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Thermo-Mechanical Simulations of SiC transistor

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Aim of the work

Develop 3D thermo-mechanical fatigue simulation method for lifetime prediction of SiC transistor using External Strain parameter for nonlinear elastic material

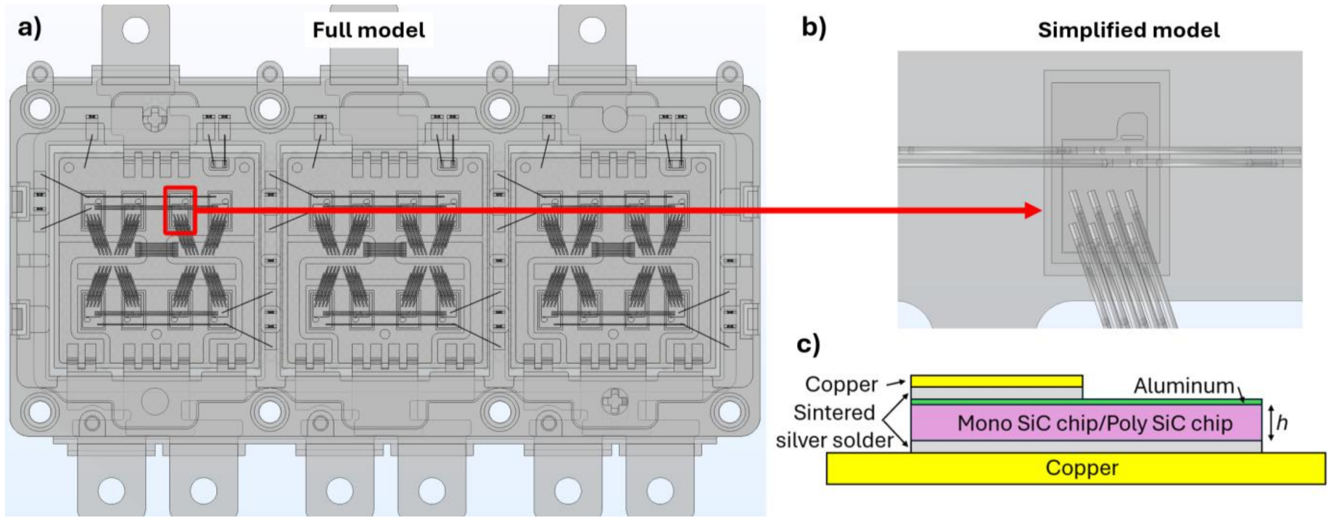
AVAILABLE INPUT DATA

- Simplified geometry and layer structure of the SiC transistor
- Power cycling test (PCT) data for 6 operating cases
- Material parameters from literature and COMSOL library

REQUIRED STEPS

- To calibrated 3D model according to measured PCT
- Use Domain ODEs and DAEs to calculate the time-dependent External Strain tensors and the accumulated density of inelastic deformation energy.
- To calculate cycles to failure using the Morrow model
- Verify the simulation method on a real application

Simplified 3D model and data from PCT



PCT case	ΔT [K]	*CTF
1	65	976000
2	75	502000
3	85	277000
4	95	164000
5	105	97000
6	115	59000

t_{on} = 3 s; t_{off} = 7 s

T_{min} = 46 °C

***cycles to failure**

KEY POINTS

- Simplified 3D model only
- Initial configuration contains monocrystalline SiC chip
- Material parameters from literature and COMSOL library

QUESTIONS

- Where is the highest mechanical stress caused by thermal expansion ?
- How will changing the substrate material affect the lifetime of a transistor ?

Simulation workflow

Thermal simulation

- Heat Transfer in Solids
- Heat source on chip surface
- Calibrated to measured ΔT

Mechanical simulation

- Solid Mechanics
- Temperature field as load
- Thermal expansion
- Nonlinear elastic material included

Fatigue simulation

- Accumulated strain energy density
- Lifetime evaluated using Morrow model
- CTF estimation

✓ **The simulation workflow combines thermal, mechanical and fatigue models for lifetime prediction**

Thermal simulation

KEY POINTS

- Stationary + Time-dependent study = faster time of thermal stabilization
- Thermal model calibrated to measured ΔT using convective heat flux
- Good agreement achieved for all PCT cases
- Last three impulses are stabilized

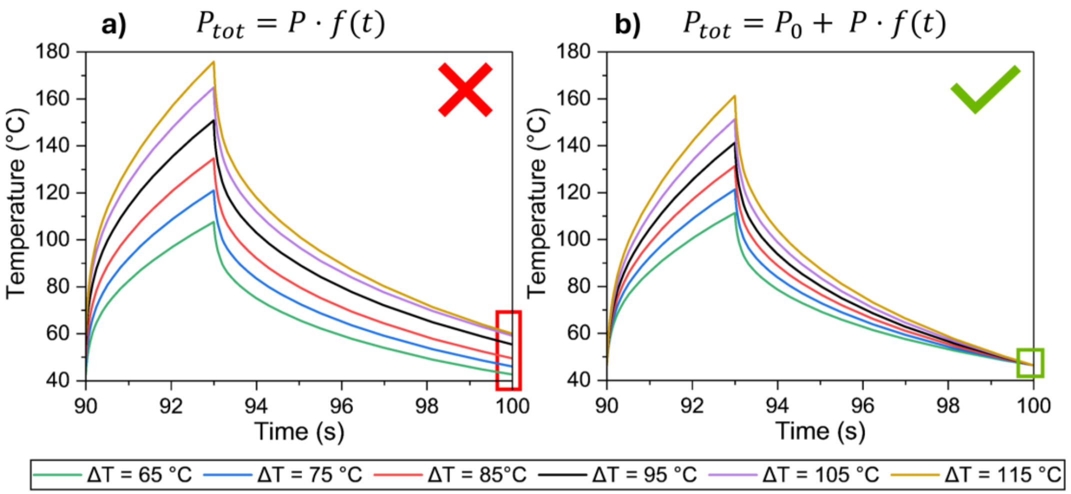
Total power **Power (transient)**

$$P_{tot} = P_0 + P_t \cdot f(t)$$

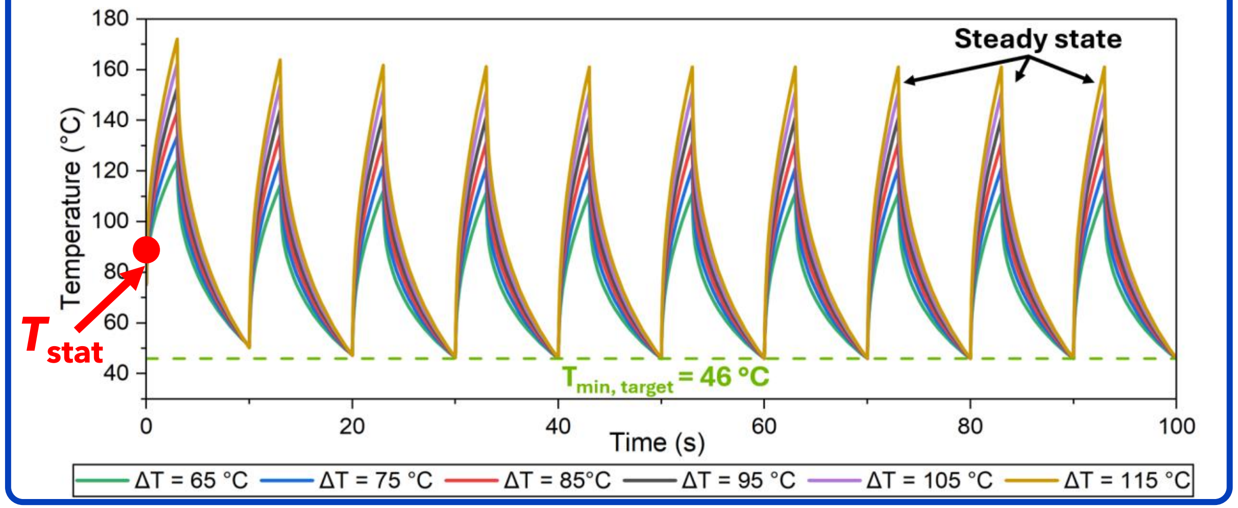
Compensation power **Function t_{on} and t_{off}**

Power (transient)

$$P_{stat} = \frac{t_{on}}{t_{on} + t_{off}} \cdot P_t$$



Stationary + Time-dependent thermal simulation

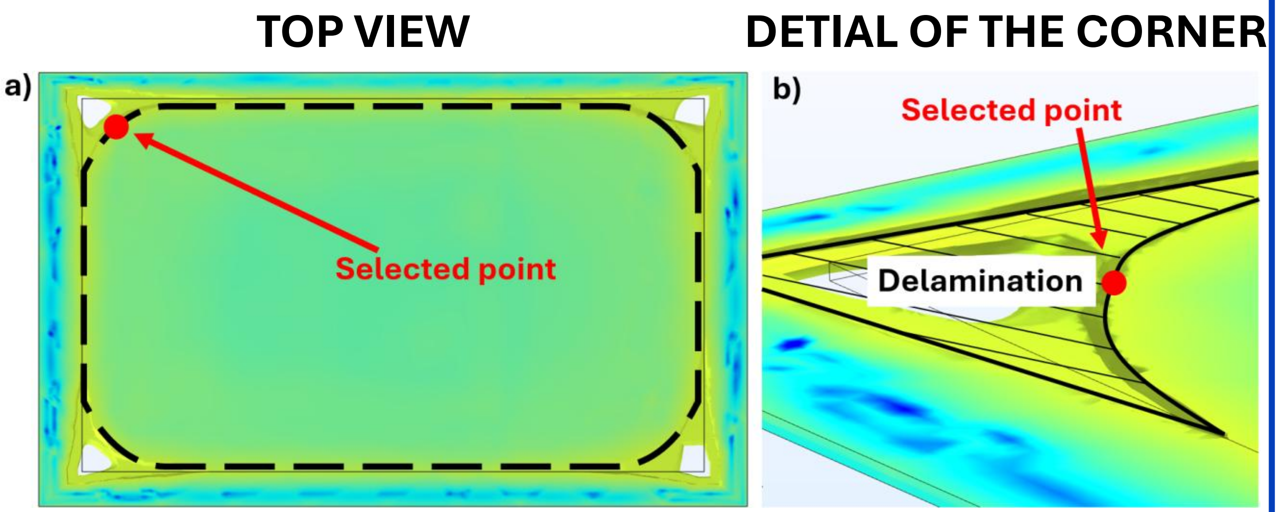


Mechanical simulation

KEY POINTS

- Highest stress concentration was observed in the solder corner
- Thermal expansion generates cyclic mechanical stress
- Nonlinear elastic material is included as symmetric External strain with tensors

Mechanical stress in sintered silver solder



Thermal history

$T(t)$

Imported from thermal simulation

Thermal expansion

$\alpha\ \Delta T$

Generates cyclic strain

Solid Mechanics analysis

σ

Computes mechanical stress

Domain ODEs and DAEs

$\dot{\varepsilon}_{ext,ij}$

Defines derivatives of internal strain variables

External strain in solder

ε_{ext}

A nonlinear term is added to the mechanics

Fatigue simulation

Fatigue evaluation

- ✓ ΔW_{accu} from the last stabilized cycle
- ✓ Material parameters W_f' and m are fitted to measured CTF

Last stabilized cycle → **Extract ΔW_{accu}** → **Fit W_f' and m to measured CTF** →

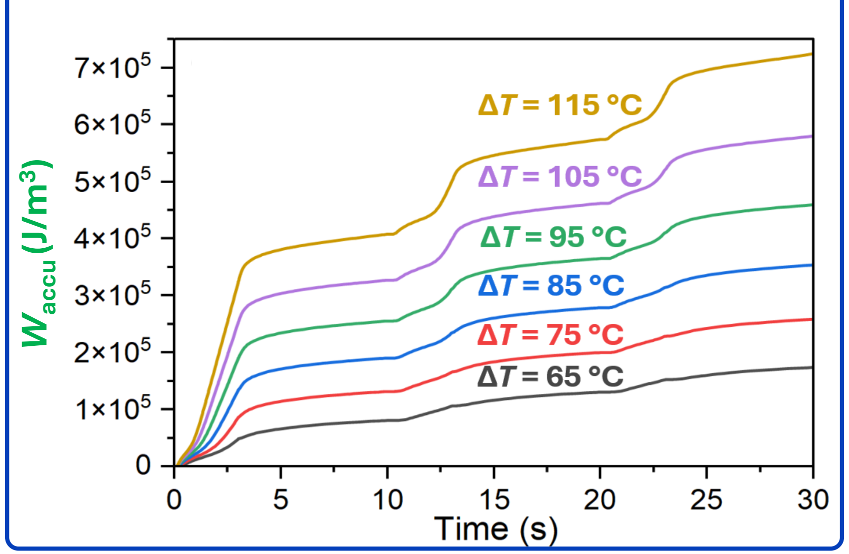
Morrow energy-based model

$$CTF = \frac{1}{2}\left(\frac{\Delta W_{\text{accu}}}{W_f'}\right)^{\frac{1}{-m}}$$

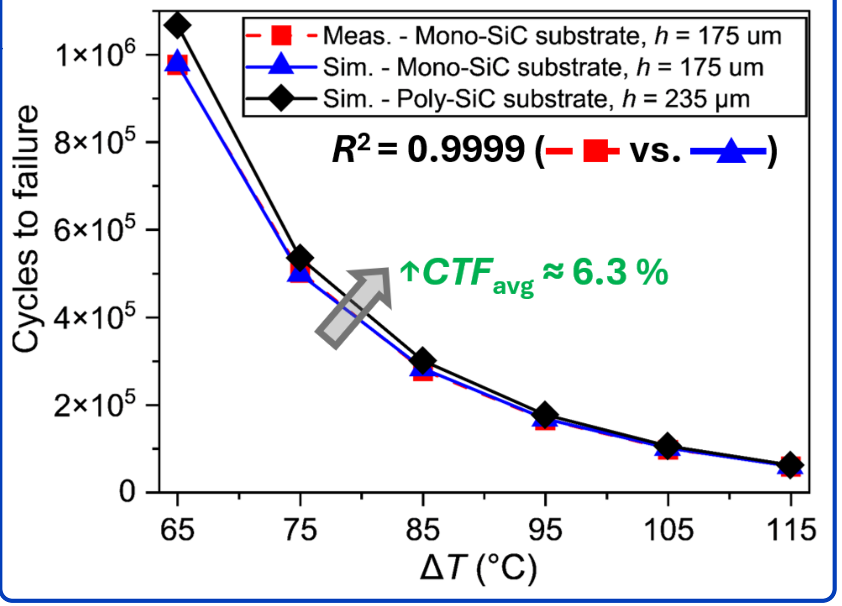
Calibrated model reproduces the measured CTF trend with high accuracy and change in substrate material showing improvement

Average CTF improvement ≈ 6.3 %

Accumulated inelastic strain energy density



Results of fitting and real application



Conclusion

RESULTS OF THE WORK

- A 3D thermo-mechanical fatigue simulation method was developed
- The model reproduces the decreasing CTF trend with increasing ΔT with high accuracy
- The method was verified through simulation analysis of the change of the substrate material
- Simulations suggest that by changing the substrate material to polycrystalline, an average increase in lifetime of 6.3 % will be achieved

Thank you for your attention

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FASTLANE

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Developed simulation method can be used for lifetime prediction and optimization for SiC transistor with sintered silver solder