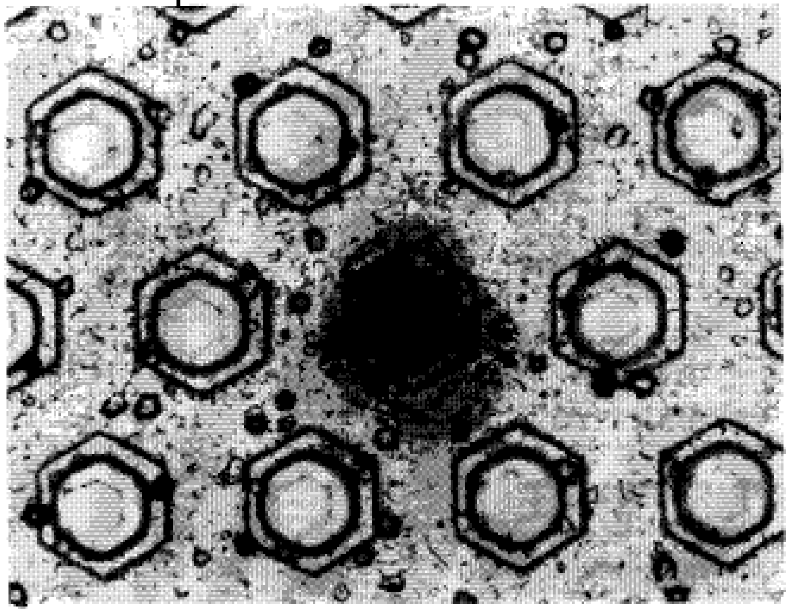
Power diodes may undergo destructive failures when they are struck by high energy particles during the off state (high reverse-biased voltage). This failure is a result of thermal runaway . In this poster, we describe the failure mechanism using a coupled electro-thermal model. The simulation results indicate that catastrophic failures result from local heating caused by ion-generated carriers.

Motivation

- Cosmic rays can cause Single event Burnout (SEB) in power electronic devices in space (e.g., heavy ions) and terrestrial systems (e.g., neutrons).
- The catastrophic failure is identified but the physical mechanism is not fully understood.
  - Previous simulation attempts could not model the full destructive mechanism of SEB, especially in diodes.
- The failure is a result of high power density that leads to thermal breakdown of the device, so
  - Electro-thermal model is utilized by incorporating the thermal diffusion equation.

- Optical image of burnout in an IRF

150 power MOSFET

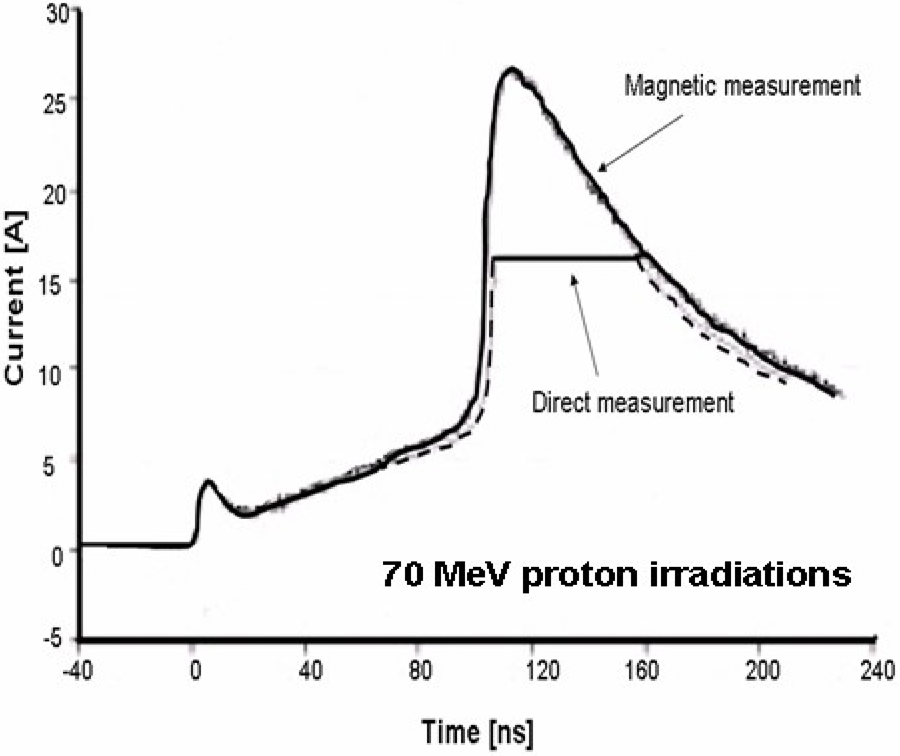


E. Stassinopoulos et al. IEEE Trans. Nuclear Science. 39, 1992 (© 1992 IEEE)

Introduction: SEB in power diodes

- **Ion-generated charge is multiplied by avalanching, resulting in a very high current causing a localized breakdown in the device.**

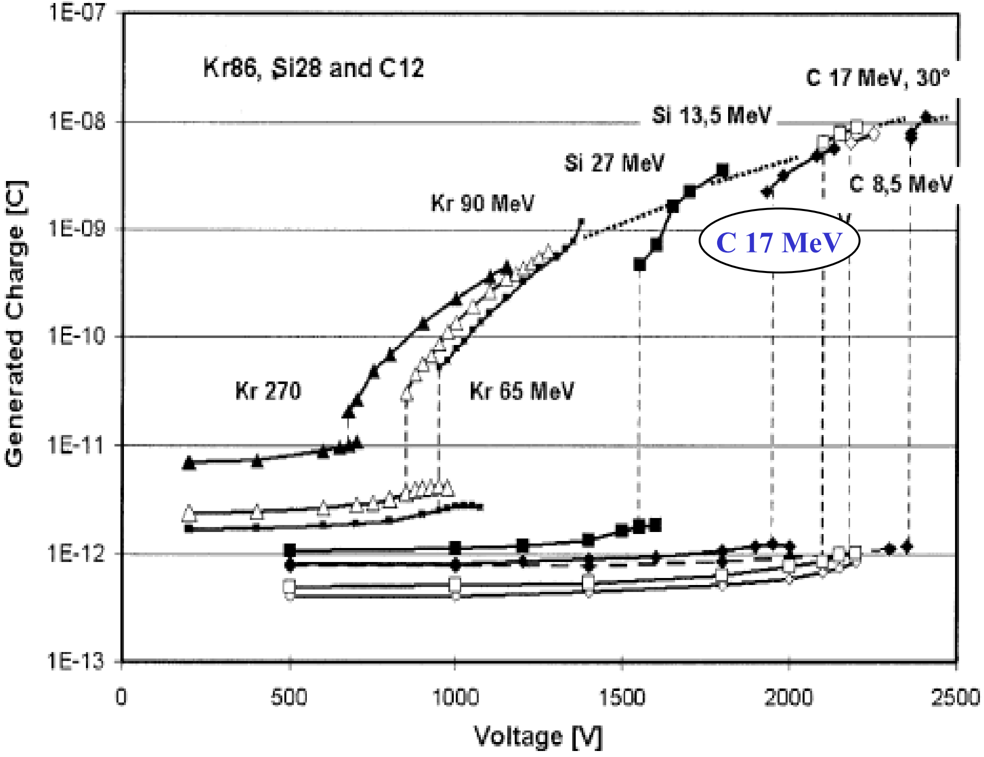
-Destructive output current showing an initial pulse of 4 A followed by a sharp rise after 100 ns, indicating permanent failure.



G. Soelkner et al. IEEE Trans. Nuclear Science. 47, 2000 (© 2000 IEEE)

-The generated charge is amplified once the impact ionization is triggered.

4 kV diodes



K. Maier et al. Nuclear instruments and methods In physics research B 146, 1998 (© 1998 Elsevier)

Electro-thermal model

- **Strike-induced charge, combined with charge multiplication due to avalanching, can result in sufficiently large current to generate high local temperatures.**
  - Non-constant lattice temperature can be simulated by incorporating the thermal diffusion equation.

$$C_p \rho \frac{\partial T_L}{\partial t} = \nabla.(\kappa \nabla T_L) + \vec{J} \cdot \vec{E}$$

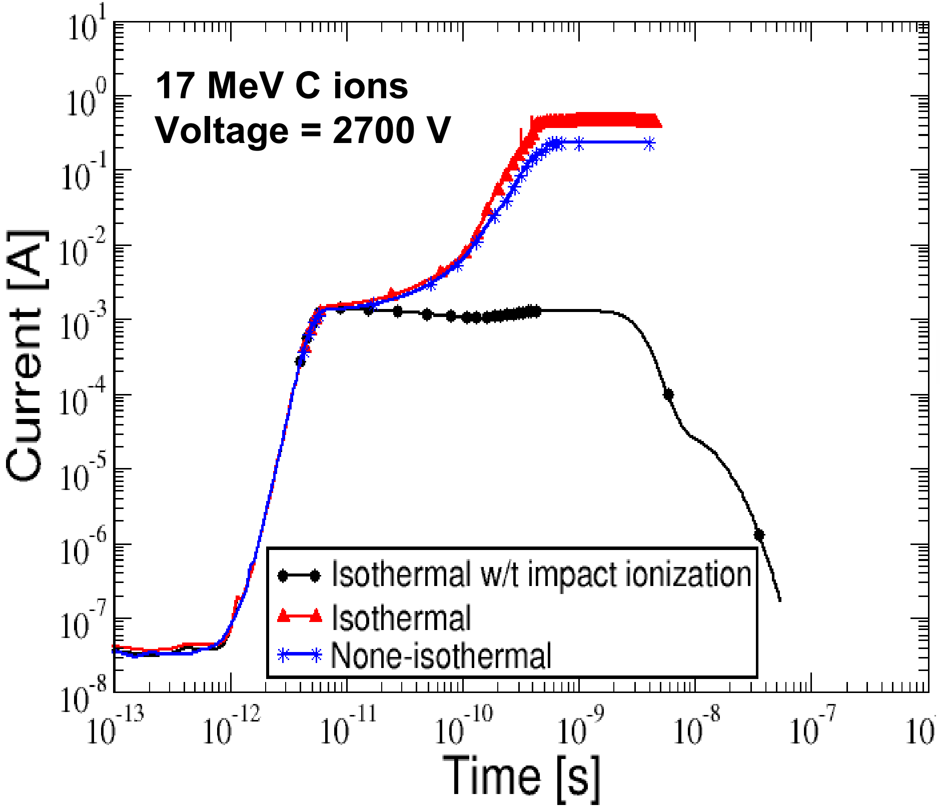
- **Most electrical properties of semiconductor devices are temperature dependent.**
  - **As temperature increases, lattice scattering increases resulting in mobility degradation.**
  - **Avalanche generated charge decreases as temperature increases because of the reduced mean free path.**
  - **Effective intrinsic concentration increases as temperature increases.**

- **The device is thermally insulated around the edge of the device except one contact held at a constant temperature (300K).**

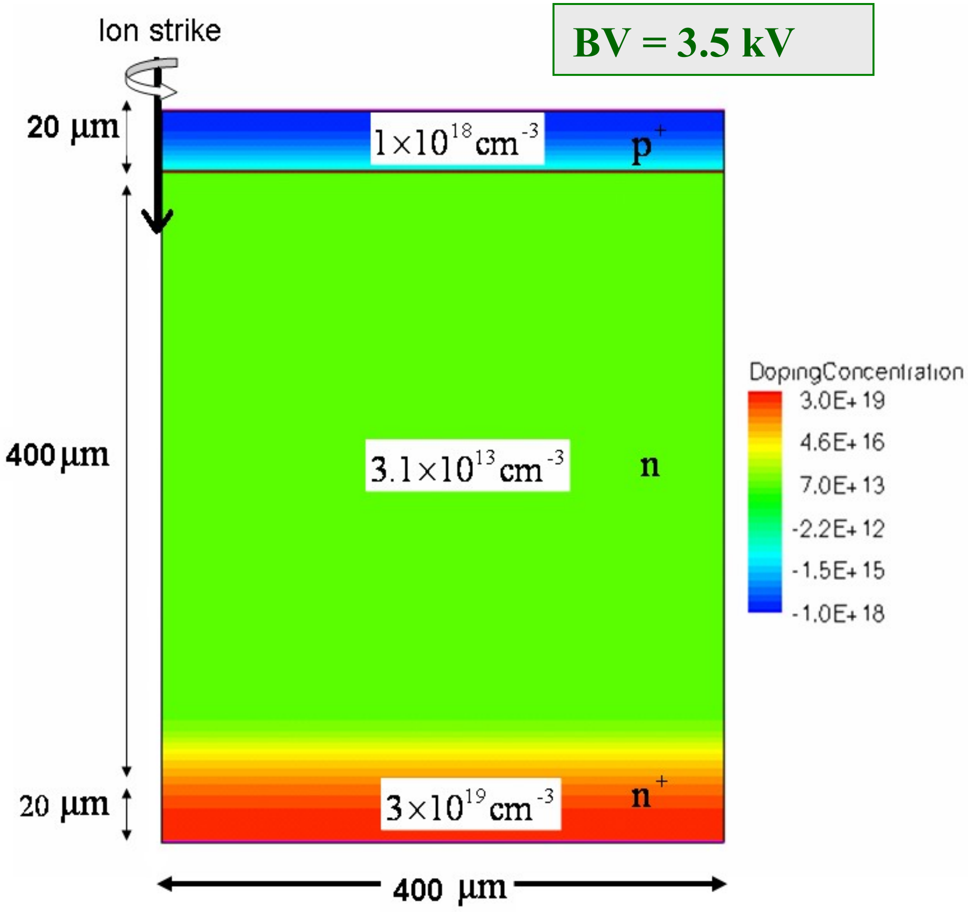
Simulations of SEB in Power diodes

- **DESSES-ISE** simulator is utilized to study SEB in power diodes with 2D axi-symmetrical geometry .
- The second peak is a result of avalanche multiplication process.
- The current is less in the non-isothermal simulation due to the decrease of impact ionization at high temperatures.

$(\mathrm{LET} = 4\ \mathrm{MeV.cm^2/mg})$



BV = 3.5 kV

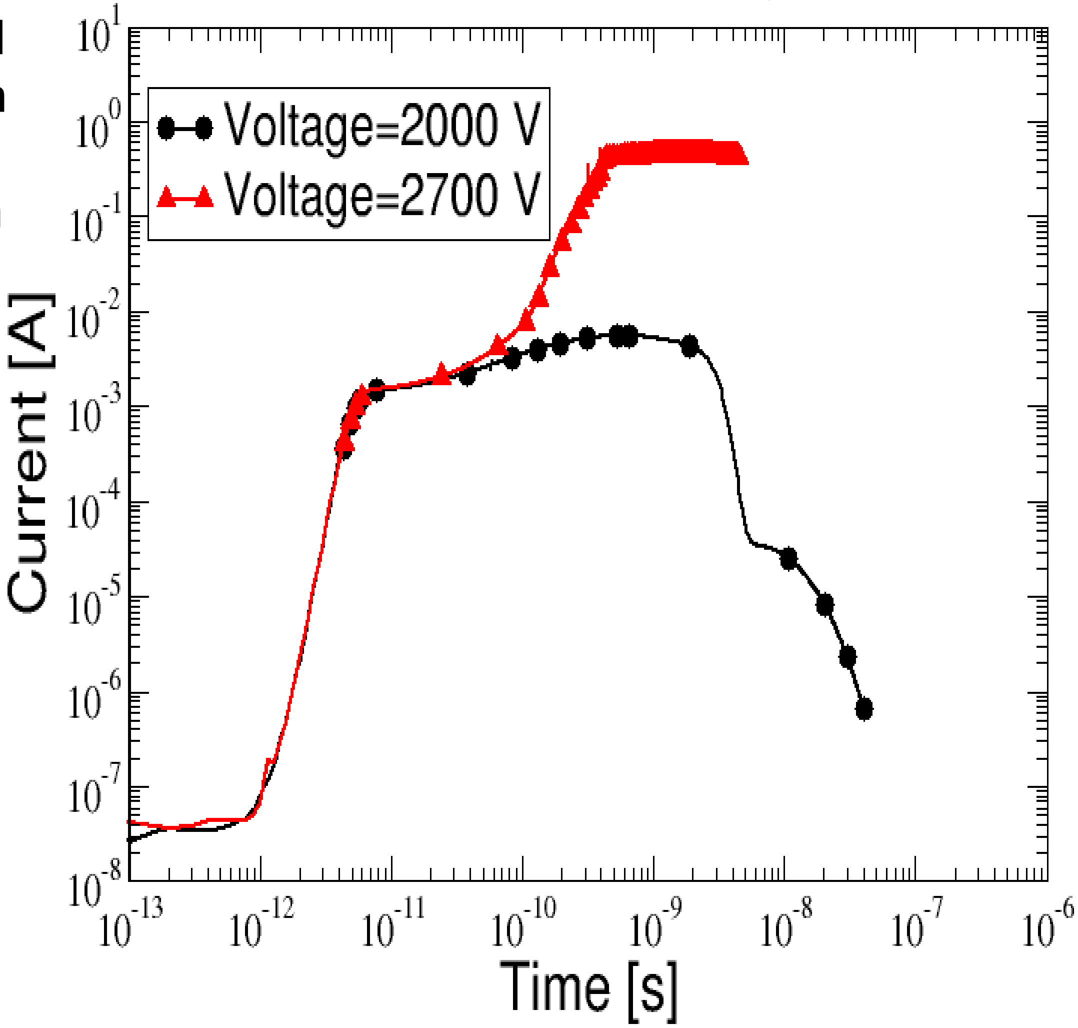


Isothermal simulations

- Sub-avalanching event is shown for the 2000 V case.
- Avalanching event is represented by the case of 2700 V where high current is observed due to the activation of the impact ionization model.
  - No actual failure occurs using isothermal simulations.
- With using non-isothermal simulations as will shown later, avalanche event will lead to thermal failure.

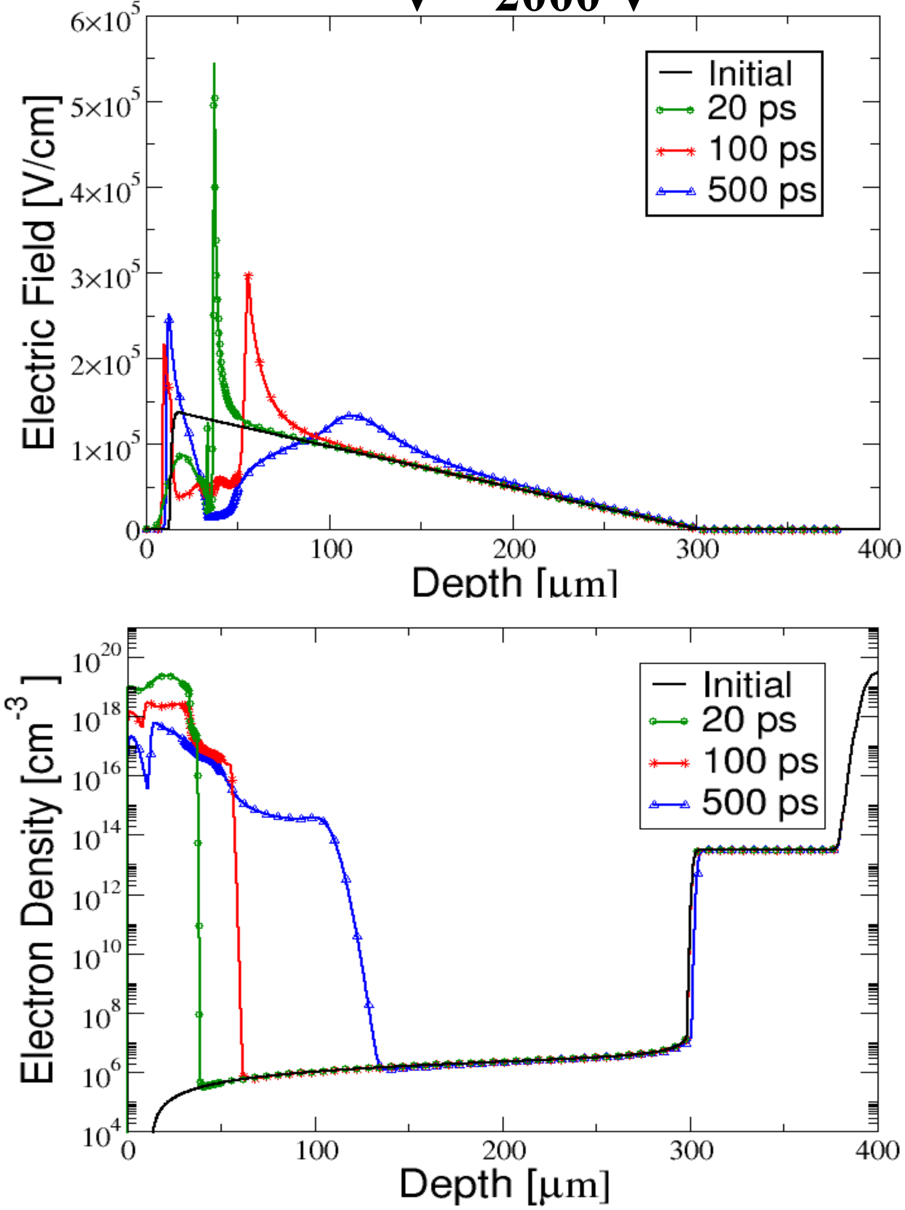
A 3.5 kV power diode is irradiated with 17 MeV C ions.

$$(\mathrm{LET} = 4\ \mathrm{MeV.cm^2 / mg})$$

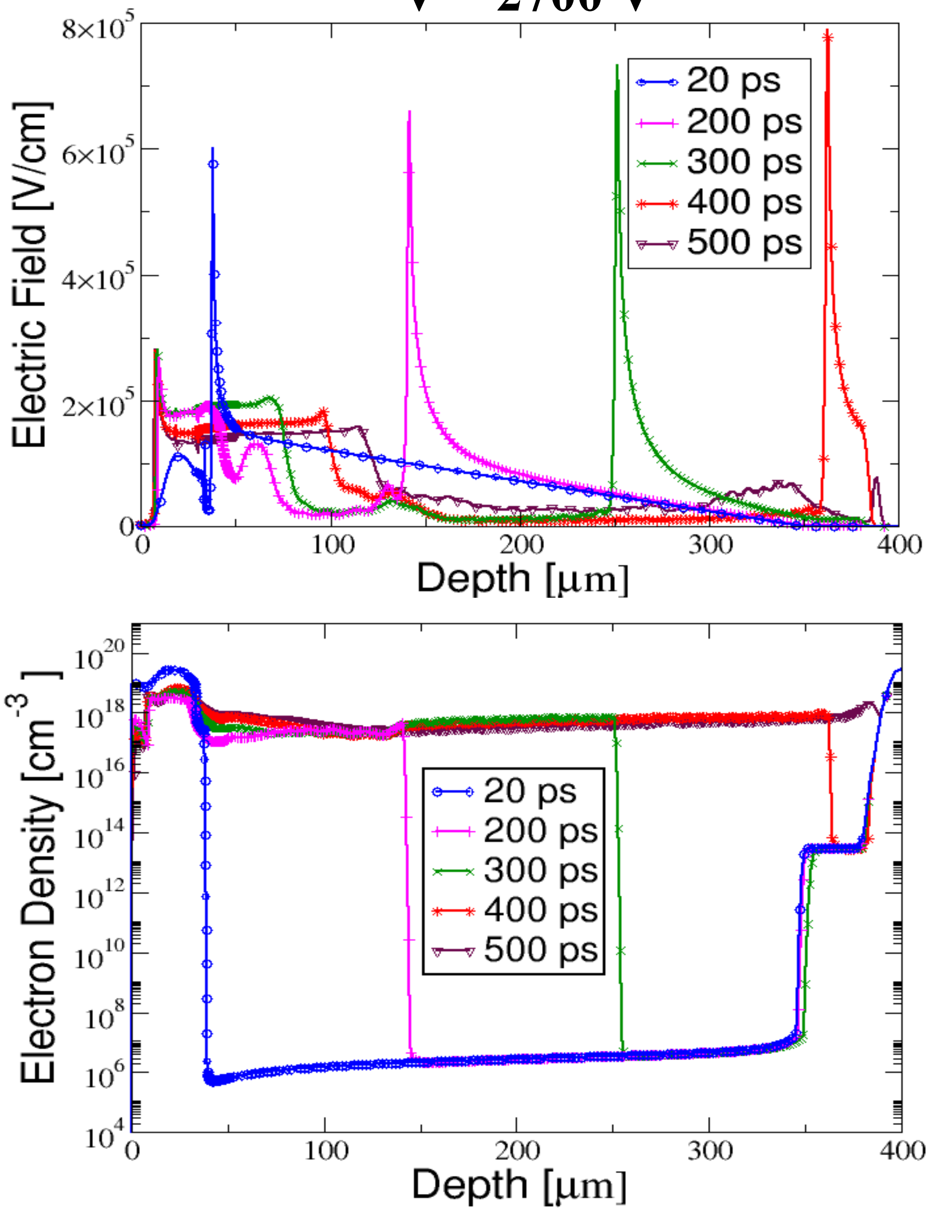


Spatial and temporal evolutions of the electric field and the electron density for different voltages

V = 2000 V



V = 2700 V



Spatial and temporal evolutions of the electric field and the electron density for different voltages

Sub-avalanching event (2000 V)

- With time, the electric field diminishes and the required electric field for triggering the avalanche multiplication can not be sustained.
- The electron density in this case can not support a current path between the anode and the cathode

Avalanching event (2700 V)

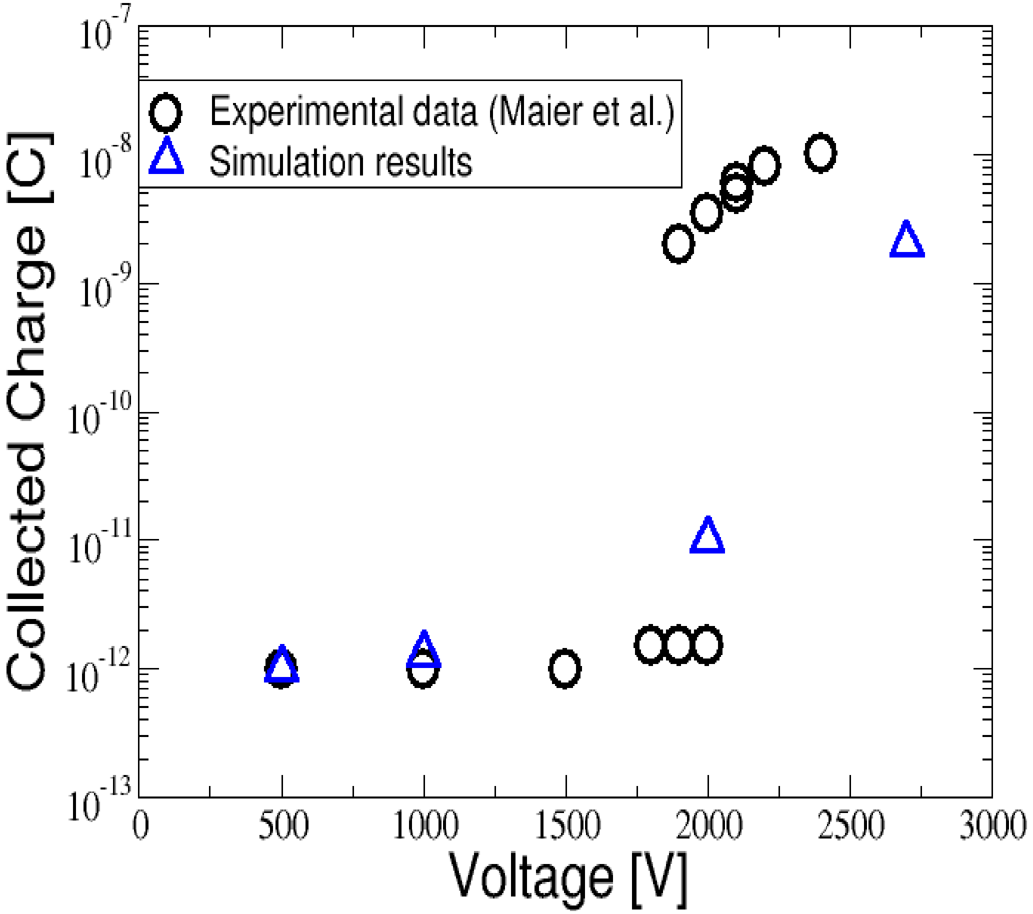
- Due to the initial higher electric field, the transient electric field is high enough to trigger the impact ionization process. As a result, the electric field peak moves throughout the device toward the anode contact.
- The broadening of the electron density in response to the field movement can produce a transient filament that shorts the device contacts where high charge will be collected.

Collected charge using isothermal simulations

- To reproduce the experimental results provided by Maier et al, we used the isothermal model since that measurement was non-destructive, which means no physical damage occurred

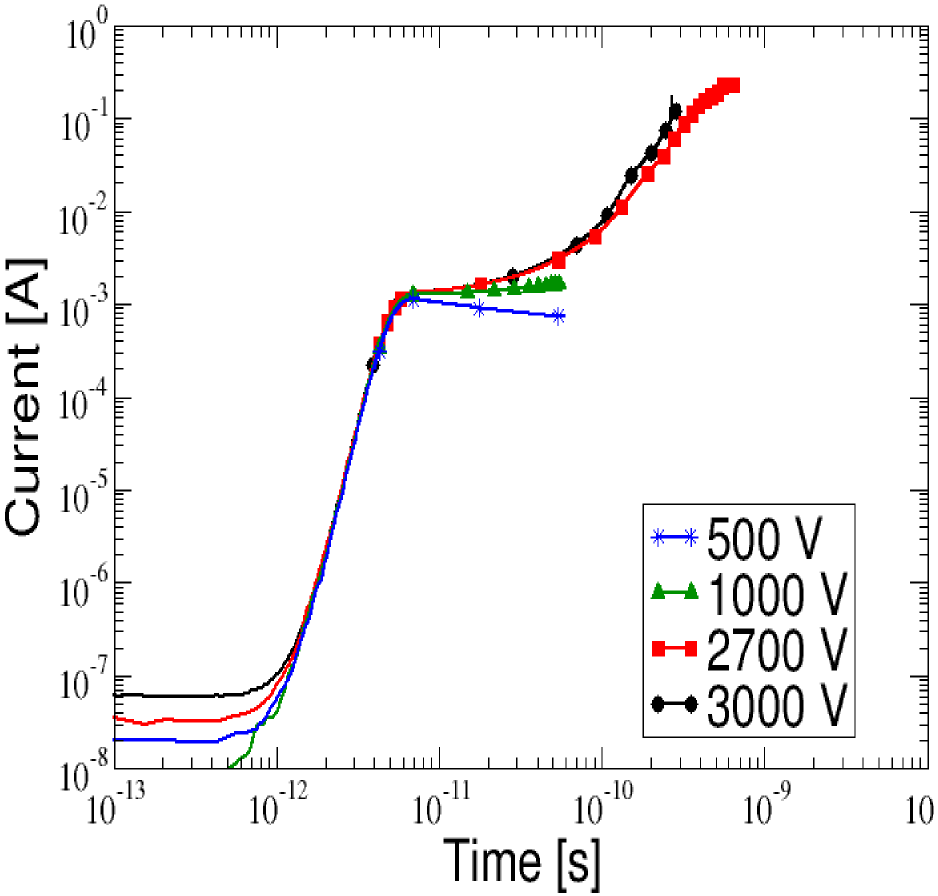
- Our simulation results for the 17 MeV C ion irradiation qualitatively agree with the experimental data.

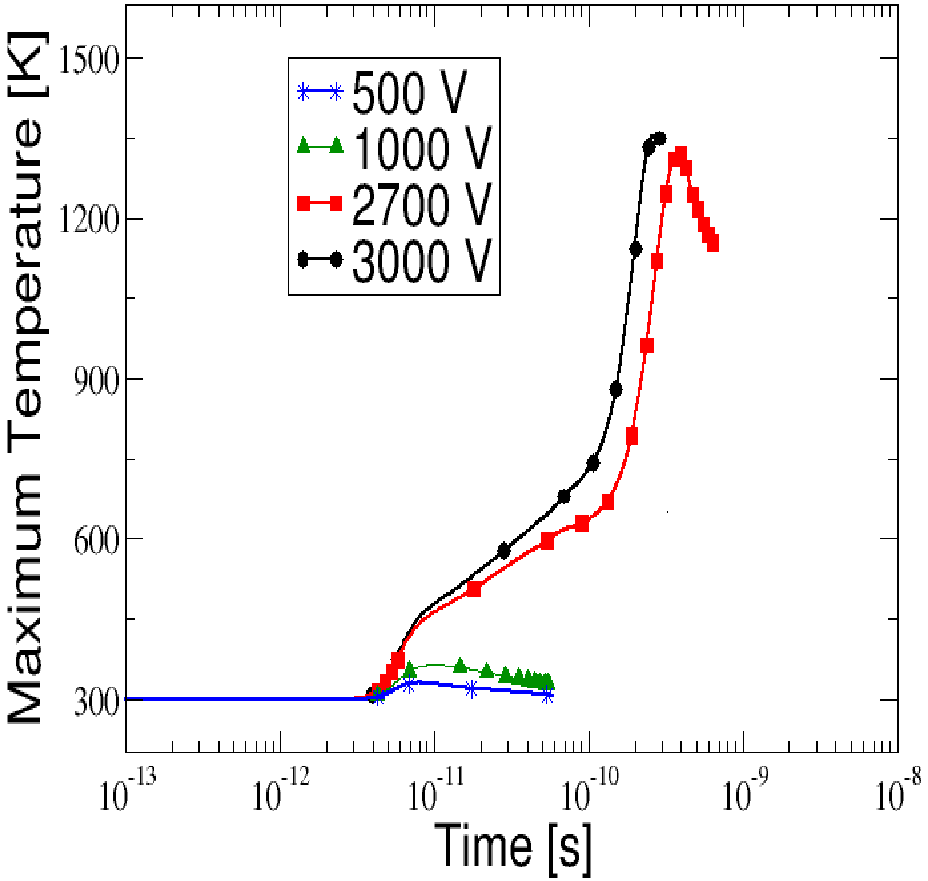
K. Maier et al. Nuclear instruments and methods In physics research B 146, 1998 (© 1998 Elsevier)



Non-isothermal simulations

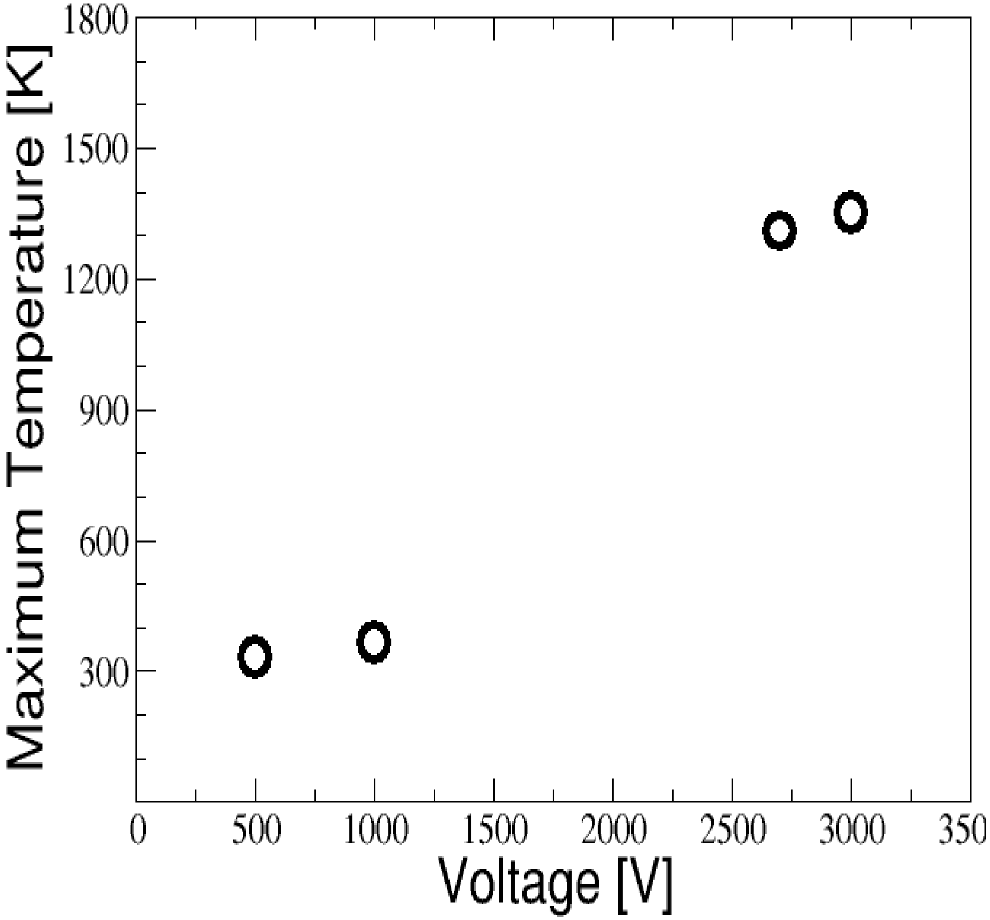
- 2700 V and 3000 V are identified as destructive events at which the lattice temperature reaches high values within the range of the melting temperatures for materials used in semiconductor fabrication, e.g., silicon and aluminum.
- For 500 V and 1000 V, the energy deposited by Joule heating was able to diffuse before heating the device, and the maximum temperature was only about 334 K.

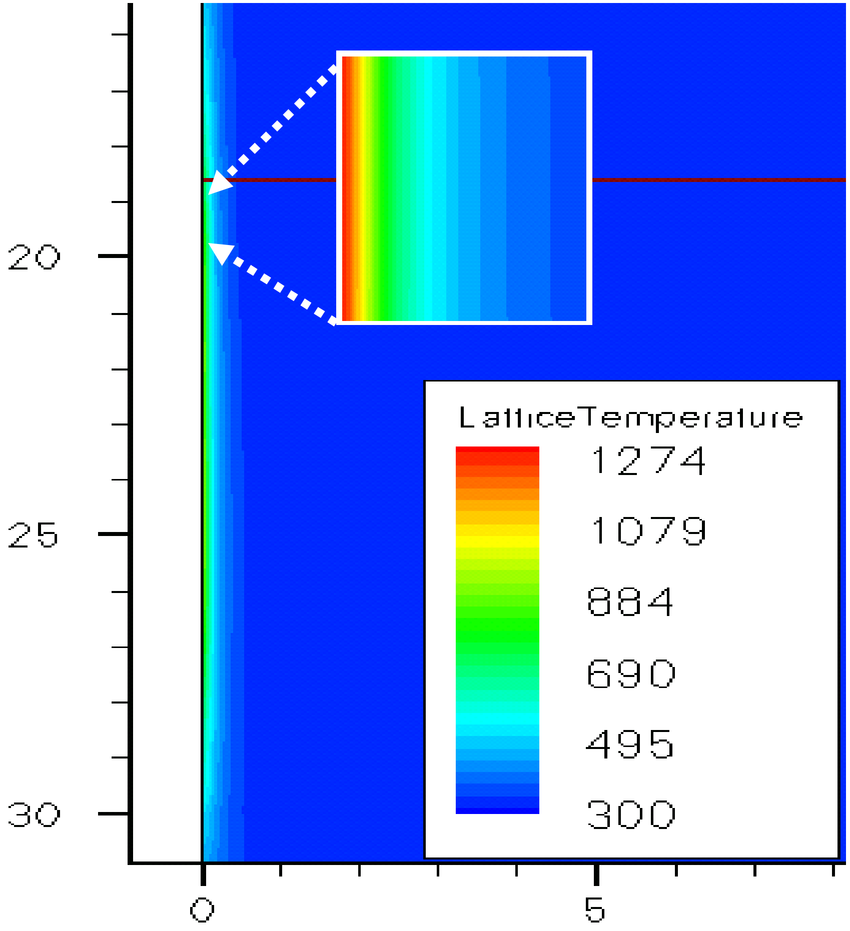




Maximum local temperature

- A local heat spot is produced near the junction as a result of an ion strike.
- This Joule heating generation is highly dependent on the applied voltage.





V = 2700 V, Time = 400 ps

Conclusions

- Collected charge obtained from experimental data was reproduced by isothermal simulations.

- Non-isothermal simulations take into account the local heat generation that leads to the increase of the lattice temperature.

- Non-isothermal simulations are able to produce the resultant destruction of SEB in power diodes, which is identified when the lattice temperature rises to high temperatures close to the melting temperature of silicon.

- The heat source is very localized along the ion strike near the junction.