Lifetime Prediction of Solder Joints in Electronics

H. Eliot Fang, Manager

Computational Materials & Molecular Sciences Department

Sandia National Laboratories

505-844-4526 (phone) 505-844-9781 (fax)
hefang@sandia.gov

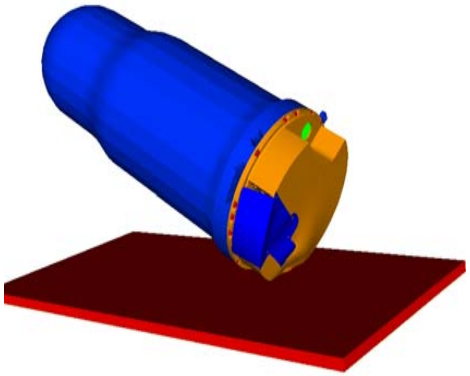
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

ASC Is A Tri-Lab Effort Supporting the Entire Weapon Lifecycle

Sandia National Laboratories

ASC Goal is to Deliver a High Fidelity Weapon Simulation Capability

Weapon codes & science

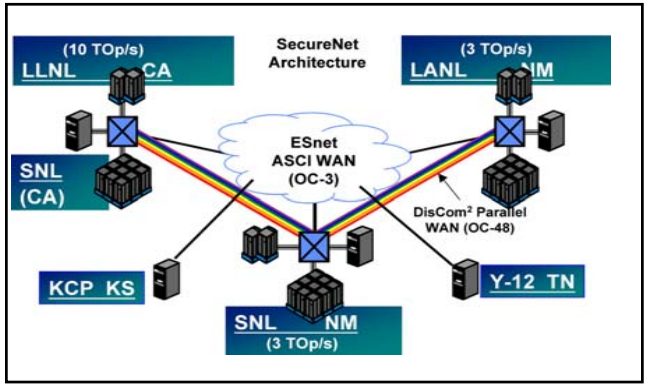


W80 WES Dynamic Response

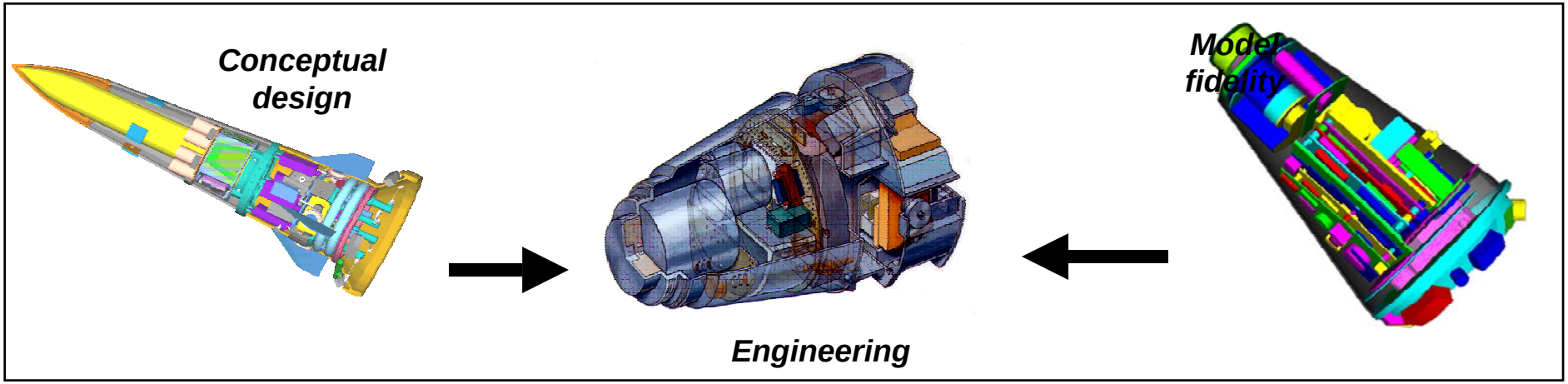
Computing power

Capacity & Capability Platforms

Computational Infrastructure



Shared Computing Resources



Sandia's Modeling and Simulation Efforts are Revolutionizing Stockpile Stewardship and Engineering

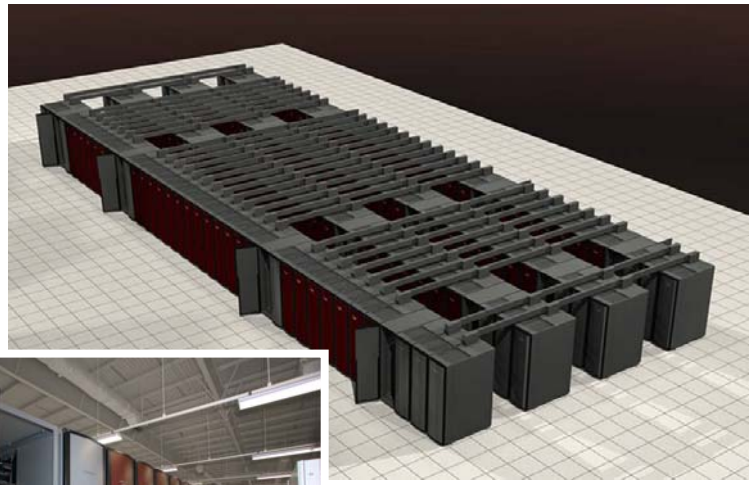
Red Storm and NW Computing Clusters (NWCC) Enable Stockpile Stewardship Mod-Sim

Red Storm (41.5 teraflops)

- Cray, Inc. is our vendor-partner for Red Storm engineering & production
  - $90M contract over 7 years
  - 2 year R&D / 5 year O&M
- Delivery by December 2004; Operational Midyear 2005

NWCC (16.7 TeraOps)

- Reserved for NWSMU work only
- Total Cost - $9.7M
- Consists of three clusters:
  - Two 1024-processor Clusters at Sandia NM (one SRN/one SCN)
  - One 384-processor Cluster at Sandia CA (SCN)
- All Systems operational in December 2004



First row of Compute Cabinets at SNL

Xyce Status

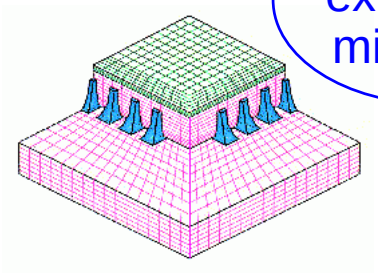
- **Spice Compatible, distributed memory, analog circuit simulator.**
- **Project begun July 1999**
- **Currently in 2.1 Internal Release**
  - ***Version 2.1 represents five years of development as part of the High Performance Electrical Modeling and Simulation (HPEMS) effort, funded primarily by DOE's ASCI Applications program at Sandia National Laboratories***
  - **Provides platform for further research and development into algorithms and methods which will provide improved capability and performance for Sandia-specific problems.**
- **Key Sandia capabilities**
  - **Predictive radiation-aware device models.**
  - **Support for large-scale modeling via MP computing.**
  - **Multi-fidelity modeling - *device, analog and digitial*.**
  - **Distributed memory State-of-the-art solution algorithms.**
- **Support SGI Irix, Linux, Free-BSD, Cplant, HP Tru64, Sun Solaris, IBM Cluster (Linux), MS Windows, ASCI White, ICC, Mac OS X.**

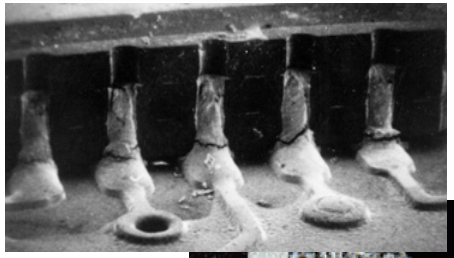
Solder degradation and interconnect failure is a major concern in our business

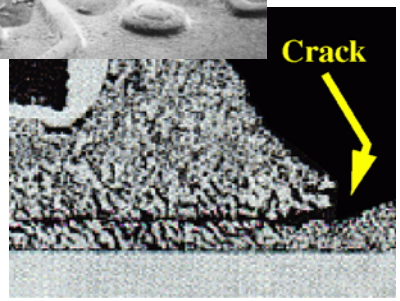
Thermal expansion mismatch

Cyclical strain in the joints

Ambient temperature change



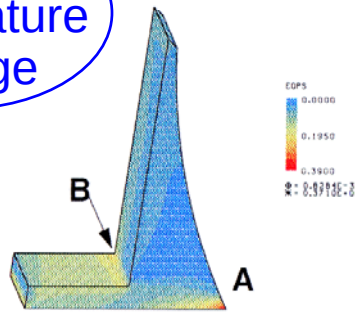


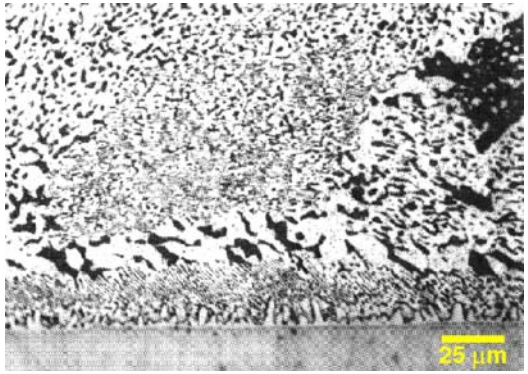


Heterogeneous microstructural coarsening

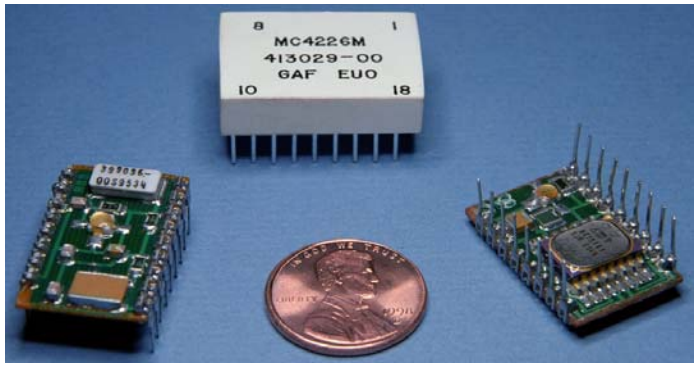
Weakening

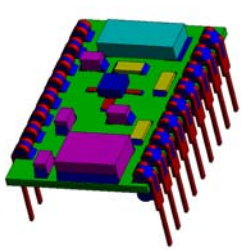
Final cracking

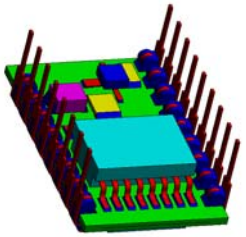


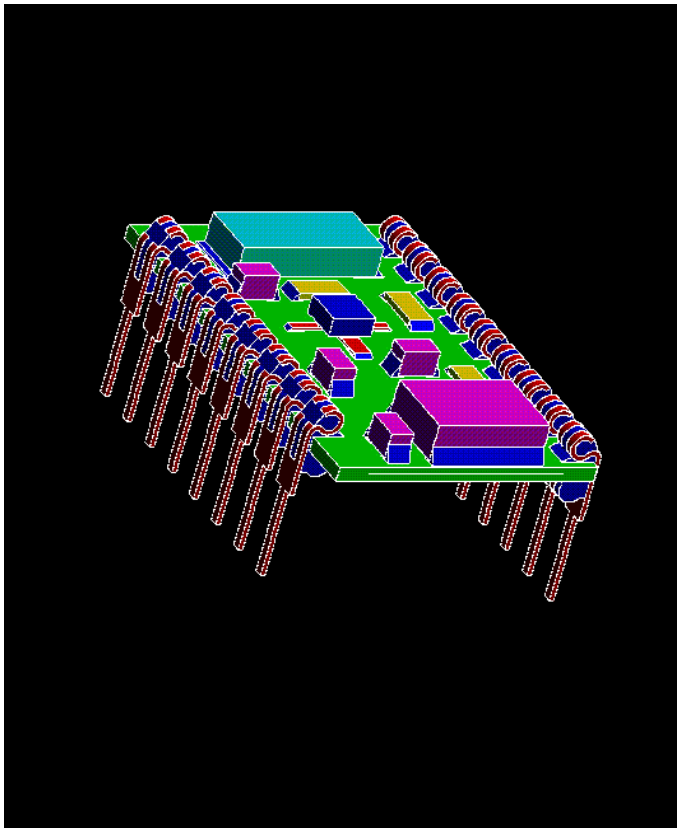


Predicting solder degradation & electronics lifetime is a cross-discipline, multi-scale challenge









- Circuit board design?
- Loading?
- Material behaviors?
- Operation / storage environment?

A multiscale modeling approach was developed to address TMF in solder joints

PI: Liz Holm (SNL/NM)

Integrated, Multiscale Approach:

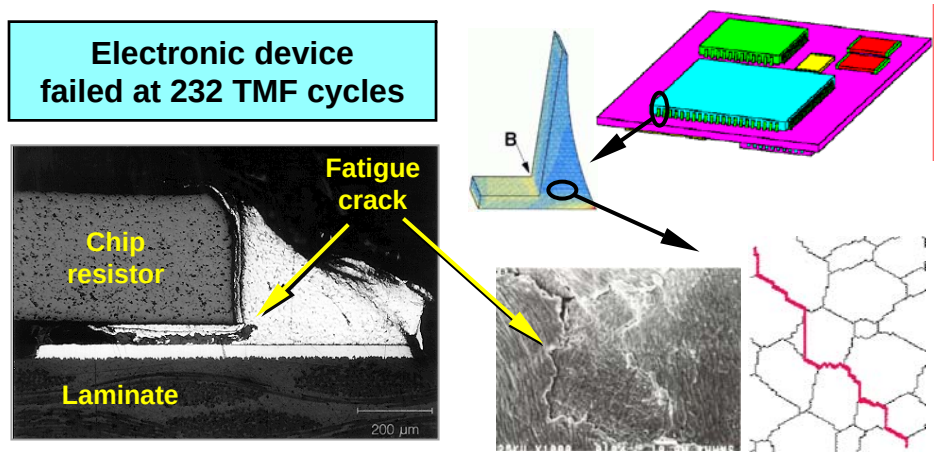
Microscale discovery of failure mechanisms

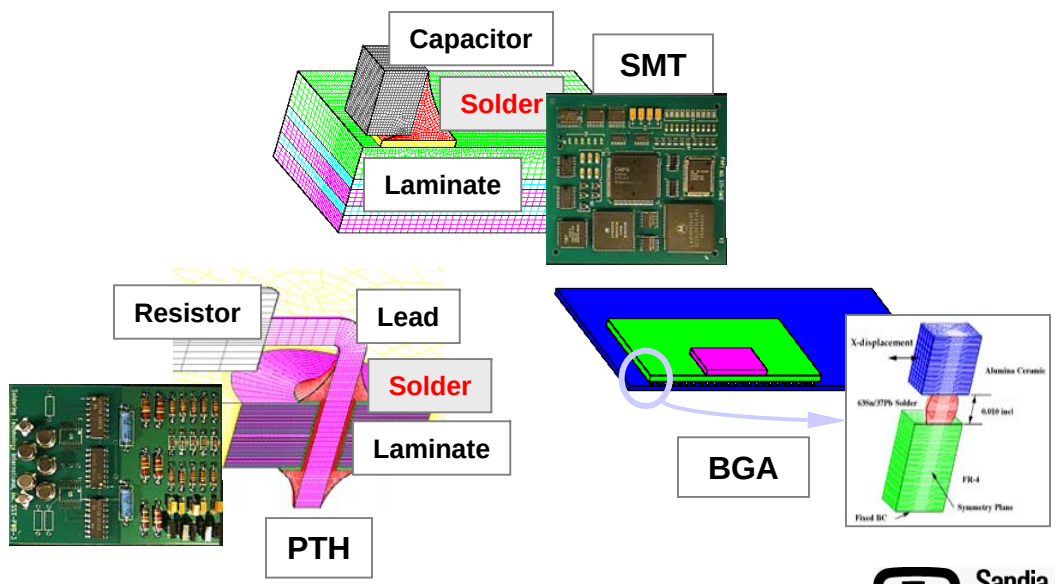
⬇

Mesoscale FEM/MPM for damage localization

⬇

Macroscale FEM for component lifetime modeling





Our coupled viscoplasticity / damage solder model takes input from microscale

Inelastic Strain Rate

Deviatoric Stress

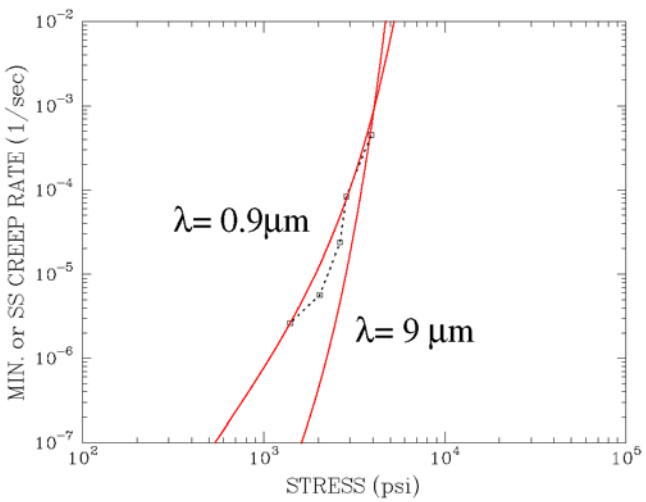
Back Stress

$$\mathbf{d}^{\mathbf{in}} = \frac{3(1-\mu_{in})}{2(1-D_{in})} f \exp\left(\frac{-Q}{R\theta}\right)\left(\frac{\lambda_o}{\lambda}\right)^p \sinh^m\left(\frac{1-\mu_{in}}{1-D_{in}}\frac{J_2}{\alpha(c+\hat{c})}\right)\frac{\mathbf{S}-\mathbf{X}}{J_2}$$

$$J_2 = \sqrt{\frac{3}{2}(\mathbf{S}-\mathbf{X})^T : (\mathbf{S}-\mathbf{X})}$$

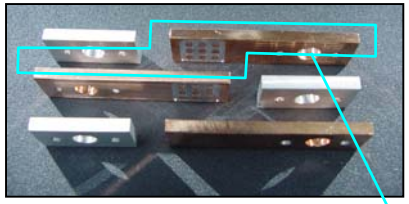
- μ_{in} & D_{in} are inelastic damage variables.
  - Based on free energy equivalence principle

- Includes grain size as an internal state variable λ which evolves during the simulation.
  - Increases in grain size reduces the creep rate (d^{in}) for relatively low stress level.
  - Increases in grain size reduces the flow strength (the sinh term) for relatively high stress level --- Hall-Petch relationship.



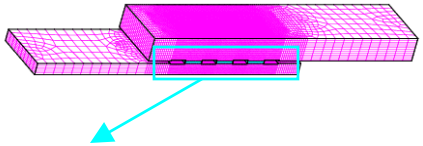
Carefully designed experiments were applied to validate the solder model

Model System: Double lap shear test vehicle

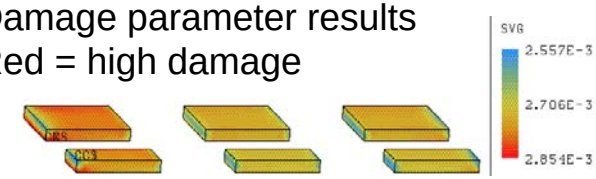


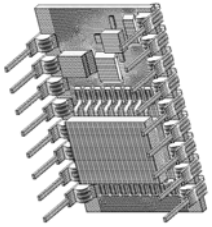
Experimental specimen (blow-up)

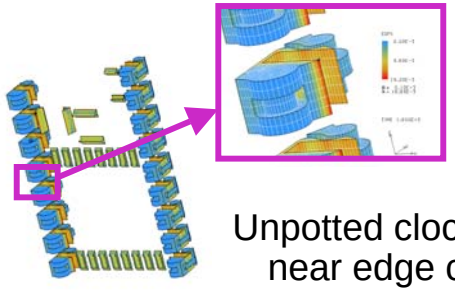
Solid model



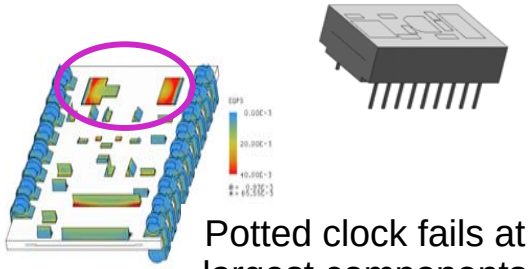
Damage parameter results
Red = high damage



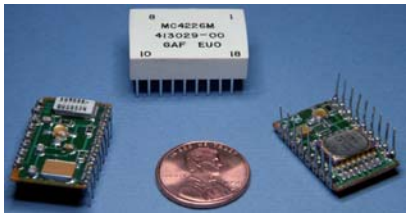


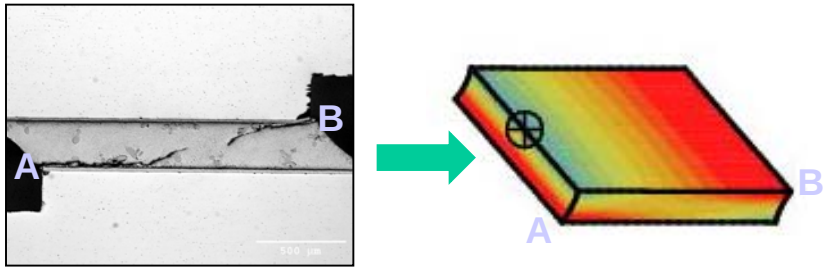


Unpotted clock fails near edge clips



Potted clock fails at largest components

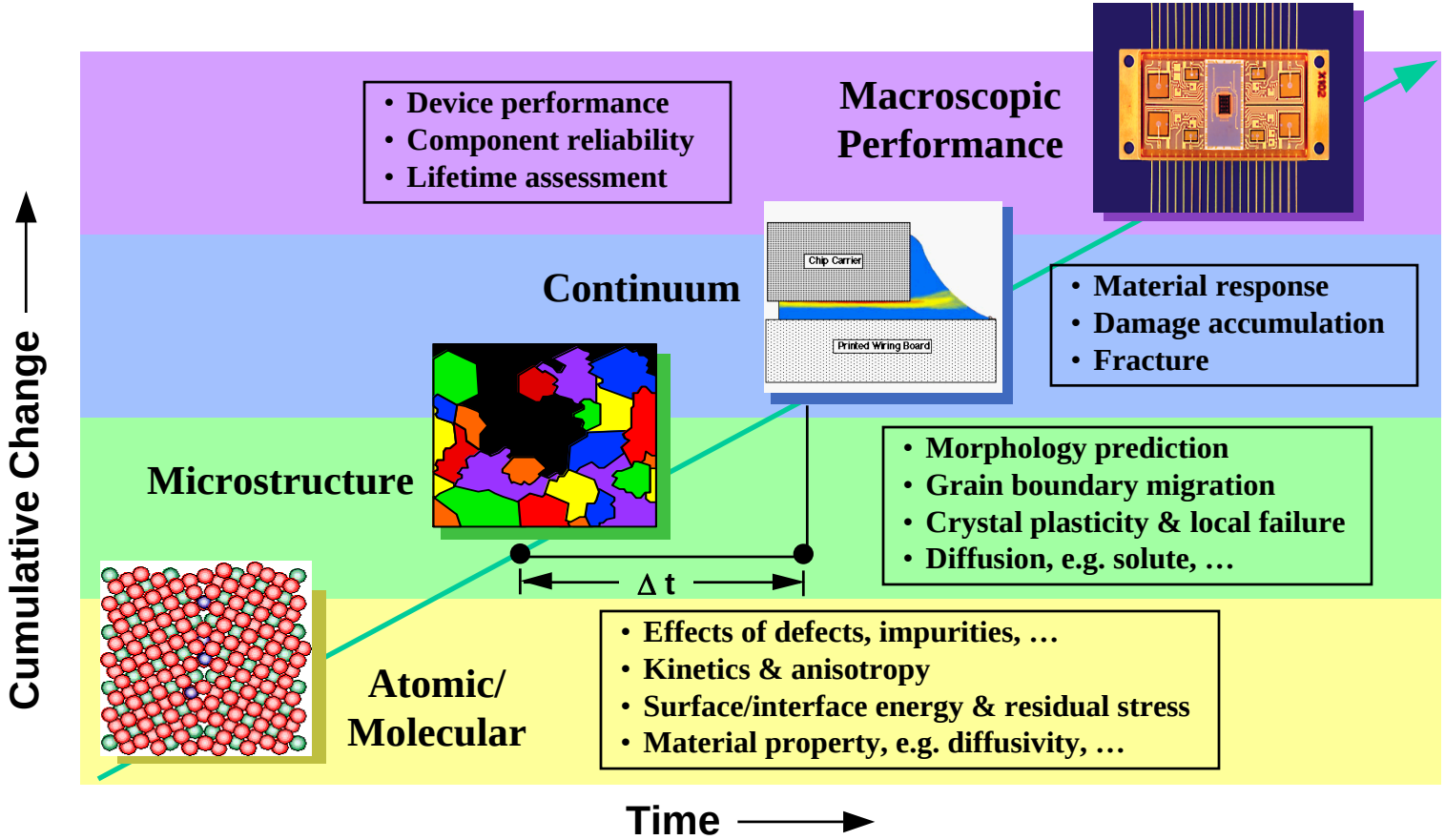




Excellent agreement with experiment

Micromechanics damage-based solder model enables predictions of thermomechanical fatigue **and** failure location in microelectronics.

Multiscale materials modeling & simulation were oversold in the past 10 years, but …



… there is an increasing need as we seek to understand and control the behavior of increasingly complex materials.