Multiscale Thermo-Mechanical Modeling

2015 ModSim Workshop
University of Washington, Seattle

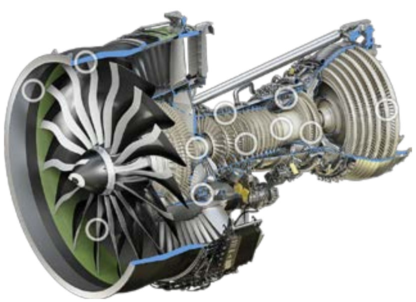
Imagination at work.

10^{7+}

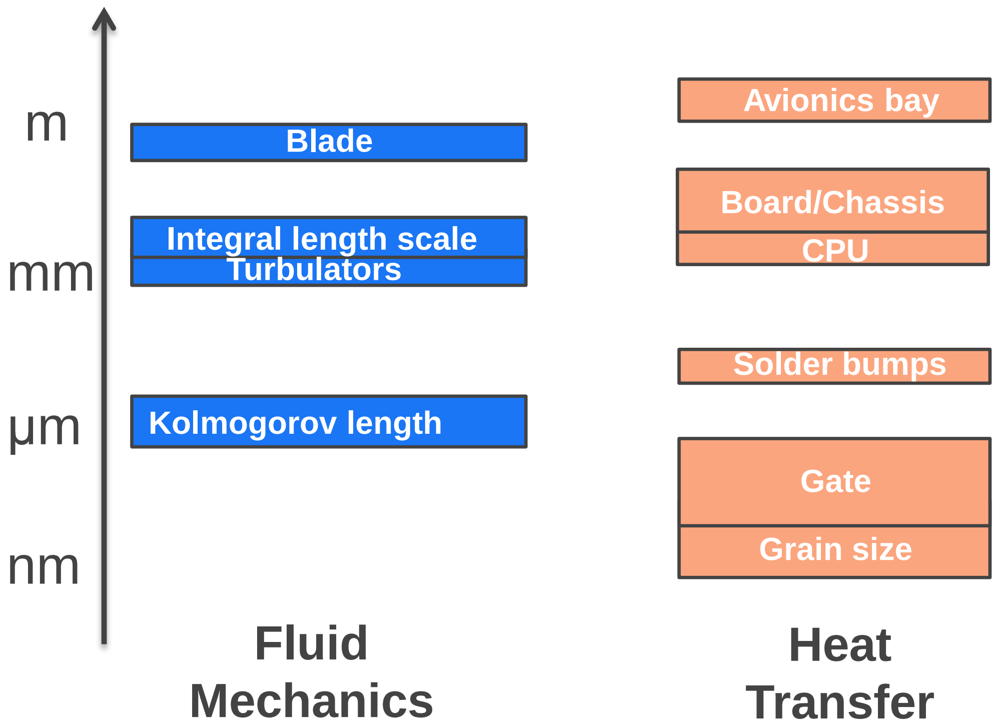
10^5

10^2

Transport Phenomena in Engineering Systems are Multiscale Problems



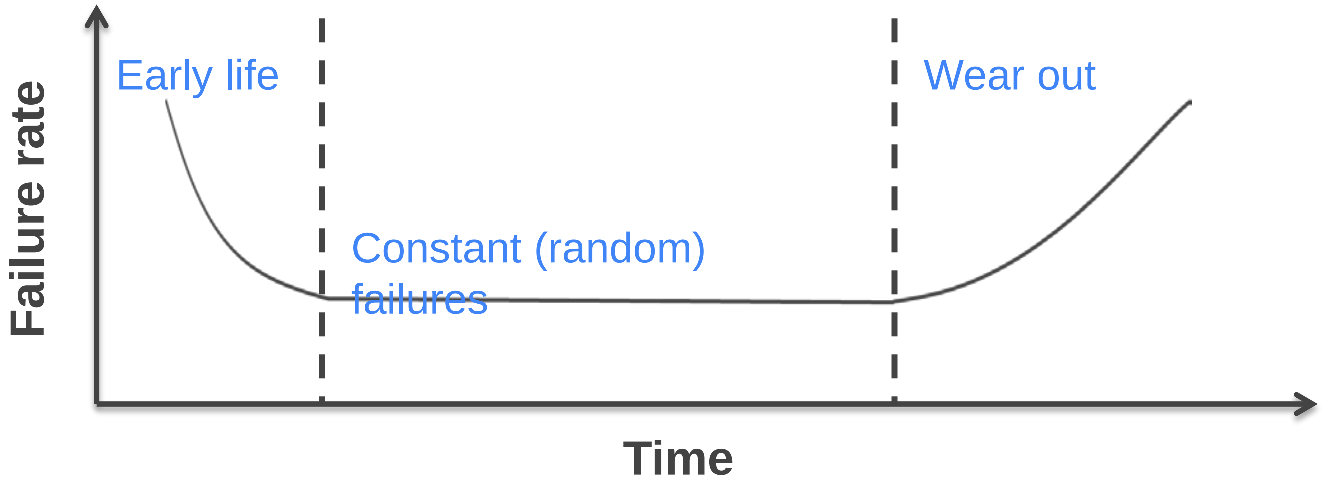
GE9X Engine



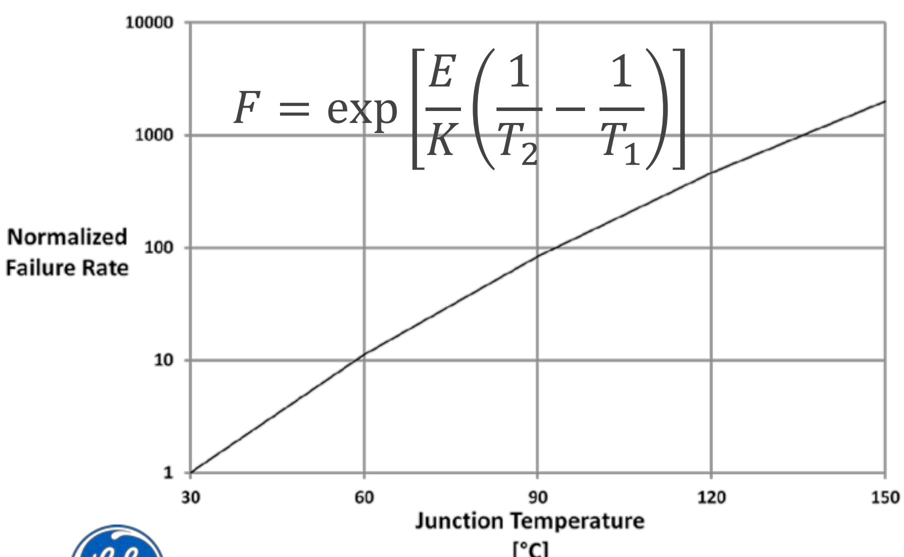
GEIP VCP

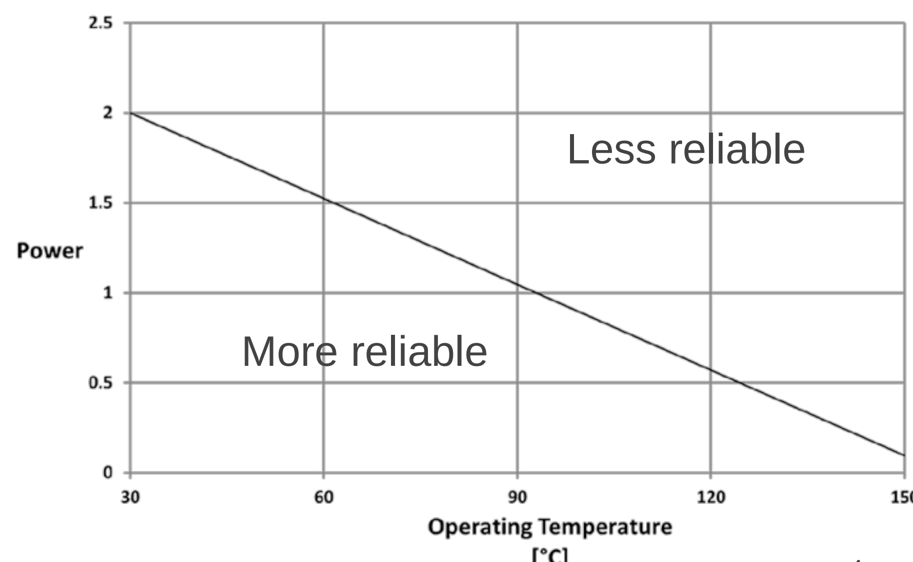
Heat transfer in electrical/electronic systems is a highly coupled, multiscale phenomenon; Need higher fidelity models for improved reliability predictions

Reliability and the 10 ºC Rule of Thumb



Probability that a device will operate continuously for a specified time @ stated conditions





GE SiC Technology for Reliable Operation in Harsh Environments

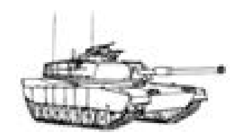
GE SiC MOSFET

1/2	Space & weight, or
2x	Power Density
2x	Reliability
$>50^{o}C$	Higher temperature capability

Gen Controls

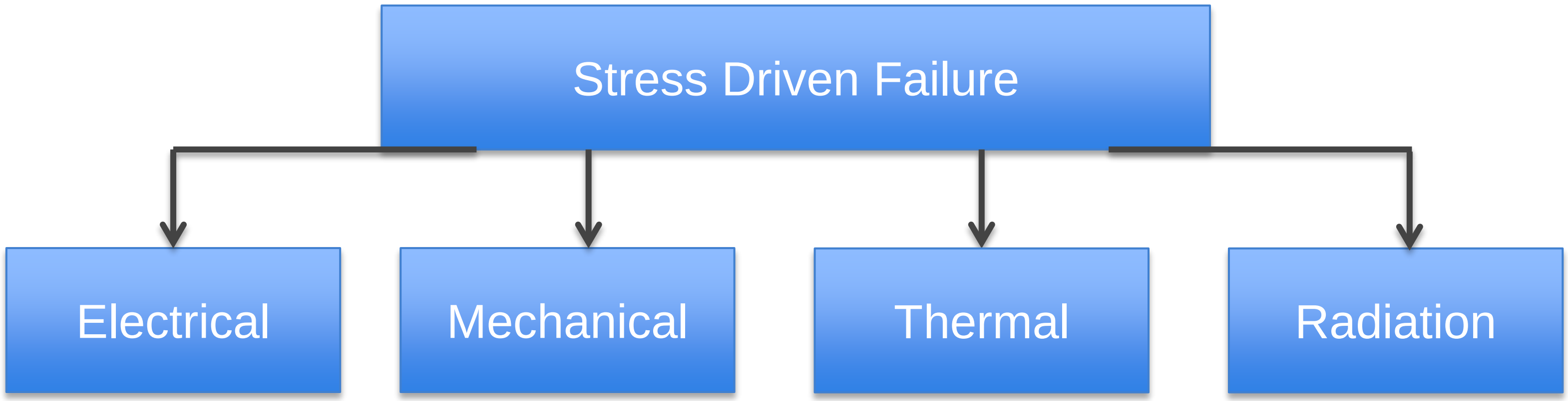
Converters

Distribution



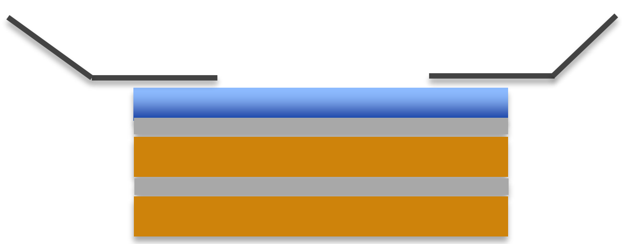
- ↓ Leakage Current
- ↑ Operating Temperature
- ↑ Radiation Hardness
- ↓ On-Resistance
- ↑ Blocking Voltage
- ↑ Heat Spreading
- ↑ Power Density

How Do Power Electronics Fail?

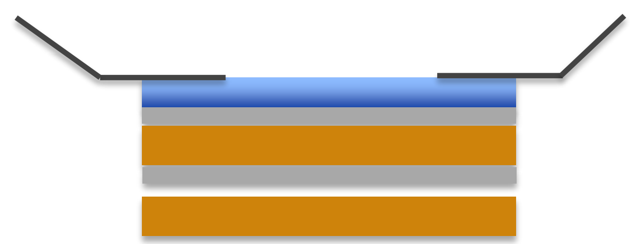


Wire bond liftoff/cracking
Substrate delamination
Die attach failure
…

Wirebond cracking [1]

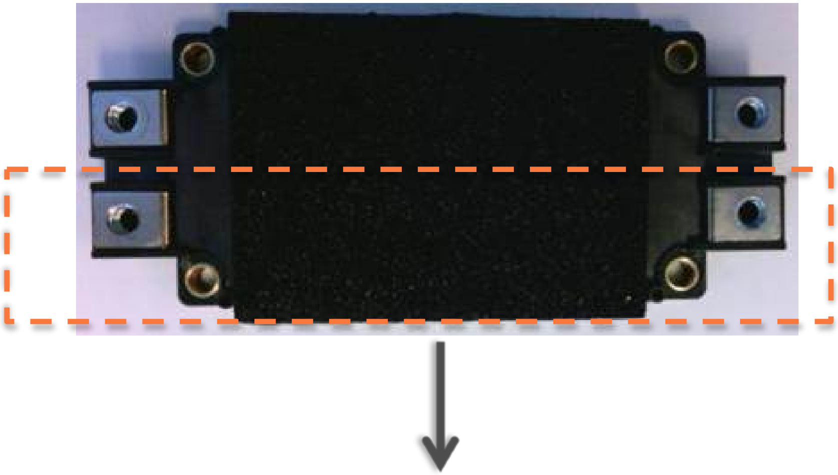


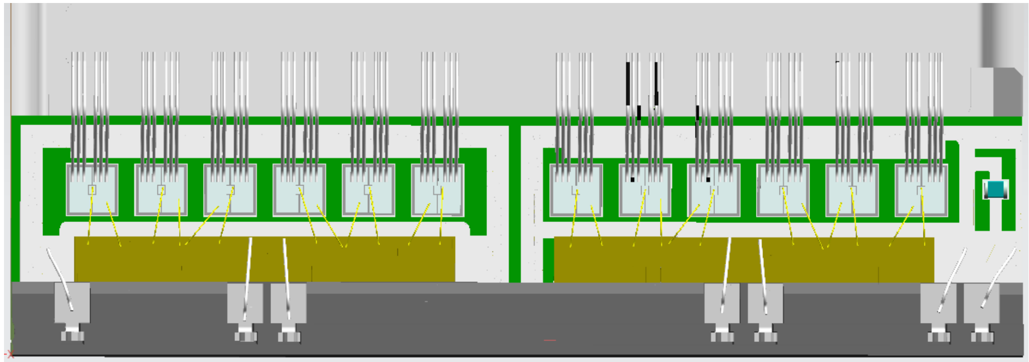
Wirebond liftoff [1]



Substrate delamination [2]

GE SiC Power Converter Module

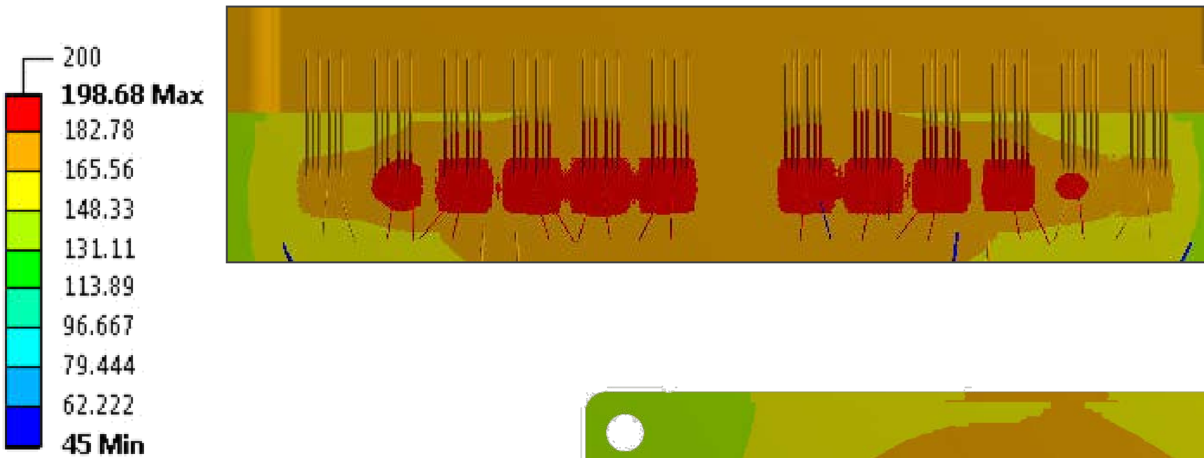


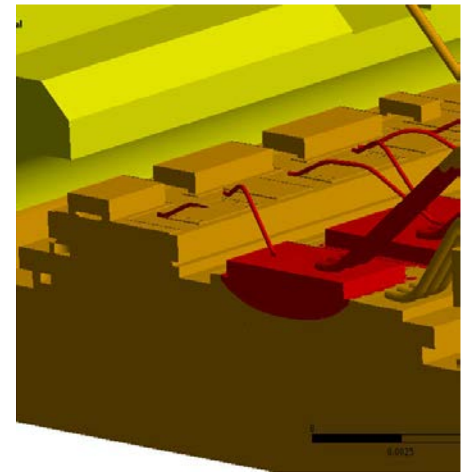


- *24 die module*
- *600 micron gate, 200 °C junction temperature limit*
- *Wirebond to system ~ 10^3*
- *10 layers in chip-ambient thermal stackup*
- *High switching frequency*
- *Air cooling with plate-fin heat sink*
- *Copper busbars, Aluminum wirebonds*
- *Copper baseplate*

- *Junction temperature ?*
- *Stress/strain levels, failures and MTTF ?*

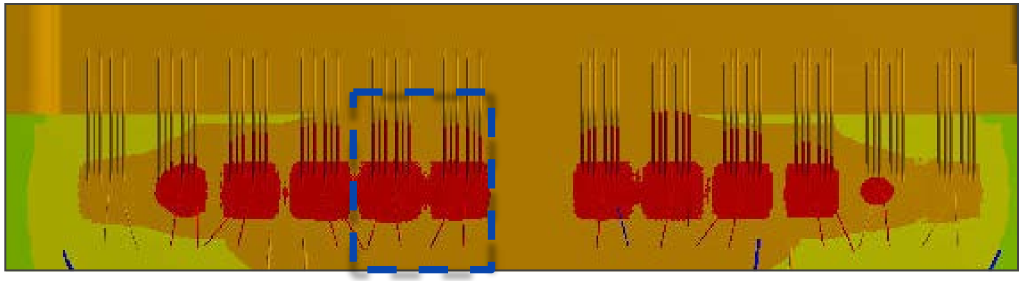
Scale Resolved Temperature Predictions

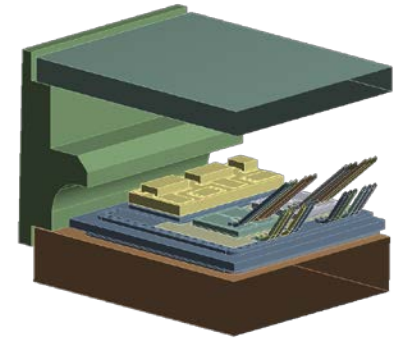


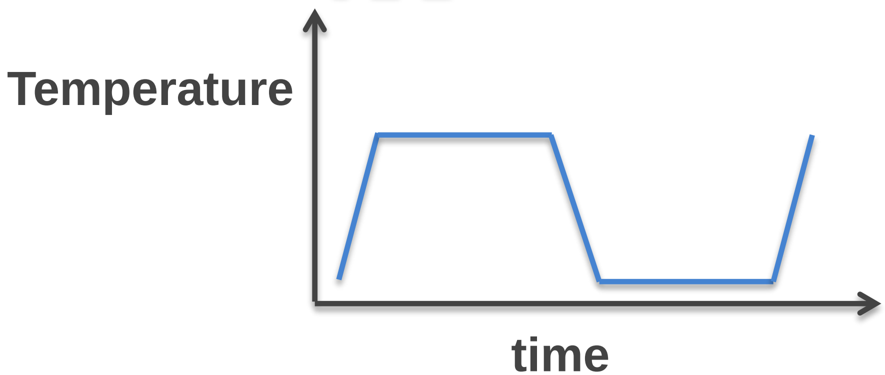


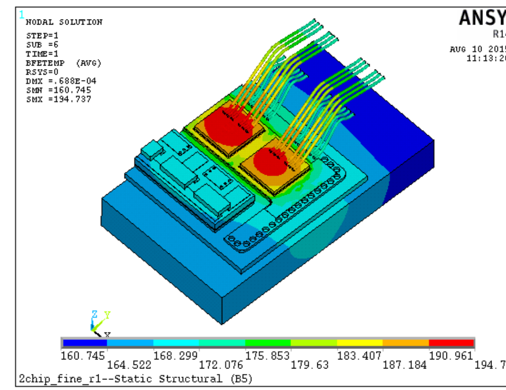
1150 W/m^2-K effective heat transfer coefficient;100 micron TIM w/ k = 4.2 W/m-K; 5 mm Al heat sink base; 45 °C ambient

Which Component Limits Life under Thermal Shock Cycling?





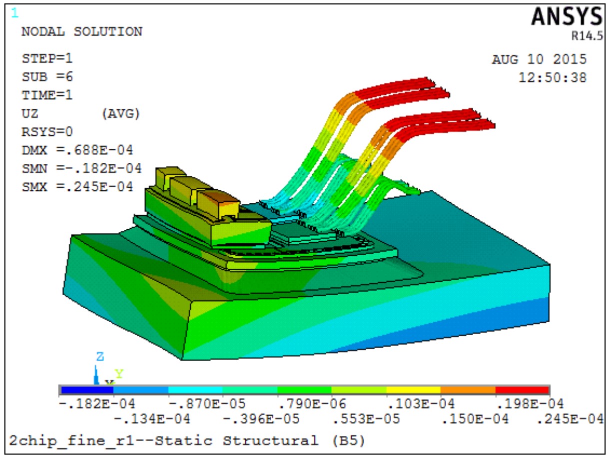




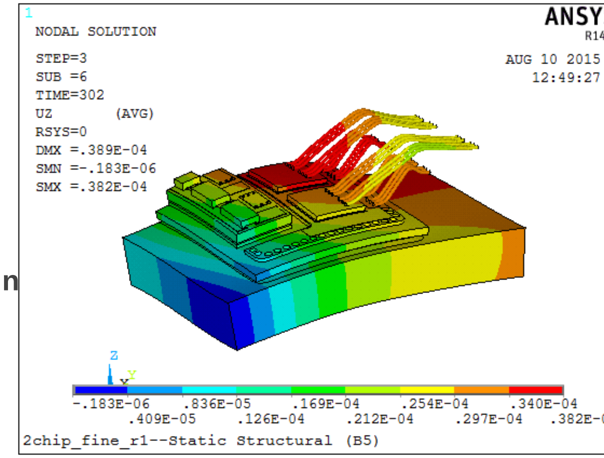
- Thermal shock cycling with 35 W/die power pulse; 10 min. time period; 50% duty cycle; 1 second ramp time
- Unsteady mechanical analysis with data interpolated from ON/OFF thermal data
- Nonlinear material properties for solder (viscoplastic), copper (multilinear kinematic hardening) and Aluminum (bilinear kinematic hardening)
- Coffin-Manson type equation (low cycle fatigue) for estimating MTTF

Failure Analysis: Thermal Shock Cycling

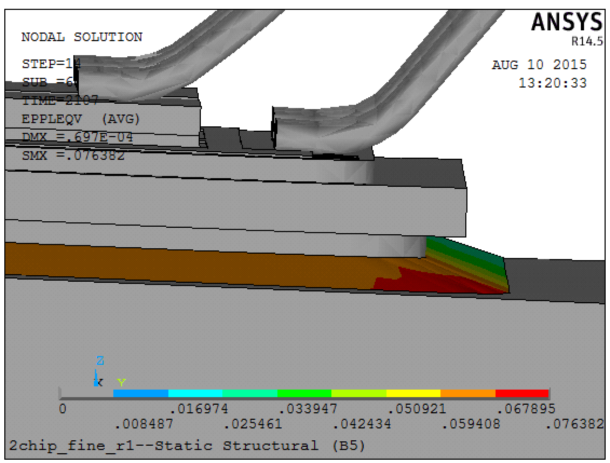
Z-Displacement



$T = T_{max}$ ⟷ $T = T_{min}$



Plastic Strain



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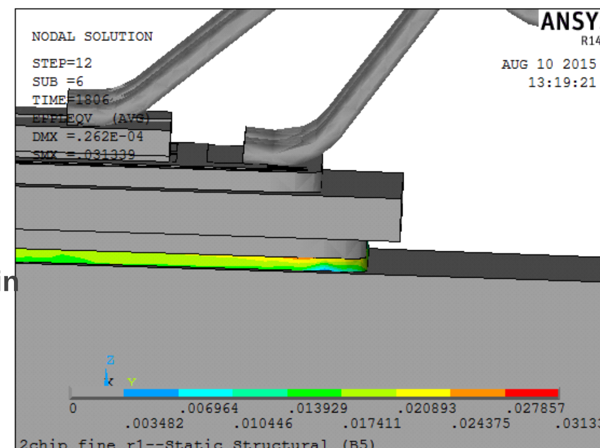

368 cycles to thermal shock failure

Conclusions

- Solder fatigue identified as limiting failure mechanism during thermal shock cycling; >350 cycles to failure
- Multiscale modeling for high fidelity analysis and improved reliability predictions
- Coupled EM ⇔Mechanical ⇔ Thermal analysis needed for simulation driven design and optimization

References

1. Lutz, Josef, et al. "Packaging and reliability of power devices." Semiconductor Power Devices (2011): 343-418.
2. Lu, Hua, Chris Bailey, and Chunyan Yin. "Design for reliability of power electronics modules." Microelectronics reliability 49.9 (2009): 1250-1255.