Thermomechanical Reliability Comparison of Flip-Chip Packages Using SAC305 versus Liquid Gallium Solder Joints

Jonathan Reggie Ebenezer, Mechanical Engineering
Mentor: Dr. Robert Wang, Associate Professor SEMTE
Ira A. Fulton School of Engineering

How does liquid gallium impact stress and warpage in flip-chip packages compared to SAC305 solder bumps under temperature rise?

Motivation

SAC305 (Sn–Ag–Cu) solder bumps in flip-chip packages faces reliability issues during heating/cooling due to residual stress and warpage. Thermal expansion mismatch between within the chip assembly leads to thermo-mechanical failure.

Liquid gallium (LG) interconnects can hydrostatically redistribute stress, reducing plastic yielding in the surrounding solids.

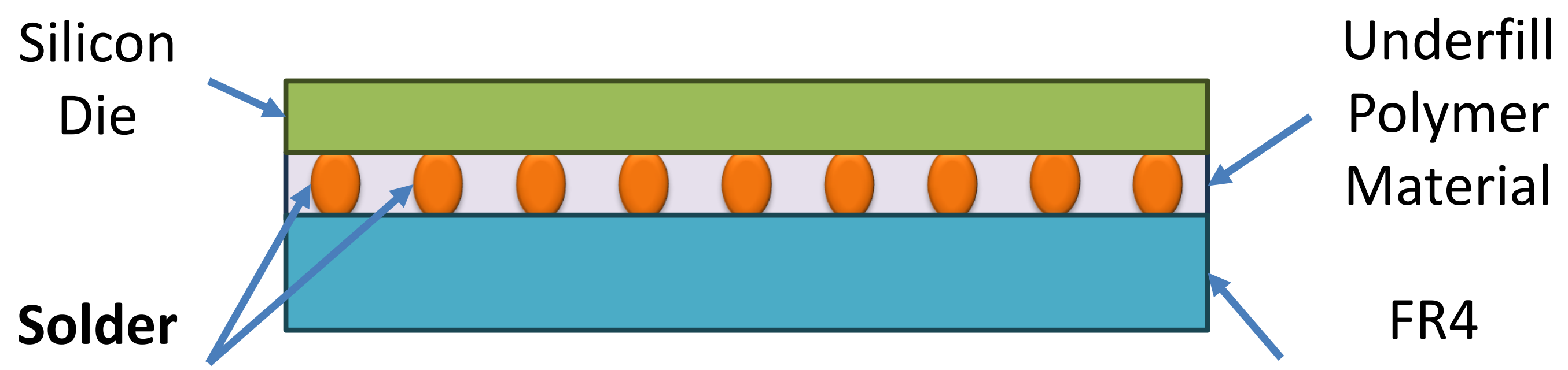

Figure 1: Flip-chip structure stack.

Results & Observations

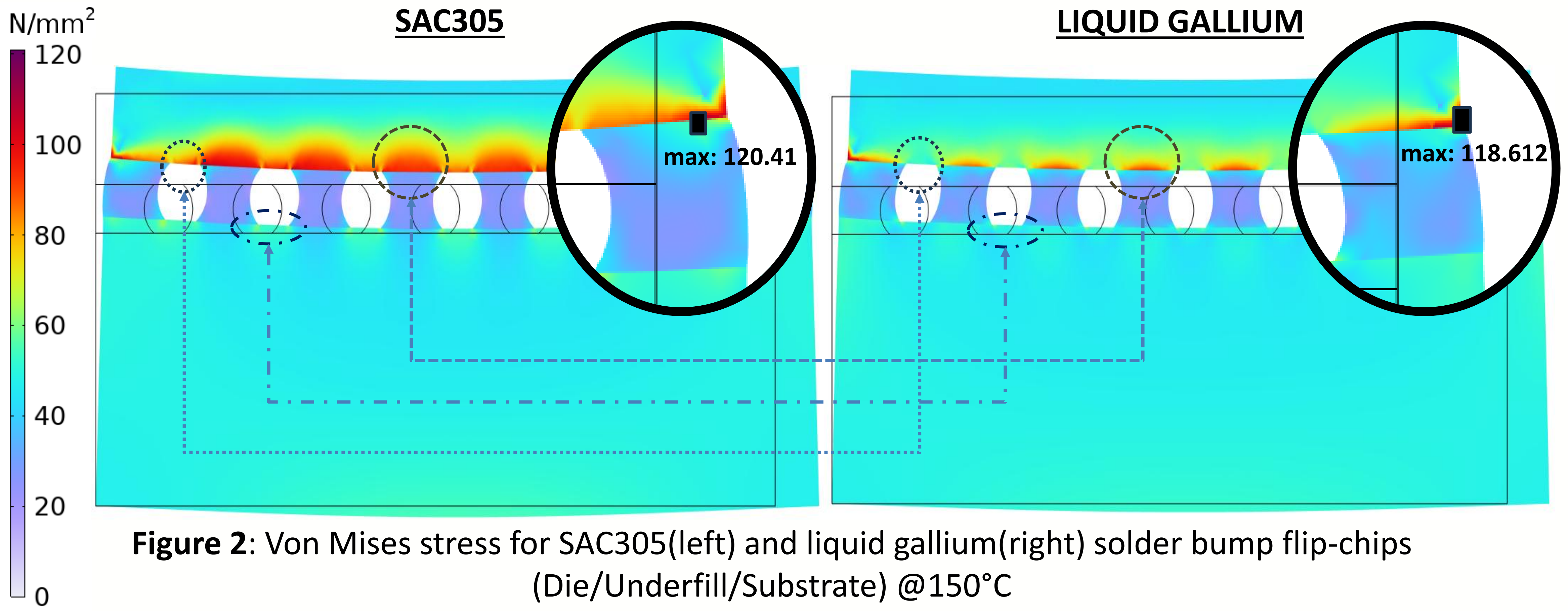

Figure 2: Von Mises stress for SAC305(left) and liquid gallium(right) solder bump flip-chips (Die/Underfill/Substrate) @150°C

- SAC305: Shear stress dominant→ Amplifies total stress
- LG: Pressure dominant→ Dissipates surrounding stress.
- Residual stress @30 °C in SAC305 = 66 N/mm² VS LG = 0
- Residual Warpage for SAC305 package @ 30 °C = 0.167 µm (figure 3)

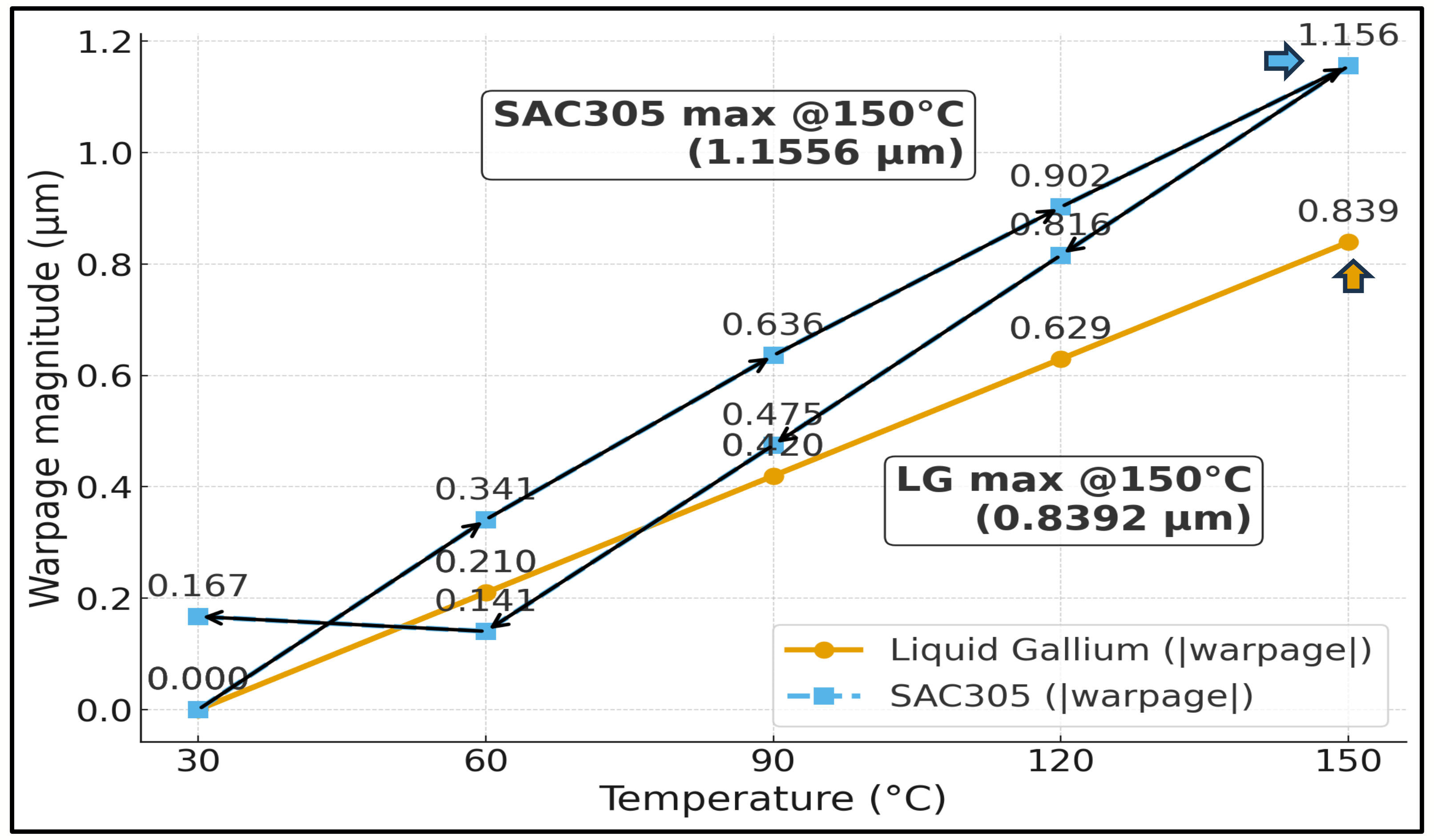

Figure 3: Warpage magnitude vs Temperature for SAC305 and LG flip-chips

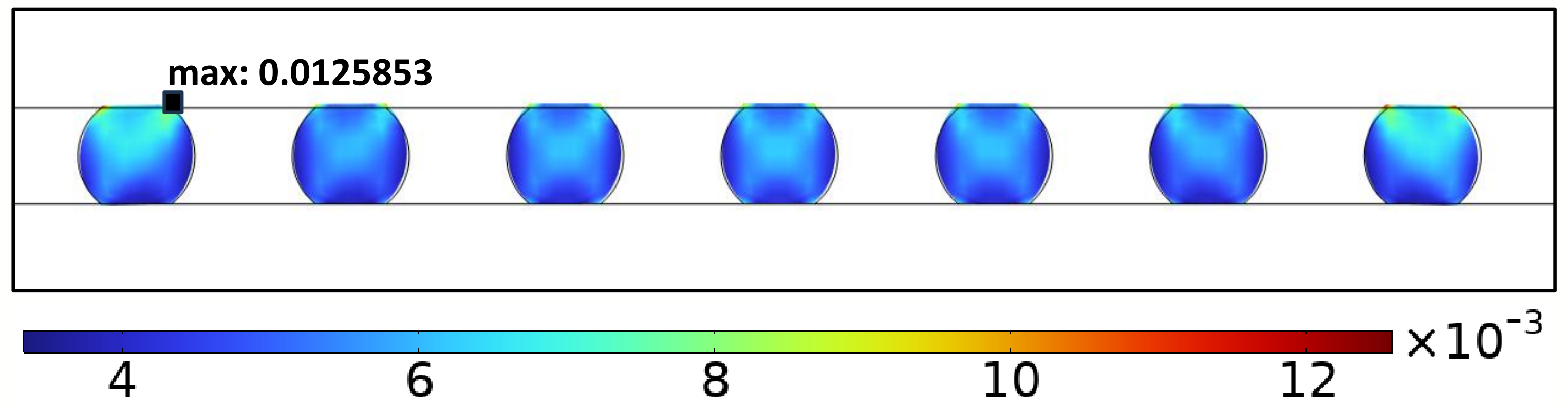

Figure 4: Residual plastic strain @ 30°C (Cooling)-SAC305

Objectives

- Validate an elastic trimetallic layer benchmark with <1% warpage deviation.
- Compare SAC305 vs Liquid Gallium flip-chips with identical geometry, constraints, and ΔT (30 → 150 → 30 °C)
- Quantify peak warpage and stress after heating, and residual warpage and stress after cooling.

Methodology & Modeling

1. Boundary Conditions: Point 1: (x = y = 0); Point 2: (y = 0)
2. Governing Equations:

Curvature relation:

$$\frac{1}{\rho} = \frac{2p}{q}\Delta T$$

Warpage:

$$w_{mid} = \frac{L^2}{8\rho}$$

Cavity pressure (Ga):

$$\Delta P = \frac{K\alpha_V \Delta T}{1 + \left(\frac{KC_{struct}}{V_0}\right)}$$

3. Validation Process:

- Using trimetallic strip→ 3 Layered Linear Elastic Model
- Analytical and simulated warpage agree to within 1%✓

Conclusion

- **Reliability**: Zero residual warpage and stress with LG → (lower risk of die-edge cracking) + (underfill/die-corner delamination) + (bump fatigue under thermal cycling) → **longer lifetime**.
- Liquid gallium's pressure load → reduces package stress → should help safety margins on flip-chip design.

Future Work

- Delamination & interfacial energy release rate (G).
- Multi-cycle (LCF) reliability modeling.

Acknowledgment

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