Mesoplasma Formation and Thermal Destruction in 4H-SiC Power MOSFET Devices under Heavy Ion Bombardment

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Abstract: Investigation into mesoplasma formation from heavy ion strike in 4H-SiC power MOSFETs. Simulations involving the time evolution of several parameters have determined that the formation of a mesoplasma occurs deep within the epi of the device. Various physical parameters were investigated, and only thermal conductivity impacted mesoplasma formation.

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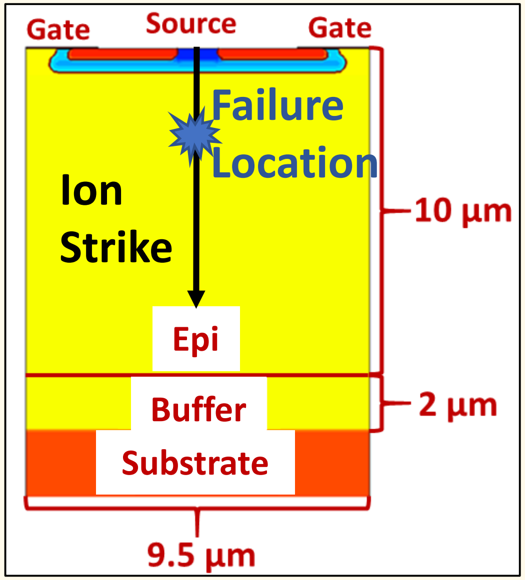
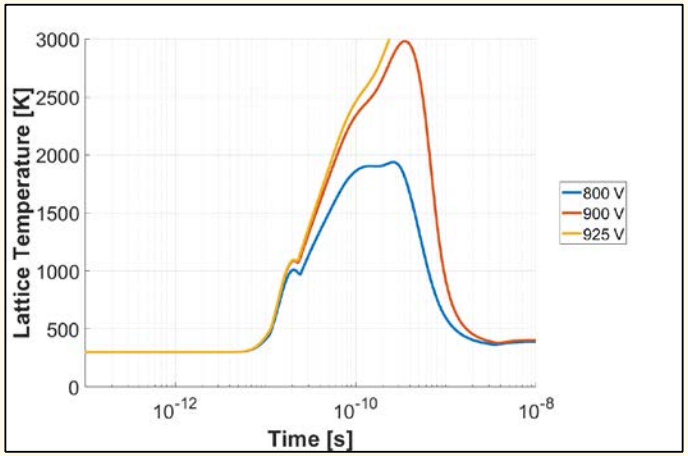
Introduction, Motivation & Investigation

- Commercial SiC power devices experience Single-Event Burnout (SEB) at half of rated blocking voltage
  - Failure from mesoplasma formation at epi/substrate interface
  - Adding a buffer layer improves SEB but still fails to reach rated blocking voltage
- Failure mechanism for buffer structure is not well understood





Simulated peak temperature of 1200 V rated buffer layer MOSFET

Investigation

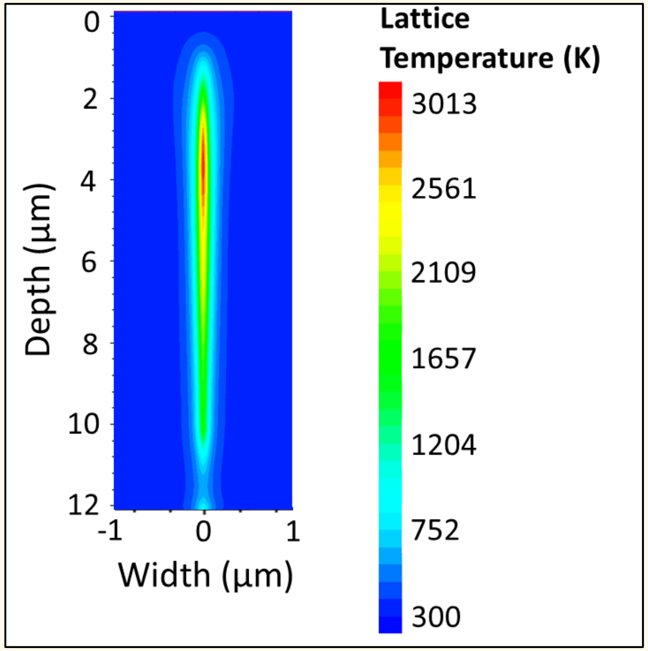
- Transient electro-thermal simulations performed
- Mesoplasma formation and thermal runaway identified as SEB mechanism
- Time Evolution of SEB Phenomenon explained
- Impact of key physical parameters explored

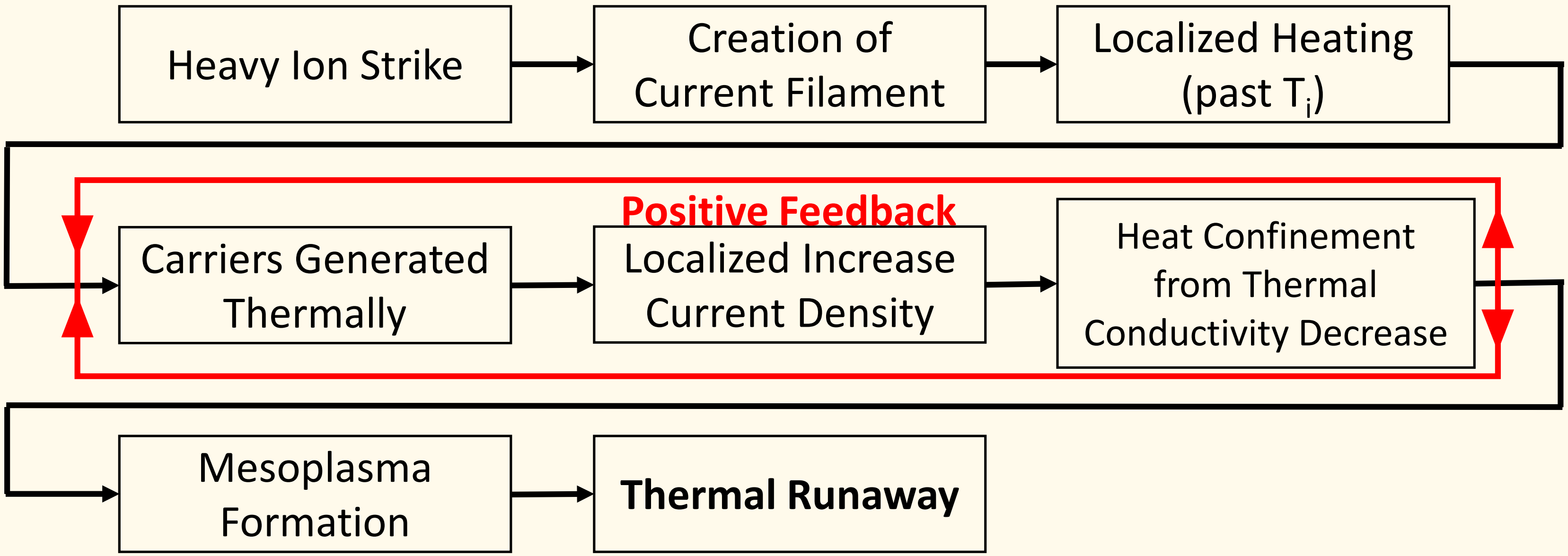
Mesoplasma Formation and Thermal Runaway

- Current filament can grow into mesoplasma
- Filament begins to be unstable at the intrinsic temperature (T_i)
  - Intrinsic carrier density equal to doping concentration

$$n_i(T) = \sqrt{N_C(T)N_V(T)}\,\exp\left(-\frac{E_g(T)}{2kT}\right)$$

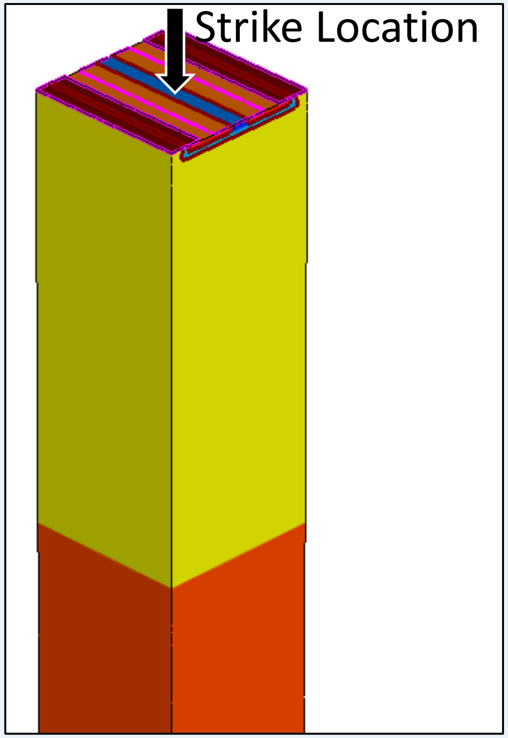
$$n_i(T_i) = \text{Doping Concentration}$$





Transient Electro-thermal Simulations

- Sentaurus used for full 3-D transient electro-thermal simulations
- Modeled 1200 V buffer layer MOSFET
- Accurate simulation requires temperature-dependent models
- Ion strike at center of P^+ region under source contact
- Failure declared at 3000 K (decomposition temperature of SiC)



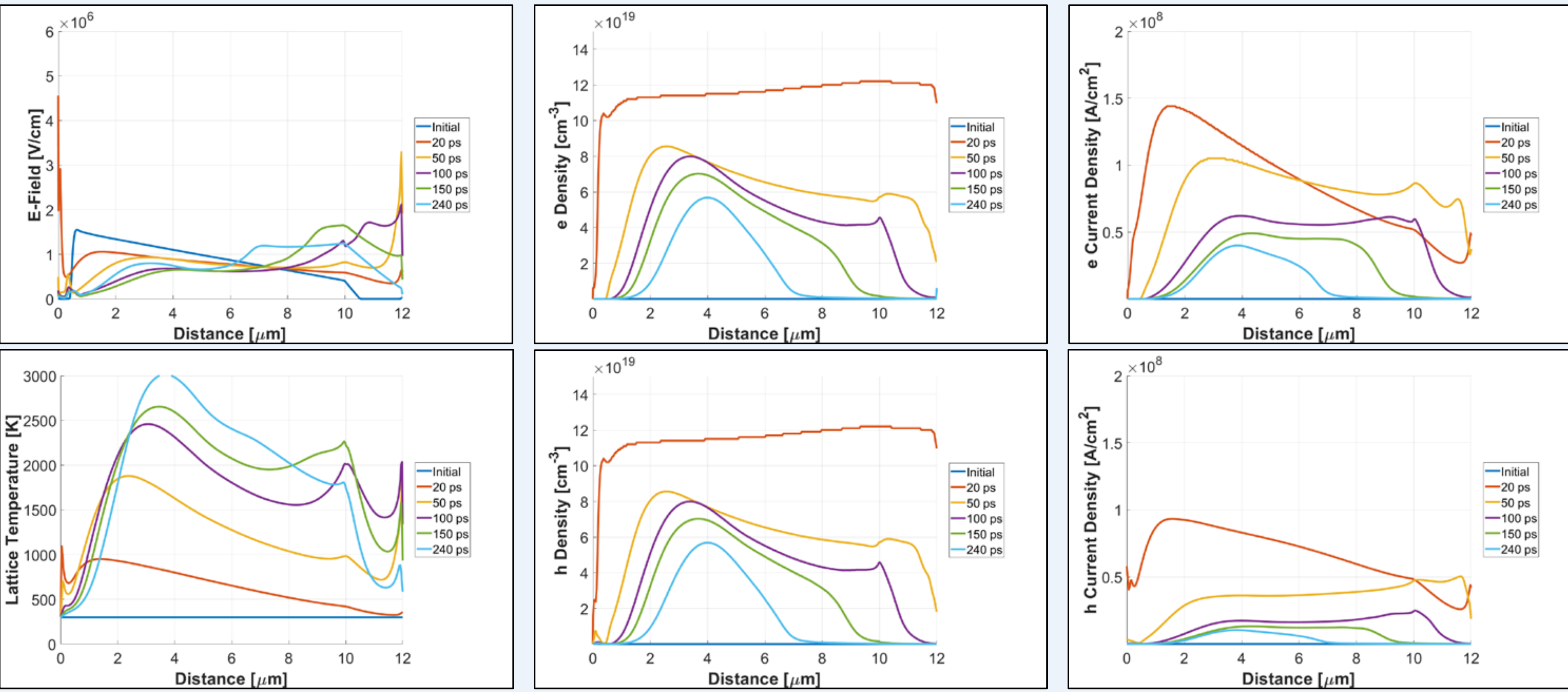
3-D model of MOSFET

Parameter	Temperature Range (K)		Equations
	Min	Max	
Thermal Conductivity	300	2300	$\kappa = {}^{611}/_{(T-115)}$
Lattice Heat Capacity	300	2700	$C_L = cv + cv_bT + cv_cT^2 + cv_dT^3$
Bandgap	300	700	$E_g(T) = E_g(0) - {}^{\alpha T^2}/_{(T+\beta)}$
Impact Ionization	300	473	$\alpha(F) = a\big(1 + c(T -$

Time Evolution of SEB Phenomenon

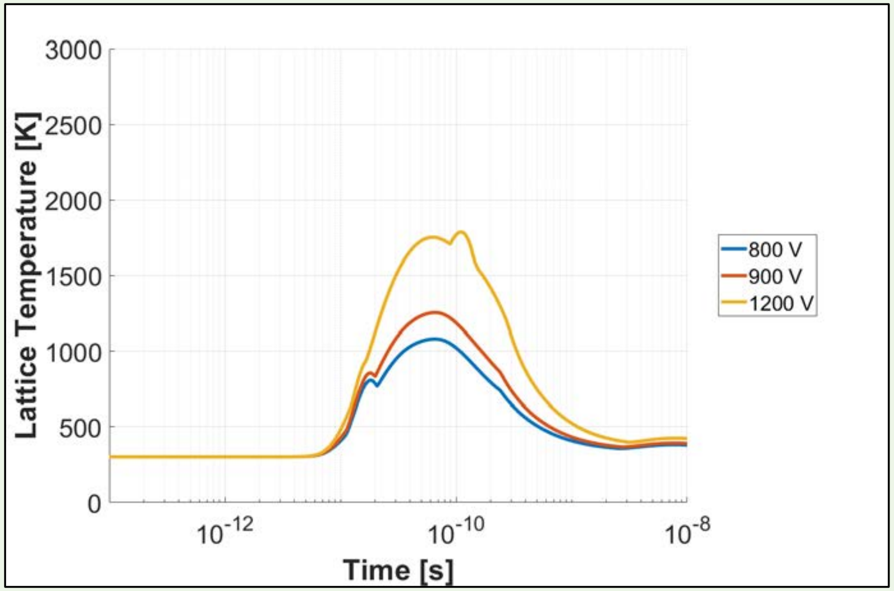
- High e-h density from heavy ion strike (> 1×10^{20} cm^{-3})
- Clustering of e-h pairs at 3.8 μm due to thermally generated carriers
  - Significant localized heating at this location due to Joule heating
  - 3000 K is reached by 240 ps

Reverse-biased at 925 V



Key Physical Parameters

- Determination of physical parameter that controls mesoplasma formation
  - Mobility, lifetime, saturation velocity, and thermal conductivity
- Thermal conductivity is the ***only*** parameter that had ***significant*** impact on mesoplasma formation
  - SEB occurrence increased to more than 1200 V when thermal conductivity kept at room temperature value
    - 12x higher than its value at 2500 K



Simulated peak temperature of 1200 V rated buffer layer MOSFET with thermal conductivity at room temperature value

Summary

- Investigated failure mechanism for 1200 V buffer layer MOSFET
  - ➢ Time evolution of several key parameters
- Thermal destruction of the device due to mesoplasma formation
  - ➢ Thermally generated carriers deep within the epi (~4 μm from source)
  - ➢ Contrast to commercial device failure from mesoplasma at epi/substrate
- Identified thermal conductivity as the most important physical parameter
  - ➢ SiC room temperature thermal conductivity value suppresses the mesoplasma formation

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