Enhancing Flip Chip Reliability with Gallium Liquid Metal Solder Joints

Motivation:

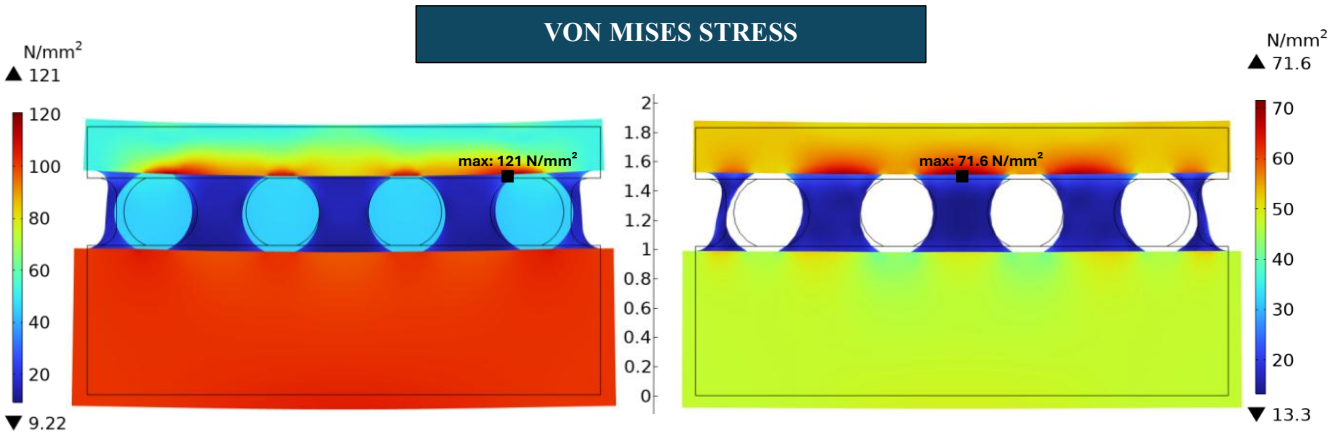
Conventional microelectronic solder materials like SAC305 in flip-chip packaging are prone to reliability issues such as cracking under thermal strain, especially in large-area chips that are pre-disposed to warpage issues. This research investigates whether liquid gallium as a solder material can improve package reliability by accommodating thermomechanically induced stress/warpage.

Approach:

- Used COMSOL Multiphysics to simulate two flip-chip assemblies with identical structures, but different solder materials: SAC305 and liquid gallium respectively (solder diameter = 0.49mm, solder pitch = 0.89mm).
- Conducted thermomechanical warpage simulations (30°C to 150°C) using COMSOL Multiphysics.
- Modeled liquid gallium as an incompressible fluid under laminar flow; SAC305 modeled with elastic-plastic behavior. Simulating the thin gallium oxide layer was computationally challenging at the microscale; hence the presence of the oxide layer was neglected in the finite element models.

Results and Discussion:

- **Liquid Gallium** showed a maximum Von Mises stress of **71.6 N/mm²**, compared to **121 N/mm²** for SAC305. Warpage reduced by **2.84×10^{-4} mm** when using liquid gallium.
- Equivalent plastic strain significantly lower in liquid gallium joints (**difference = 6.55×10^{-3}**).
- Liquid gallium exhibited uniform stress distribution and no localized plastic deformation.
- The peak stress location shifted from the solder-silicon interface (**SAC305 - left image**) to the underfill-silicon interface (**liquid gallium- right image**) when switching solder materials.



Conclusions and Future Work:

Liquid gallium shows promise as a solder material to complement or partially replace traditional SAC305, particularly for low-stress and thermal cycling-sensitive applications. Future work includes exploring alternative underfill materials, exploring alloys of gallium, and/or including the gallium oxide skin.