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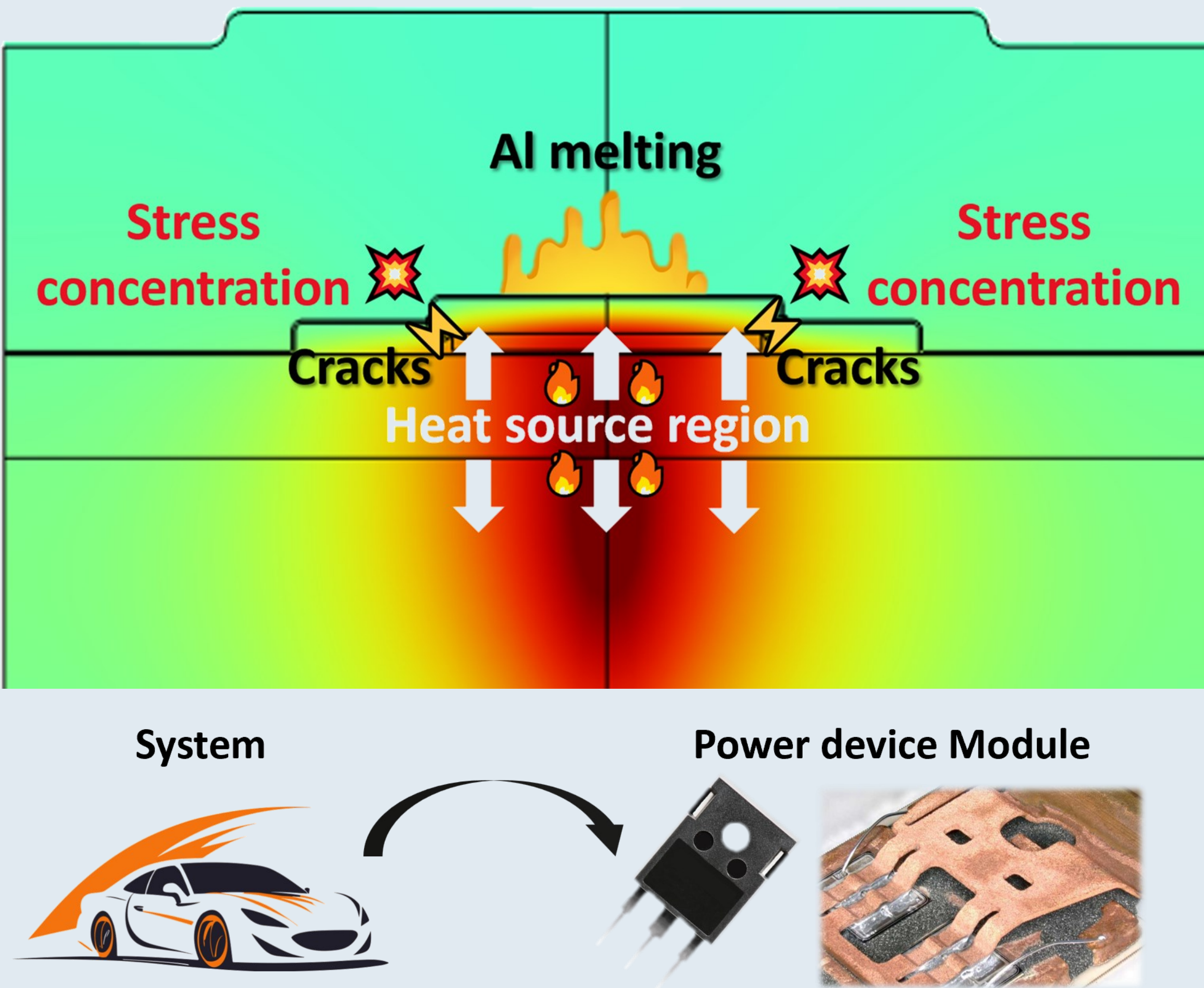
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Thermomechanical Simulation of SiC MOSFETs Under Harsh Short-Circuit Stress: A 2D Multiphysics Damage and Failure Analysis

Semiconductor power modules are essential to power systems but suffer damage over time due to harsh thermal and mechanical stresses. While damage is traditionally studied experimentally via short-circuit tests, our alternative approach uses a full transient 2D Multiphysics model for more comprehensive analysis.

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Introduction & Goals

A coupled 2D electrothermal-elastoplastic transient model of a planar-gate 4H-SiC vertical MOSFET (1.2 kV - 80 mΩ) was developed to simulate short-circuit stress ($V_{DS} = 600$ V, $V_{GS} = 20$ V, and $T = 300$ - 1500 K). These devices are essential for high-voltage, temperature, and frequency applications, where thermal and mechanical robustness is critical. This study identifies failure thresholds in regions exposed to heat and mechanical stress, particularly the SiO₂-ILD and Al-metallization, under harsh operating conditions.

Simulation results reveal key degradation mechanisms, helping improve the design of more robust chips and enabling faster, more reliable protection for next-generation smart gate drivers. The model captures SiO₂ fracture and Al phase change, identifying critical time and energy thresholds for failure, clear markers of irreversible damage under high-power switching. These insights are vital for predictive analysis and high-reliability power semiconductor design.

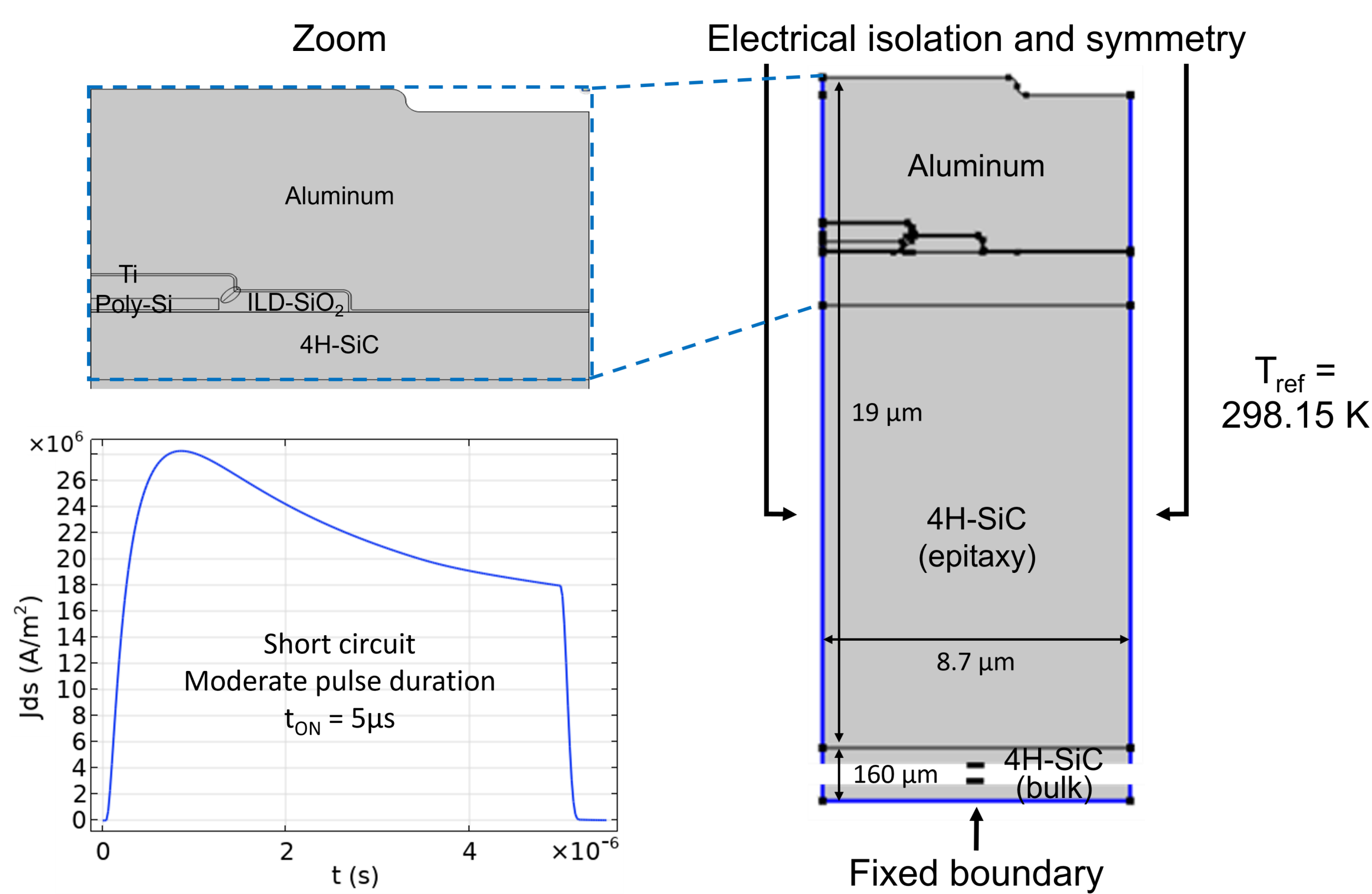


Figure 1: Model geometry, materials, and conditions

Methodology

- Coupled Thermal Modeling:** The model couples Joule heating from semiconductor physics with heat transfer, including Al phase change process. A cooling phase follows peak heating to complete the thermal cycle.
- Mechanical Simulation and Damage Modeling:** The mechanical behavior is simulated using the mapped thermal field as input, incorporating elastoplastic material laws. SiO₂-ILD damage is predicted based on the Rankine criterion.
- Fatigue Tracking:** Repetitive thermomechanical cycling tracks cumulative stress and crack growth over successive power pulses.

Main results

- Thermal and mechanical stress concentrations as well as damage paths matched experimental observations.
- Al melting at 3.2 µs and ILD cracking at 3.0 µs aligned with tests, just beyond the 2.5 µs damage-free limit.
- Early cycles showed a linear relationship between crack length, damaged area, and global elastic energy.

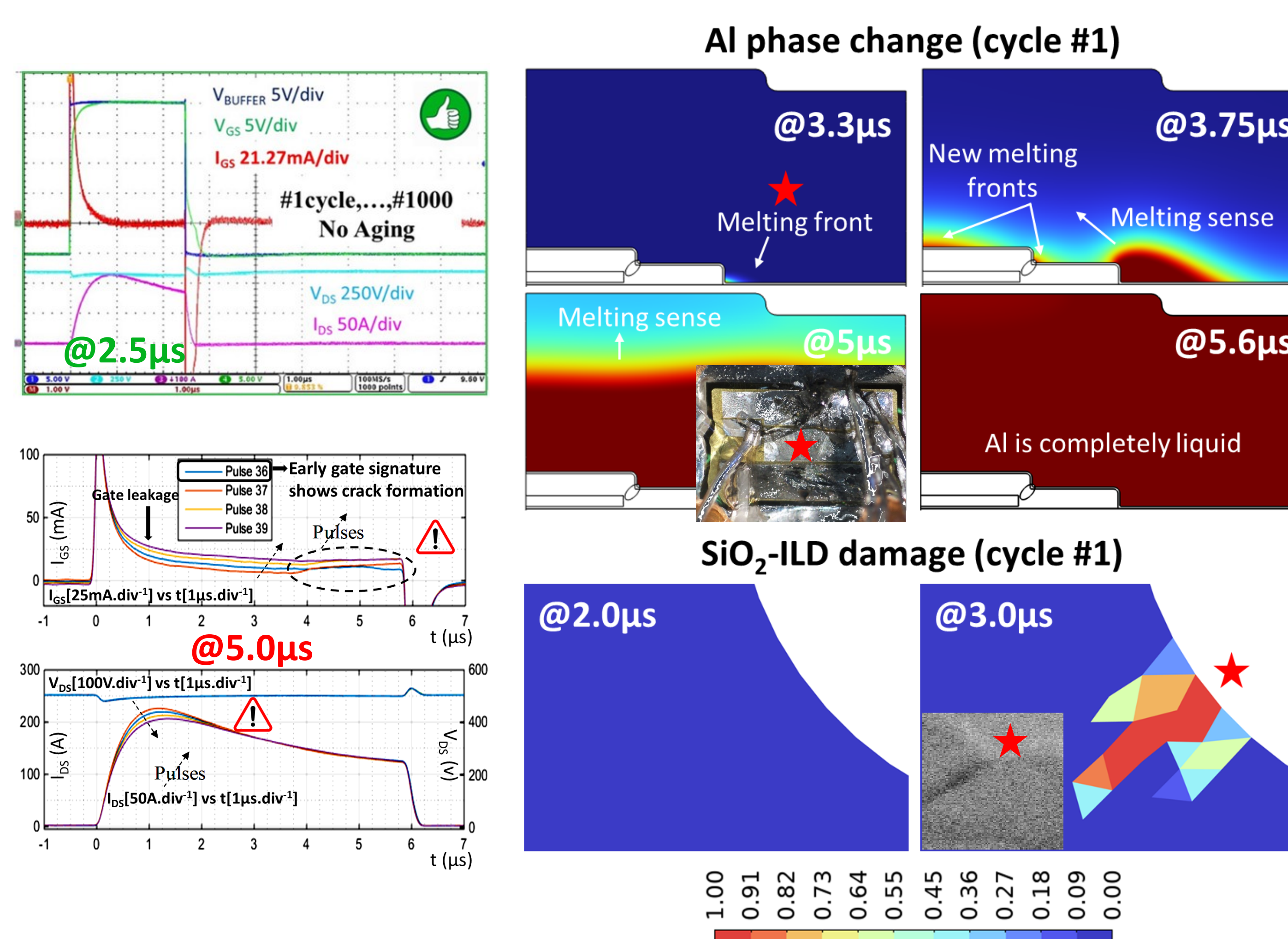


Figure 2: Al melting and SiO₂-ILD fracture (single pulse)

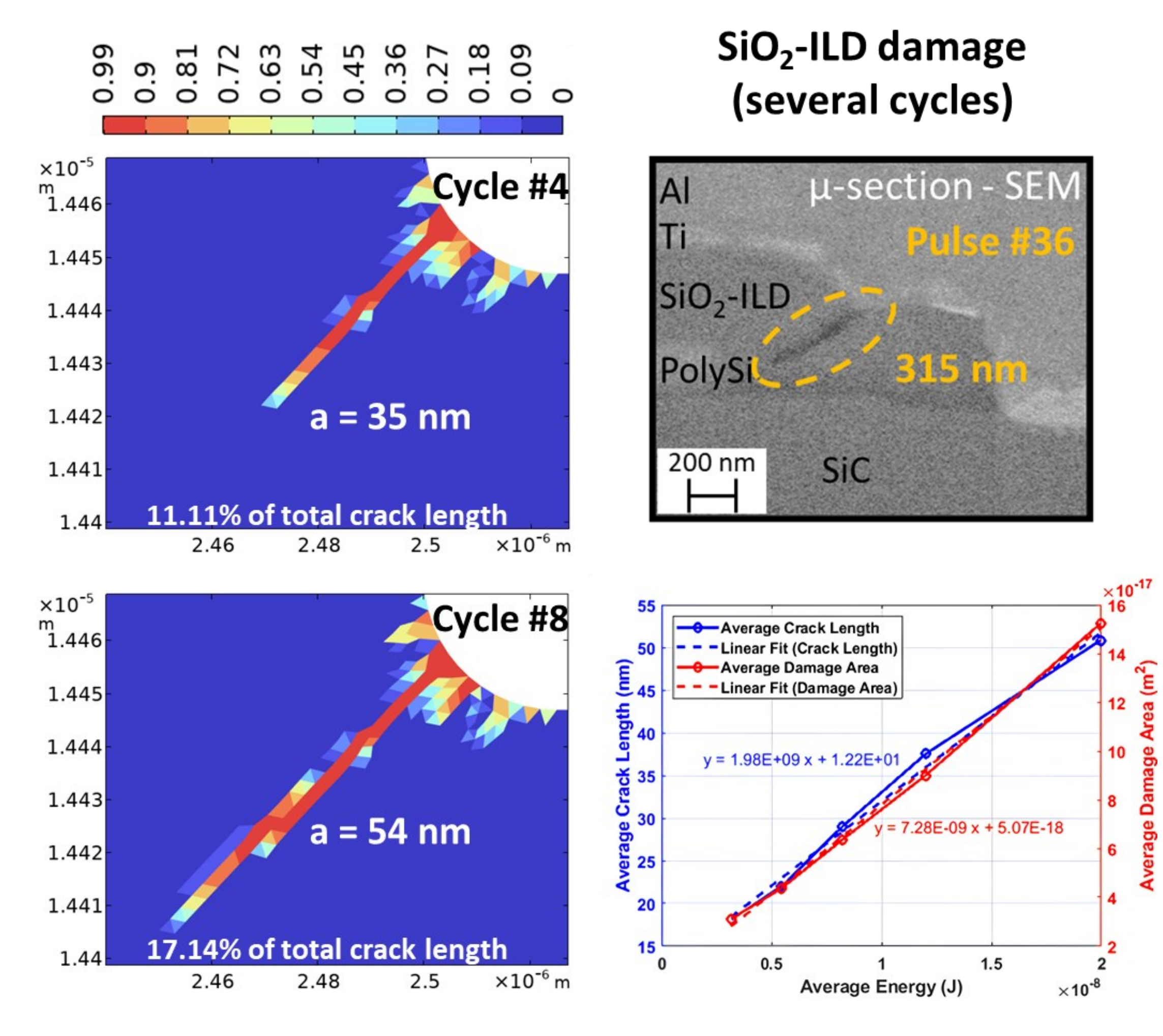


Figure 3: SiO₂-ILD damage growth (several pulses)

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Project Recognitions:

- Best Paper Award - MIXDES 2023 Conference, Kraków, Poland
- Best Paper Award - ESREF 2024 Conference, Toulouse, France
- Invited Paper - IEEE IRPS 2024 Conference, Dallas, USA