Using Advanced Manufacturing Techniques for Thermal Management of High-Reliability Power Components

Jens Eltze

Apex Microtechnology

IMPORTANT DISCLAIMER

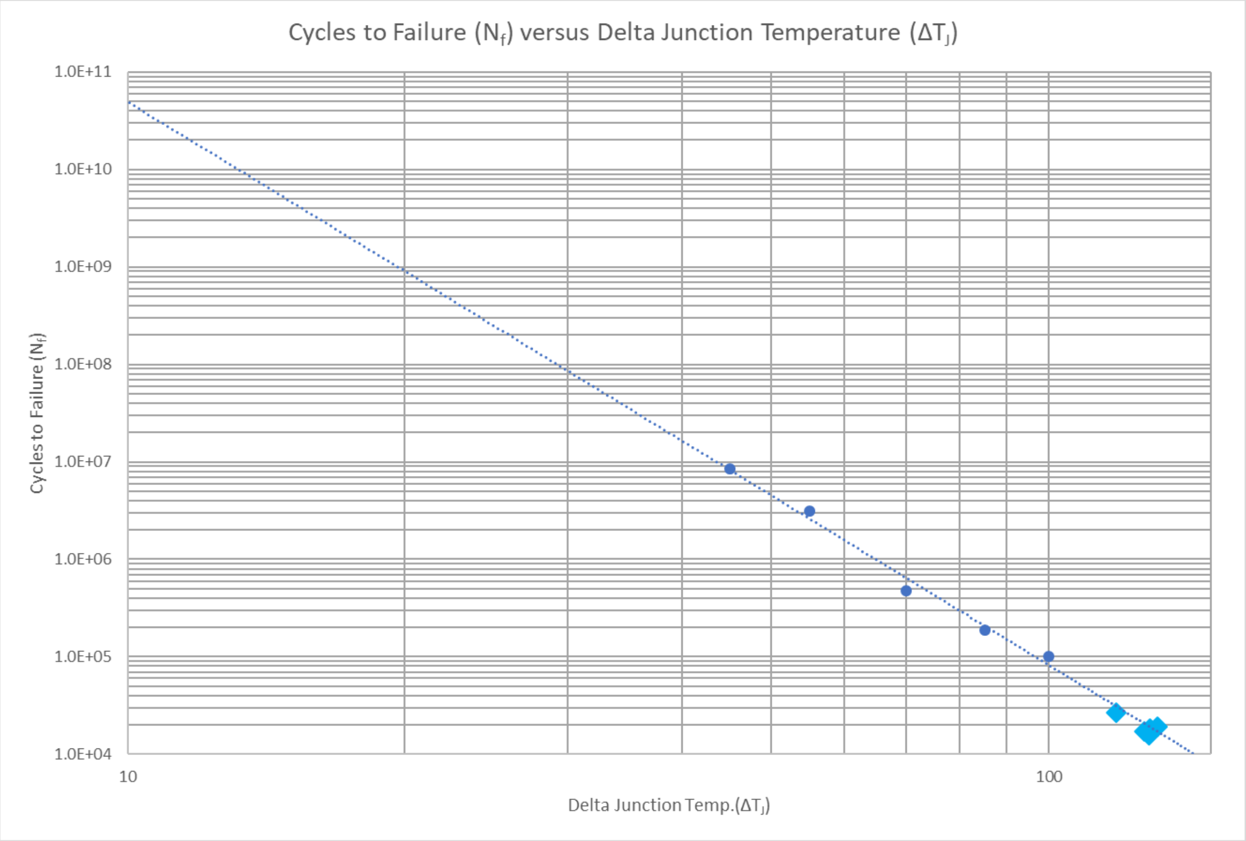
- The numbers in the presentation are not fully accurate due to confidentiality agreements, but represent the results of studies done for designs of high reliability modules
- The presentation is intended as a showcase how to achieve high reliability. As each module is unique, each design requires its own technical approaches
- Special thank you to Dr. Fang Luo, Riya Paul, Hongwu Peng and Amol Deshpande from University of Arkansas for providing a technical portion of the subsequent presentation
- Thank you to Heraeus for approving the use of proprietary graphs and information in this presentation

Why is Thermal Management Important?

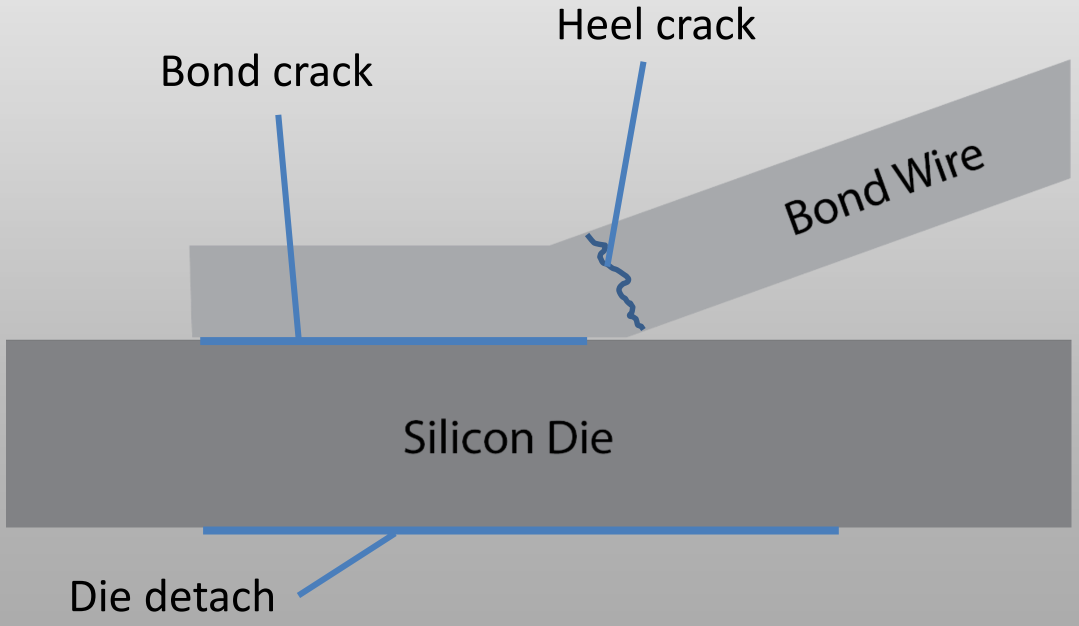
- SiC devices can withstand temperatures beyond 200°C. Why do I need to worry about thermal management then?
- High reliability = operation with very low failure rate
- Most failures are not due to the temperature itself, but due to thermal stress caused by cyclical change in temperature

Typical Failure Mechanisms for Temperature Changes

- Typical lifetime graph (Al Wire Bond)



- Most common failures mode: interconnect failures

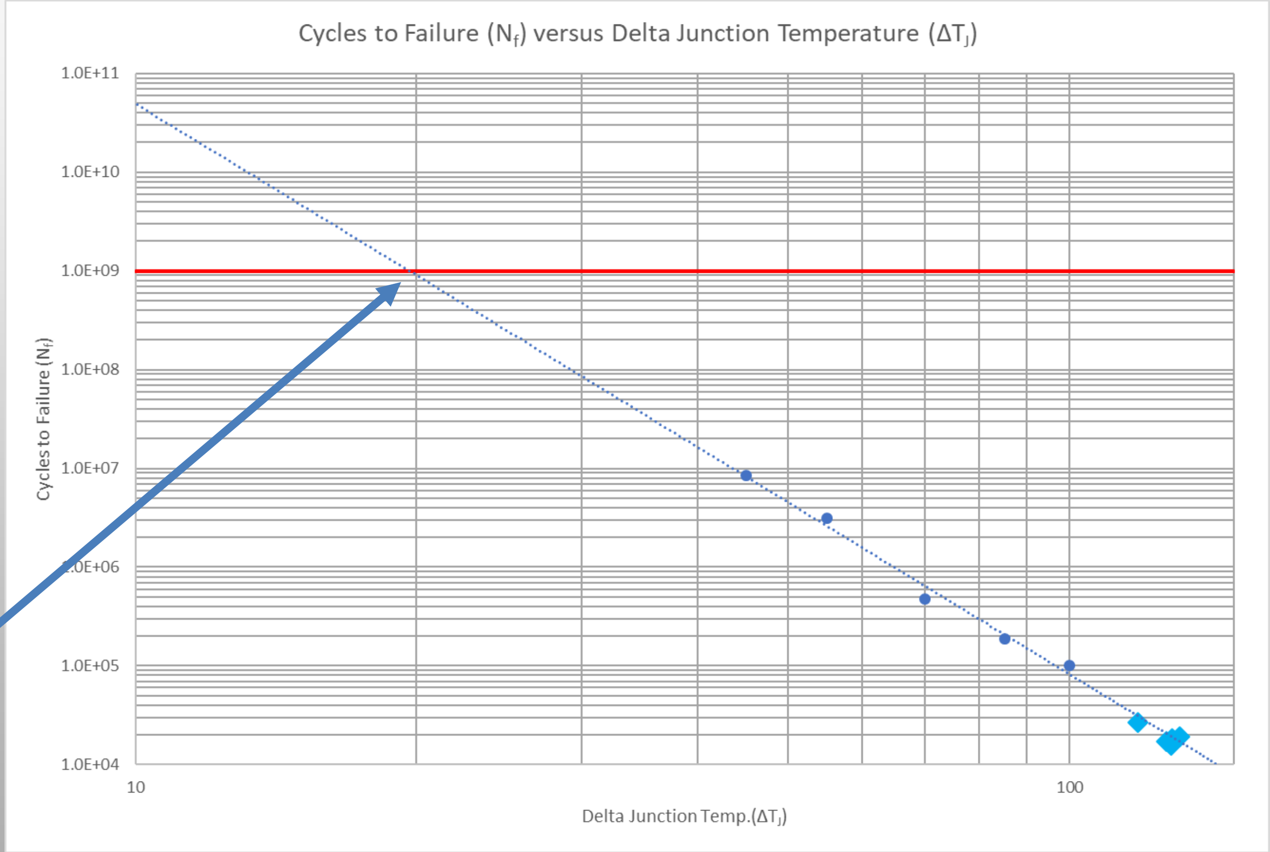


Case Study: Robotic Manufacturing

- Robotic precision positioning system
  - – 24/7 operation
  - – 20 ms positioning pulse @ 100 Hz
    - 300 V DC, 40 A_{PEAK}
  - – 8 Hz operation
  - – 4 year expected life

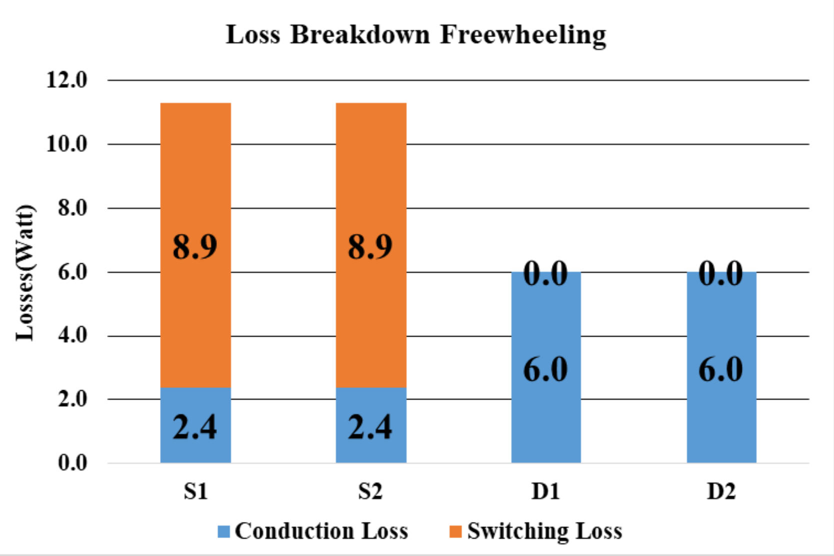
→ 1 billion power cycles over lifetime

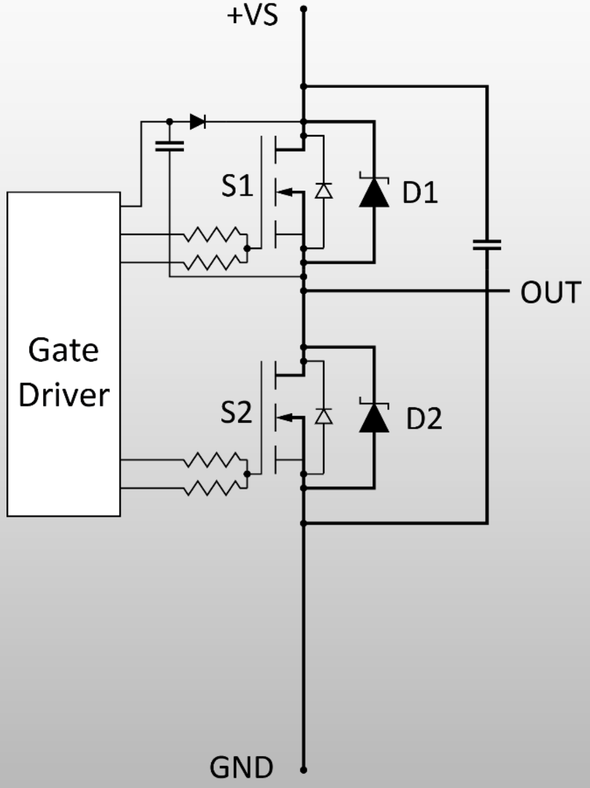
- Junction temperature rise per power cycle must be less than 20 K when using Al wire bond



Power Loss Contributors (PWM Control)

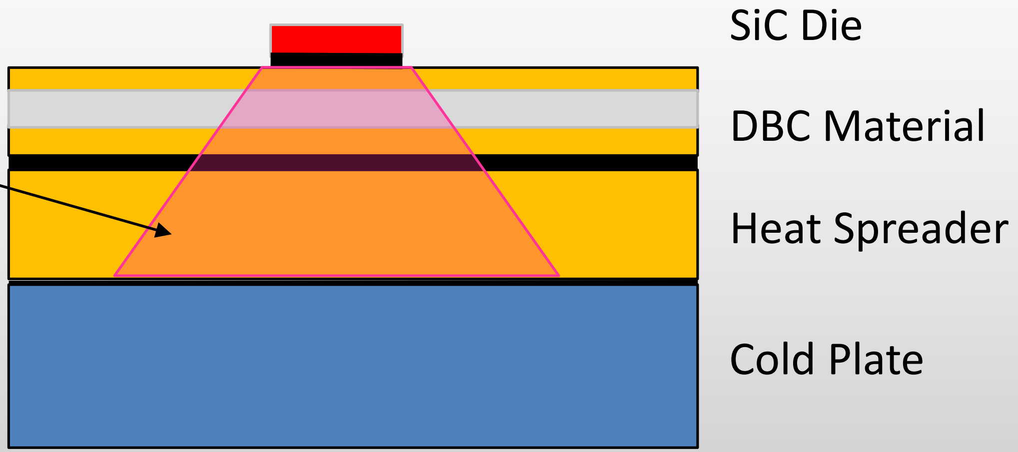
- Conduction Loss: $P = \int I^2(t) \cdot R_{DS}(on)\,dt$
- Switching losses (unless zero current switching is suitable)
  - Switching losses also depend on gate drive resistance
- Case study example
  - $P_{LOSS} = 34.6$ W

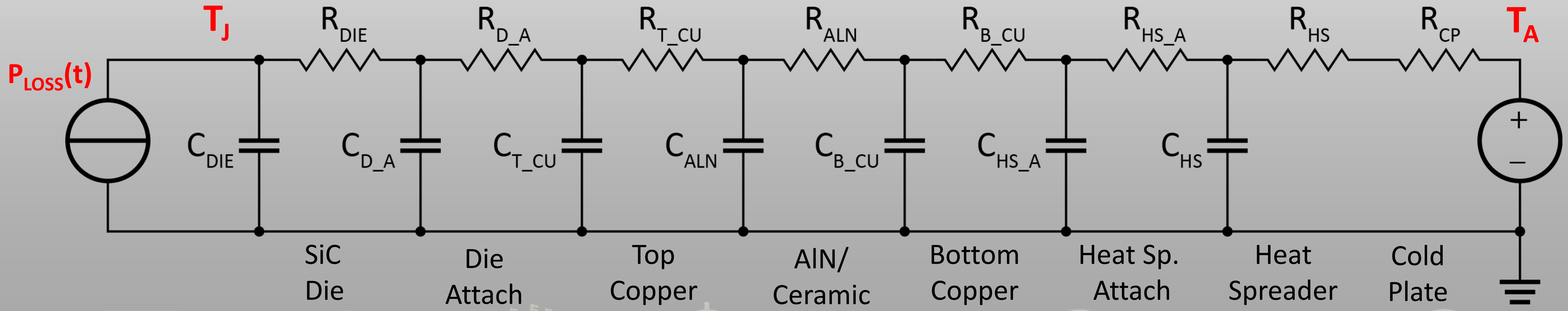




Thermal Impact of Power Loss – Simulation Model

- DBC stack-up
  - Heat dissipation angle assumed to be 45°
- Resulting thermal model
  - Cauer R-C Thermal Network (w/o cold plate attach)

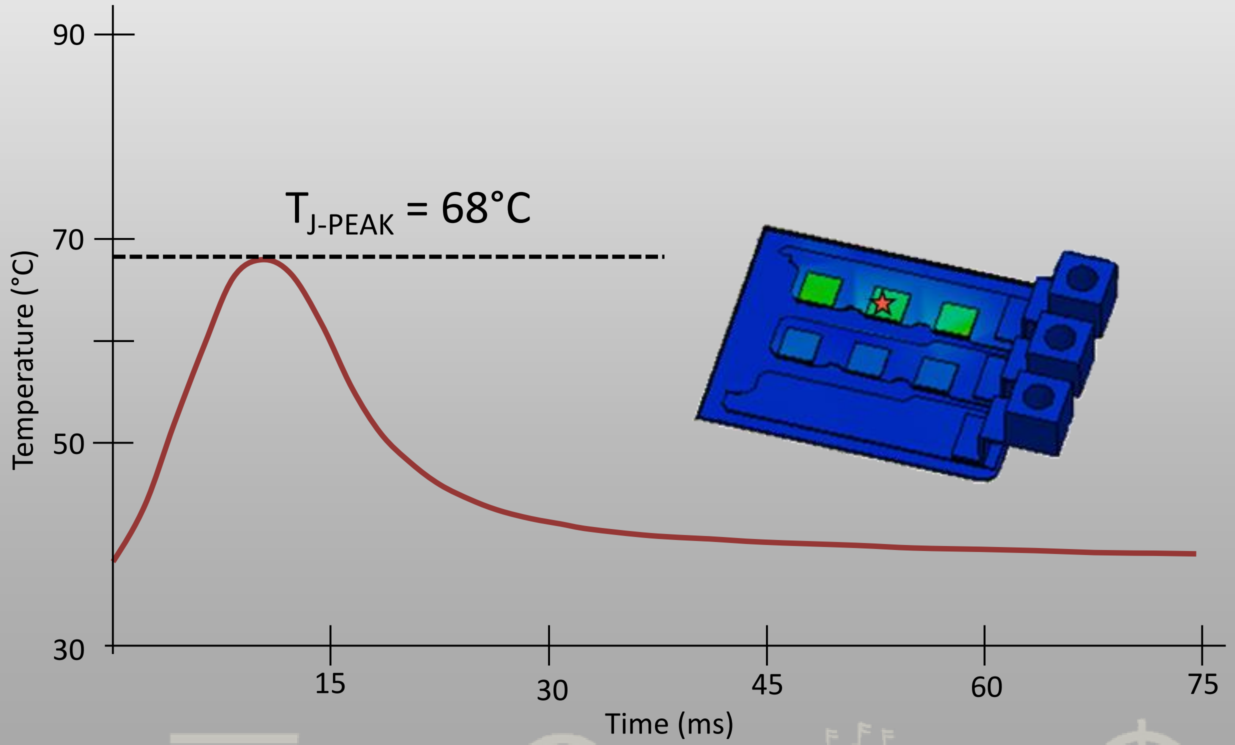




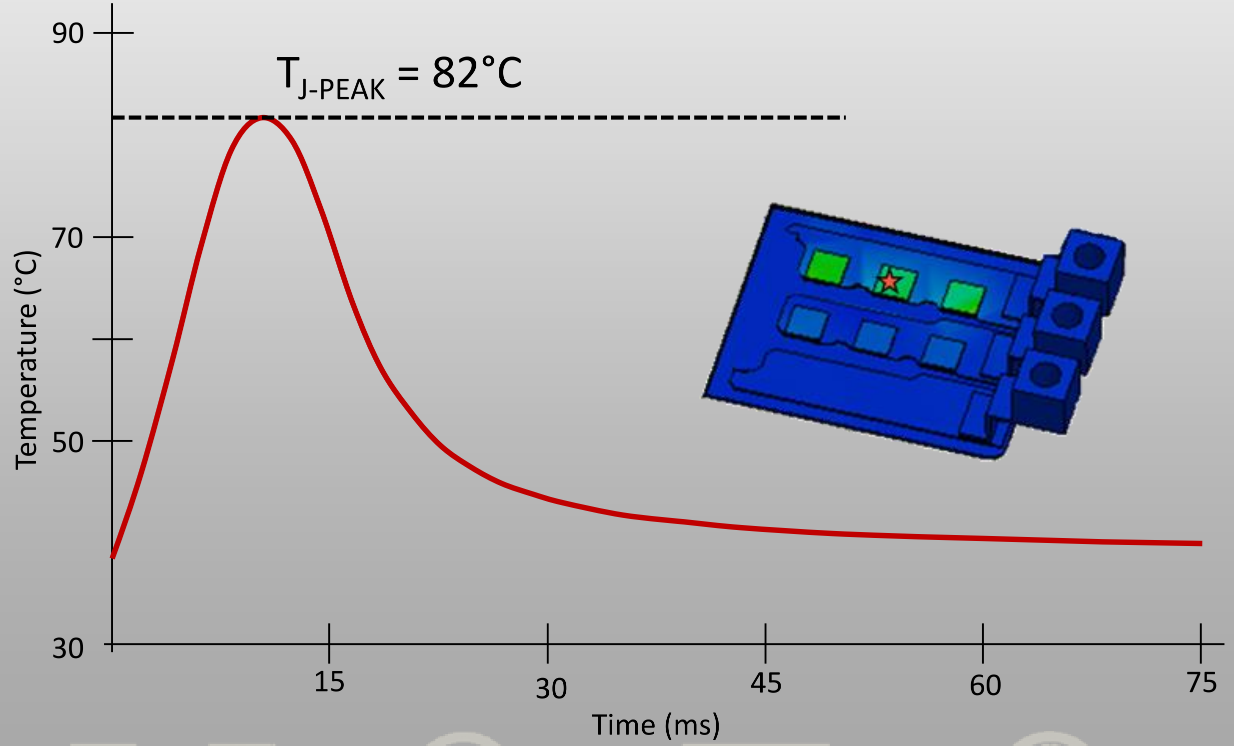
Simulation of the Thermal Impact due to Power Loss

- Simulation with industry standard DBC stack-up:
  - 0.3mm (Cu) + 0.5mm (AlN) + 0.3mm (Cu)

$R_G = 0\ \Omega$: $\Delta T_J = 31$ K



$R_G = 2\ \Omega$: $\Delta T_J = 45$ K

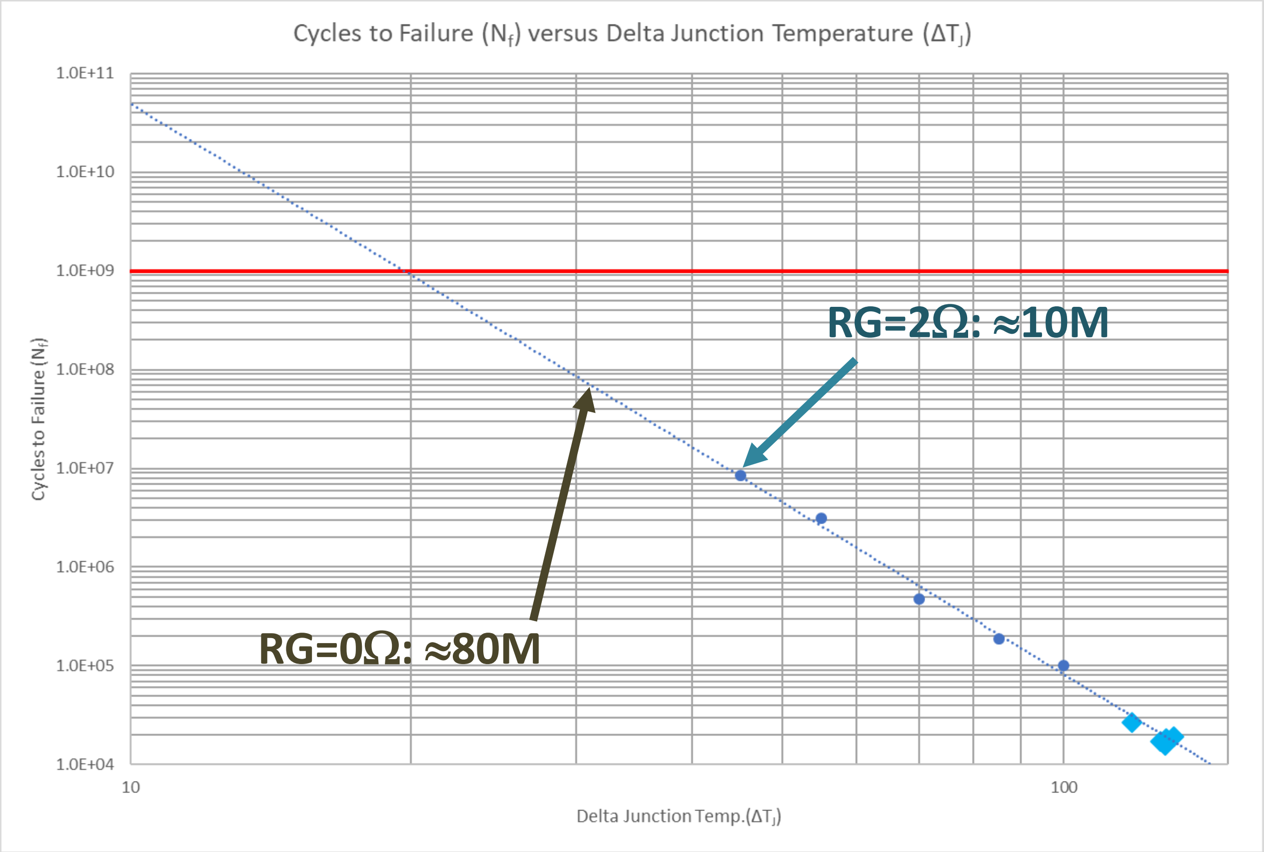


Reliability Challenge

- The system generates 34.6 W pulses of power loss in the Silicon Carbide MOSFET

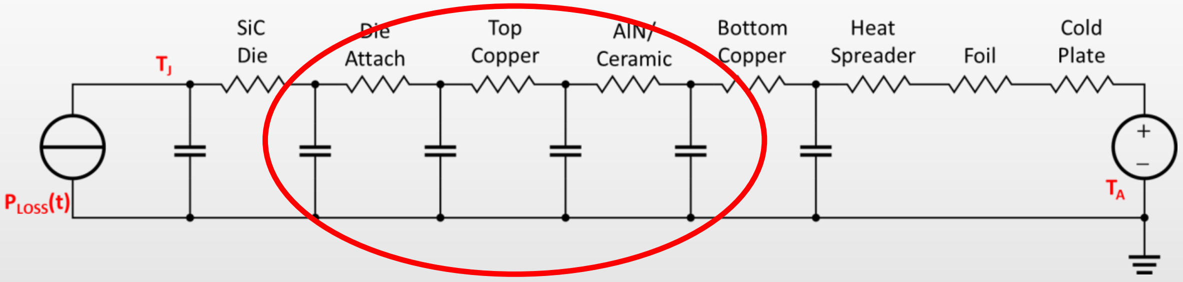
- To achieve 1 billion power cycles, we need to keep the temperature rise of the MOSFETs below 20 K if we use common mounting techniques

- Thermal simulations show that the conditions are not met, resulting in lower reliability of the module

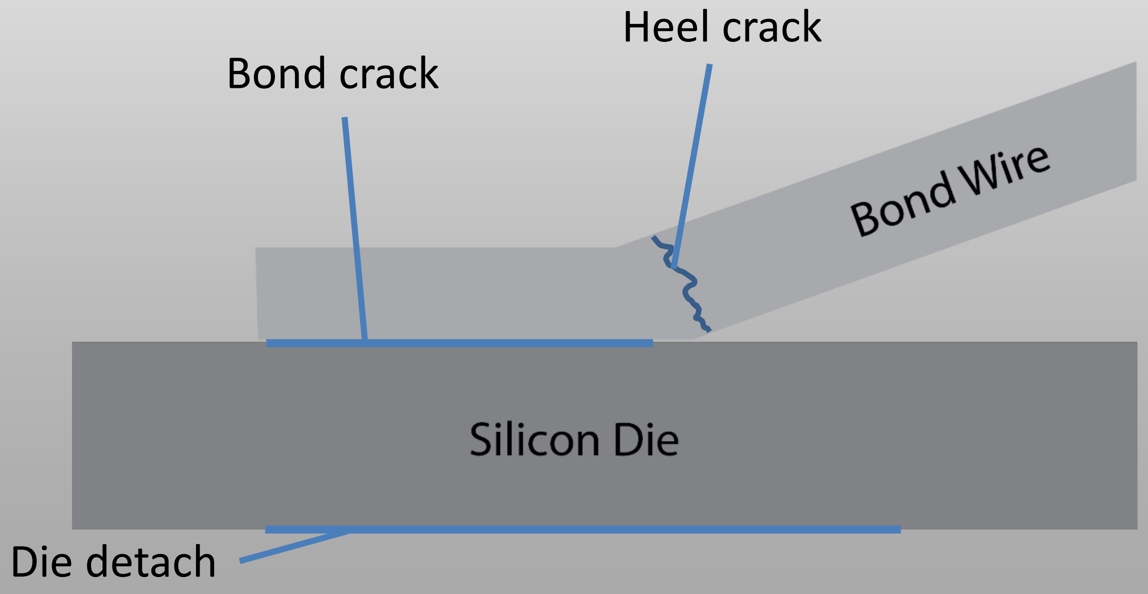


Ways to Improve the Reliability

- Option 1: Increase the thermal capacitance close to the die attach to reduce the temperature rise
  - Example: add graphite layer
- Option 2: reduce temperature increase by adding more output MOSFETs in parallel
  - Impact on cost of module
- Option 3: Relax temperature rise requirements by selecting alternative mounting techniques
  - Replace the traditional aluminum wire bonding with alternative connectivity methods

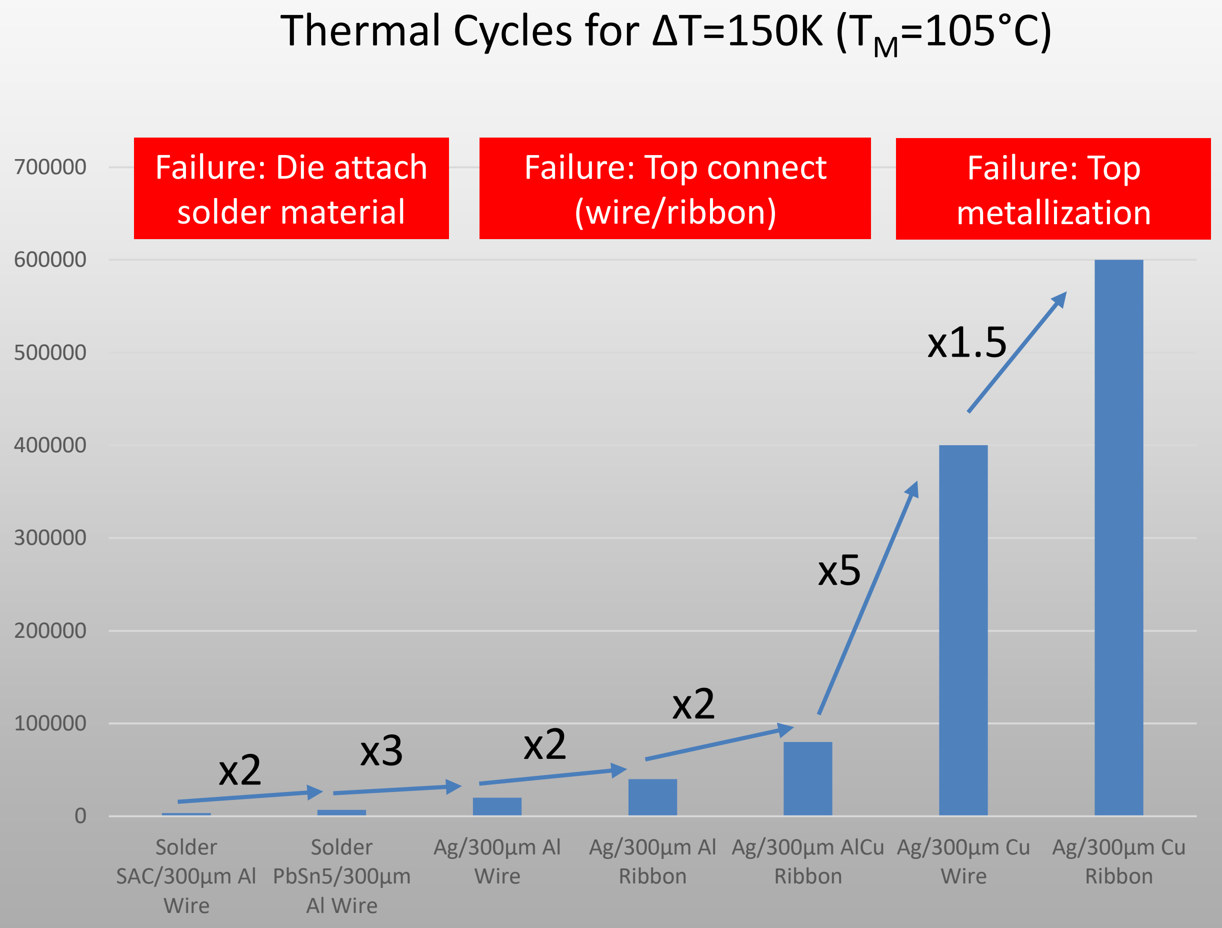


Tweakable thermal capacitances



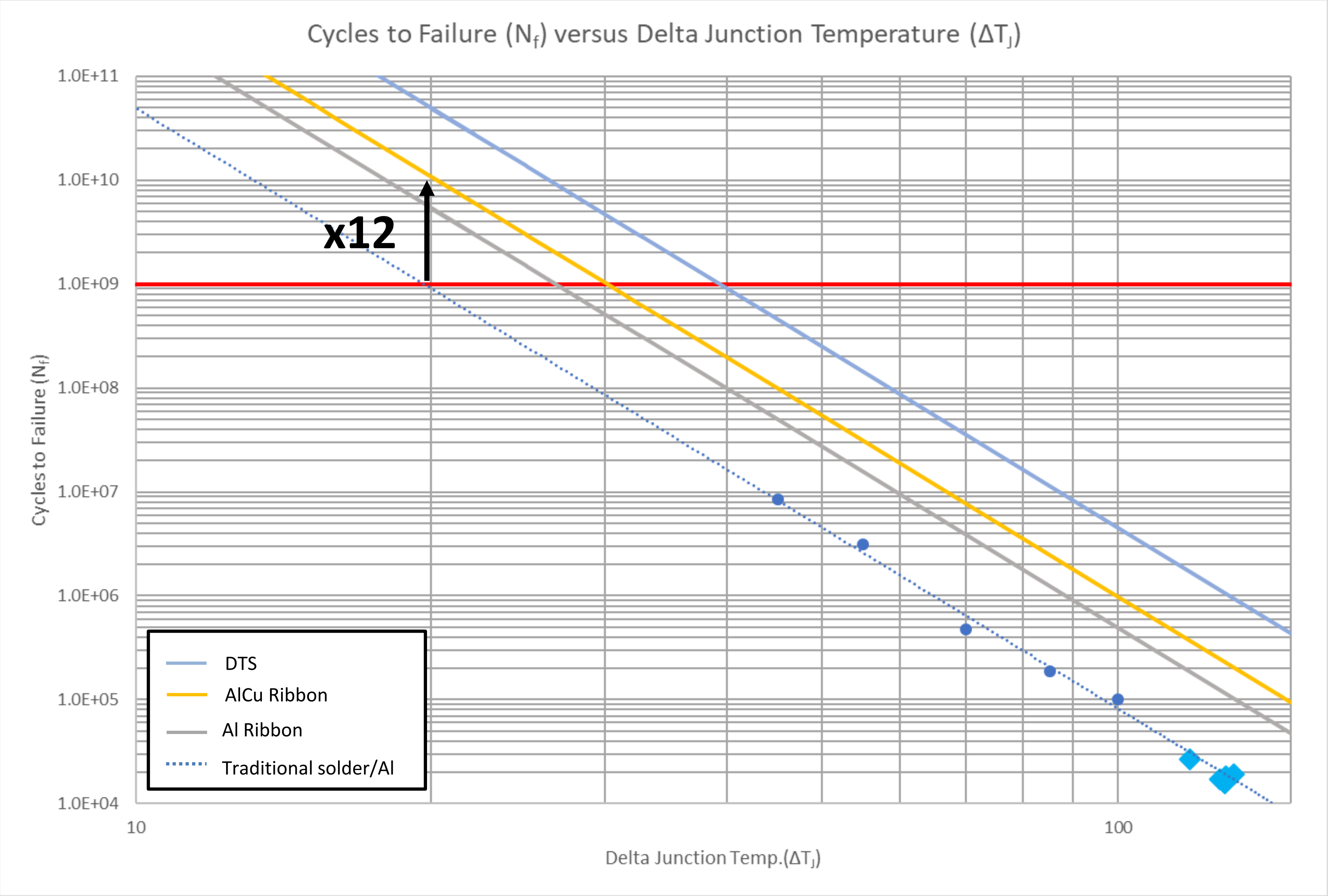
Considering Package Material and Technology

- The graph provided by Heraeus shows the relative improvement from traditional solder and Al wire bond technology to advanced interconnect options
- Moving from Al wire/solder to AlCu ribbon/silver improves reliability by a factor of 12



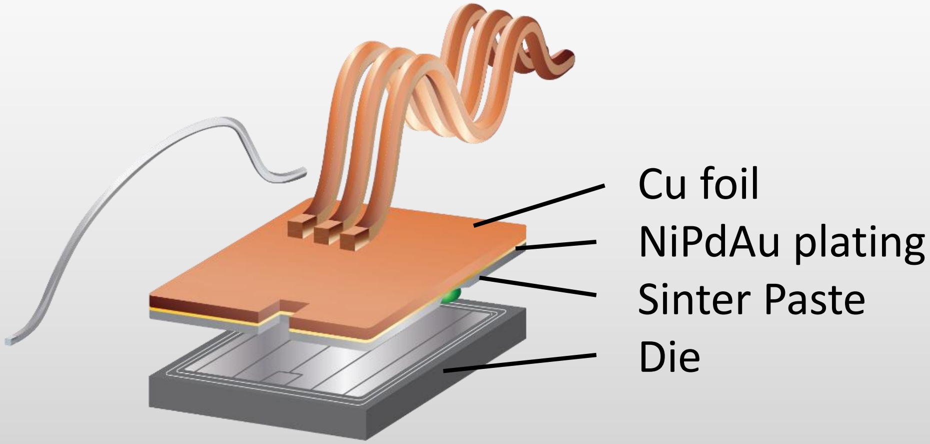
Source: Heraeus

Reliability Prediction for Interconnect Options



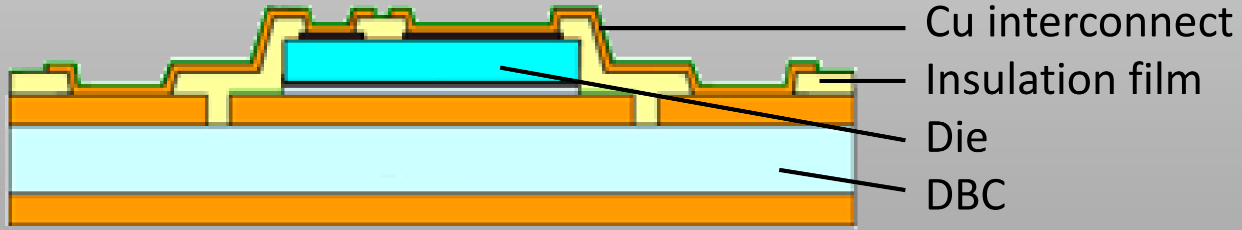
Outlook: Further Reliability Improvements

- DTS (Die-Top System)
  - Heraeus indicates an increased power cycling capability by a factor of 50 compared to soldered die with Al wire interconnection
    - Comparison done on substrate level, i.e. DBC with attached die



Source: Heraeus

- Wire-less interconnections
  - Adds new path for power dissipation
  - Shorter connections



Summary

- Long-term reliability of power modules depend strongly on the temperature rises when operating the module. Thermal management is critical for designing modules that meet defined reliability requirements

- Thermal management is not only about removing the heat from the module, but also providing thermal capacitances within the module design to smoothen out short-term spikes

- Modern mounting techniques reduce the burden on thermal management, but they don’t eliminate the need for thorough analysis

APEX

MICROTECHNOLOGY

PRECISION • POWER • ANALOG

Corporate Headquarters:

5980 N Shannon Rd
Tucson, AZ 85741, USA
Phone +1 (520) 690-8600
Email: info@apexanalog.com
www.apexanalog.com