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An Assembly-Based Structural Model for LTCC Package Design and Reliability

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Outline

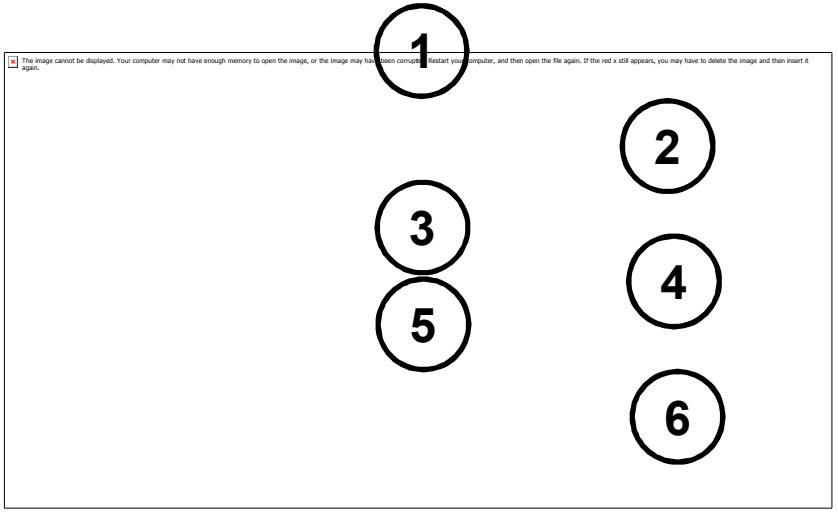
- **RF Package Design and Testing**
  - **Materials and assembly process**
  - **Prototype testing environment**
  - **Results of prototype testing**

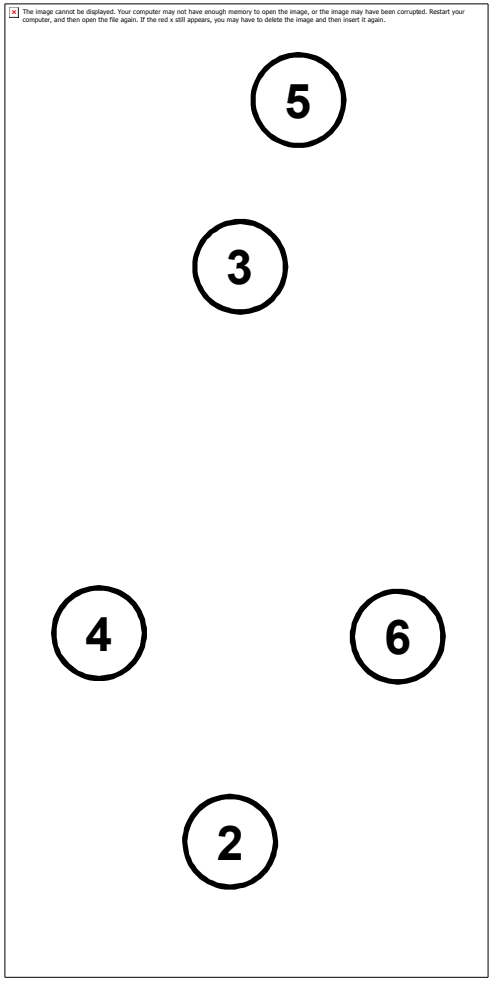
- Thermomechanical Model Development
  - Meshing details
  - Materials
  - Boundary Conditions

- Results
  - LTCC package structure
  - Seal frame solder joint

- Concluding Remarks

LTCC Package Materials





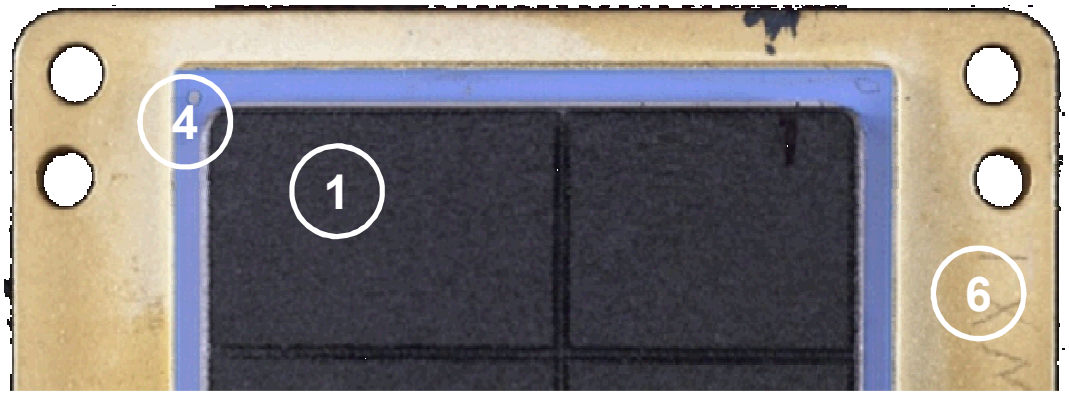
1. Lid (Kovar)
2. Seal Frame (Kovar)
3. Frame Solder (Sn-Pb 63/37)
4. LTCC-951
5. Backplate Solder
6. Backplate (Al-SiC 9)

Major RFIC Package Assembly Steps

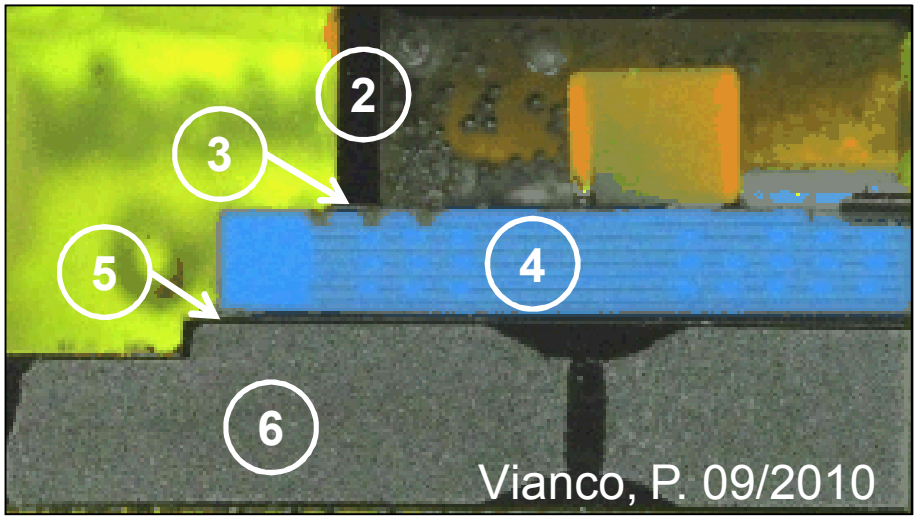
Step	Description
1	Frame and LTCC are heated for soldering; cool to RT.
2	Soldered Frame/LTCC and Backplate heated for soldering; cool to RT.
3	Two sequential epoxy cures in oven; cool to RT.
4	Wire bonding on hotplate; cool to RT.
5	Epoxy cure in oven; cool to RT.
6	Wire bonding on hotplate; cool to RT.
7	Flex cable attach on hot plate; cool to RT.
8	Weld lid at RT.
9	Electrical tests.
10	Thermal cycles tests.

Dwell periods and thermal rates maintained among the steps.

Prototype Test Assembly Includes All Structural Components of Device



Section view



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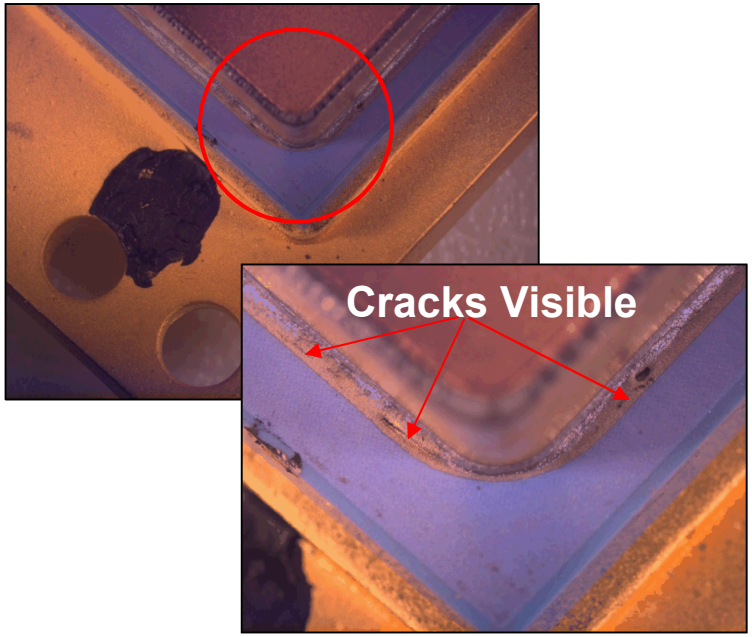
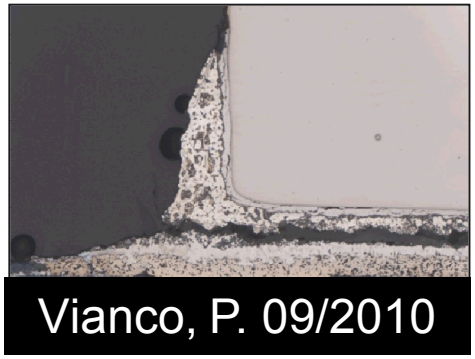
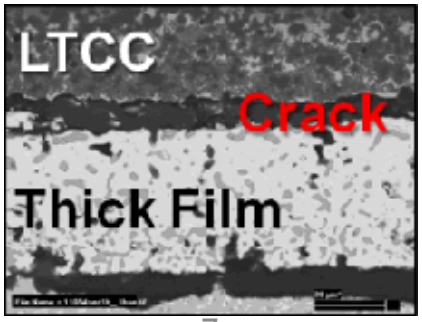
Prototype Testing Show Cracks Forming Around the Seal Frame Corners



- Electrical tests performed at -40°C followed by heating to 75°C
- Thermal cycling ranges from -55 to 125 ° C up to 1000 times.
- At specified intervals, prototypes are inspected and tested for hermeticity and electrical functionality.
- Cracks typically form along the corners of the solder joint for the backplate and seal frame solder.
- Cracks form and propagate along intermetallic layers from 60 to 260 temperature cycles.





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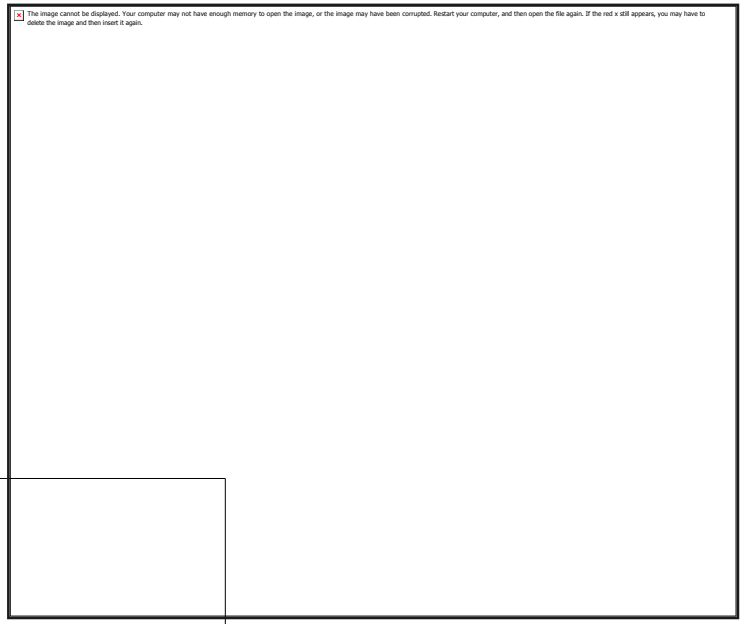
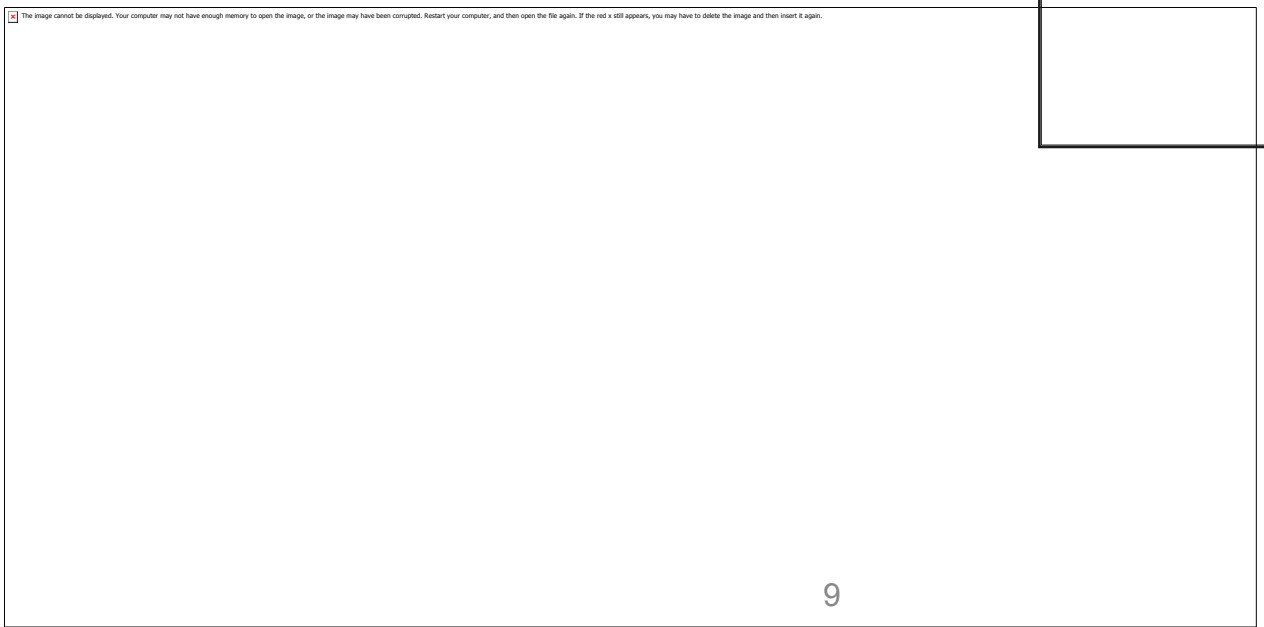
Multiscale Mesh Resolves Micron Scale Solder Joints to Centimeter Scale Seal Frames

- 8-node Hexahedral elements.
- Aspect ratio ≤5:1
- Discretization count:
  - 760k elements
  - 890k nodes

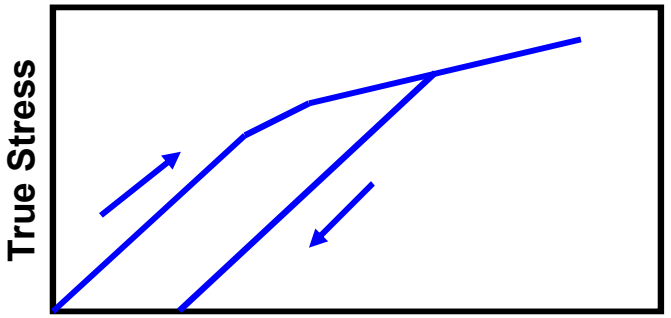


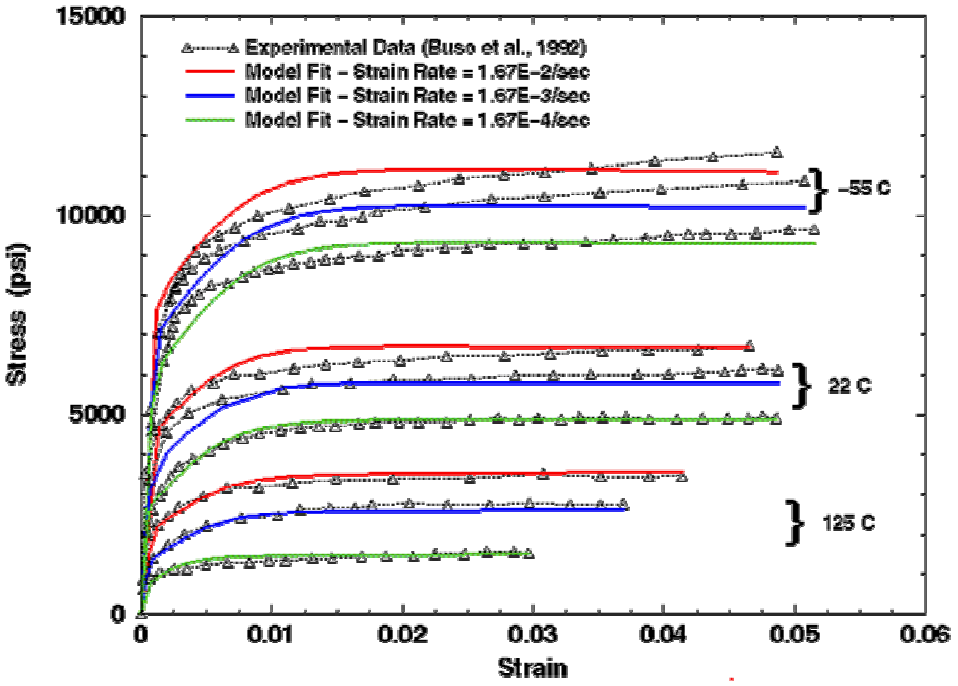


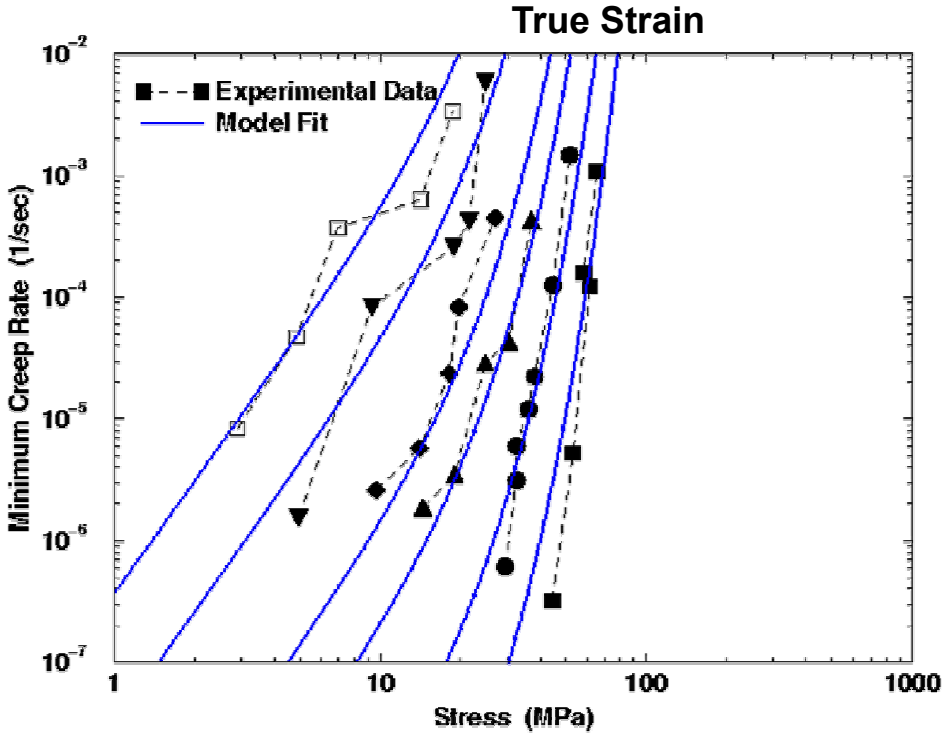
Solder Constitutive Model

- **Take advantage of model capabilities including capturing**
  - ***rate-dependence (temperature and loading)***
  - **failure.**

[M. Neilsen, 2009]







Material Properties

AlSiC-9

Property	Value
Model	Elastic
Elastic Modulus	188 Gpa
Shear Modulus	76 GPa
CTE	7.4 ppm/K, F(T)

LTCC 951

Property	Value
Model	Elastic
Elastic Modulus	129 GPa
Poisson Ratio	0.232
CTE	6 ppm/K, F(T)

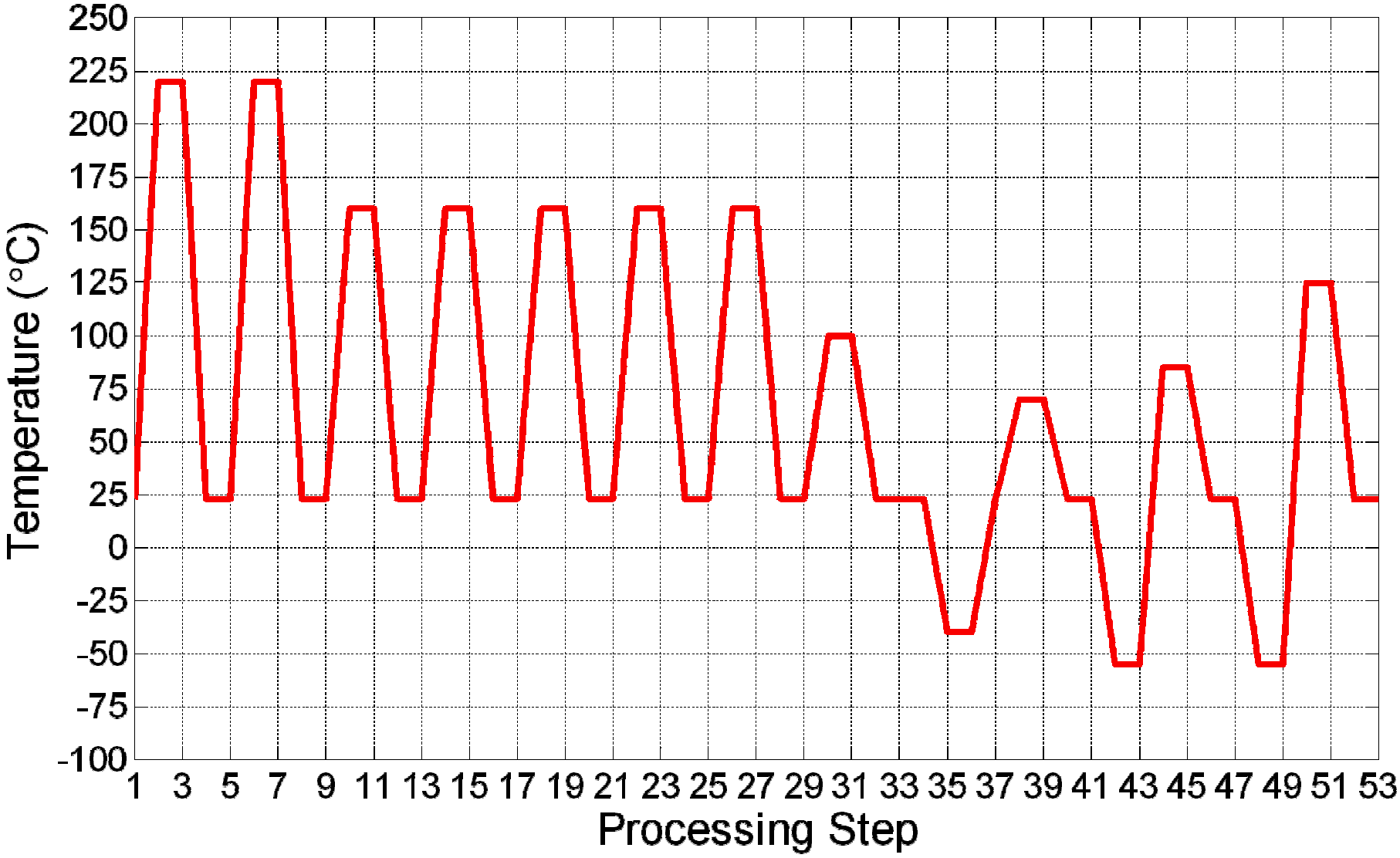
Kovar (Ni-Fe-Co, UNS K94610)

Property	Value
Model	Plastic
Elastic Modulus	138 GPa
Yield Strength	410 MPa, F(T)
Hardening Modulus	13.8 GPa
Poisson Ratio	0.317
CTE	6.1 ppm/K, F(T)

Eutectic Sn-Pb Solder

Property	Value
Model	Solder
Shear Modulus	11.9 GPa
Bulk Modulus	55.4 GPa
CTE	25 ppm/K, F(T)
Other Parameters	[Neilsen, 2009]

The Simulation Represents the Entire Assembly and Testing Process



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Solder Acts as a Compliant Layer for the Structure

- ***Von Mises Stress measures material distortion; characterizes yielding and failure in ductile materials.***
- ***Maximum Principal Stress indicates prominent directional stress; characterizes failure in brittle materials.***
- **Solder yields during assembly; Kovar does not yield.**
- **Residual tensile stresses primarily in Frame wall, Lid, & LTCC.**

<u>Stress Distributions</u>

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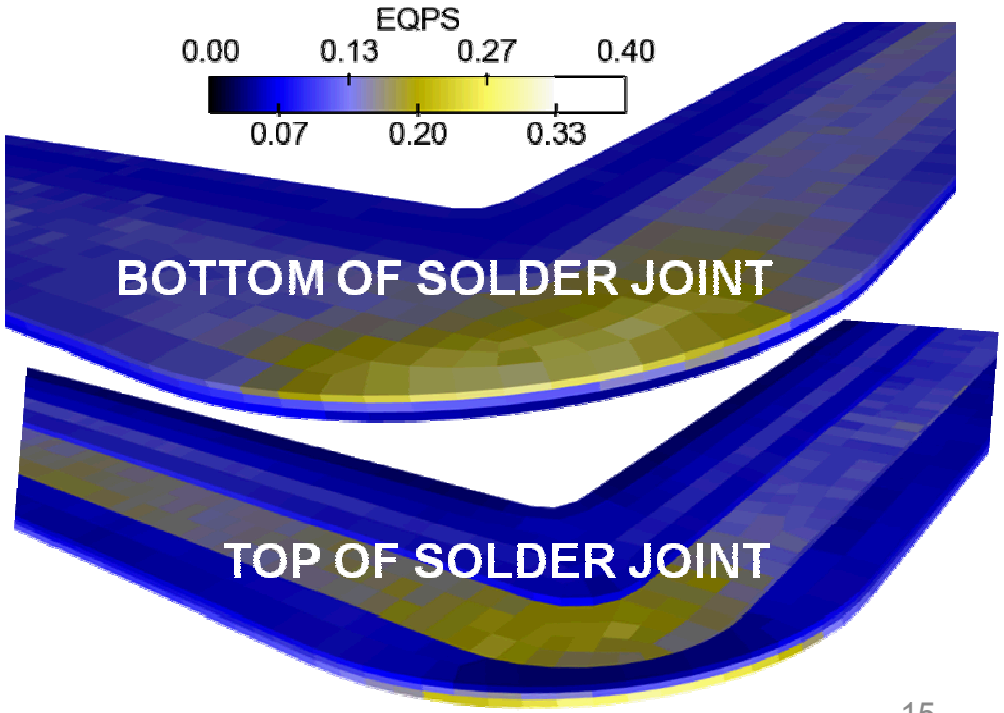
The Seal Frame Solder Fails Around the Edges and Corners

- **Stress peaks along solder outer edges.**
- **Solder yields early at elevated temperatures.**
- **Residual von Mises stress in solder is ~23 MPa.**

Plastic Strain Distribution



Stress Distribution

Place an image of the Max Princ Stress around the seal frame corner here.

The Assembly Process Significantly Impacts Product Lifetime

Assembly/Testing Steps	Seal Frame Solder EQPS
Assembly	0.35
Electrical Tests	0.43
Single Thermal Cycle	0.52

Coffin-Manson Failure Criterion

$$\text{No. Cycles till Failure} = \left(\frac{2.28}{\sqrt{3}\Delta EQPS} \right)^{\frac{1}{0.51}}$$

Strain Increment

$\Delta EQPS$

equivalent plastic strain accumulated in one cycle (load + unload)

H.D. Solomon, IEEE Trans., CHMT-9, 1986
W. Engelmaier, IEEE Trans., CHMT-6, 1983

Concluding Remarks

- Using assembly-based process modeling, a structural model was developed to predict premature solder failure in RFIC LTCC package prototypes.
- The solder EQPS was predicted by modeling the assembly process, which, in turn, captured the residual manufacturing stress in the device.
- By modeling the subsequent testing and thermal cycling, the increase in the seal frame solder EQPS was determined.
- The Coffin-Manson Failure Criterion was used to predict the solder life to be within the experimental measurement bounds of 60 to 260 temperature cycles.
- The stresses from assembly prove to be critical in extending assembly lifetime.