Bi-containing SnAgCu Alloys: Material property evaluation for advanced semiconductor devices

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Body sizes of high performance semiconductor devices have been increasing to meet performance and functionality demands. Stress and strain caused by mismatches in CTE between circuit boards and these components are exacerbated by these increases. Solder joint fatigue life can worsen because of these increases in stress and strain. New and potentially more creep resistant solder is needed to improve the long term reliability of the product. In this work we report preliminary mechanical testing results of SAC305 + Bi and also findings from a critical review of literature.

**Background**

> Liquidus projection of SAC phase diagram [1]
> 217°C eutectic temp
> Microconstituents may be predicted from phase diagram

**Creep in Solder:**

- Temperature dependent
- Stress dependent [3]
- Negatively affected by microstructural coarsening (includes IMC growth)
- SAC has higher dislocation activation energy than pure Sn [4]
- Three model equations
  - Hyperbolic sine (a.) [5]
  - Power law (b.) [5]
  - Anand model (c.) [6]

\[
a = A \sinh^n(B \phi) \exp \left( - \frac{Q}{RT} \right)
\]
\[
b \phi = A \exp\left( \frac{Q}{RT} \right) \left( \frac{\sigma}{\sigma_y} \right) \frac{1}{n}
\]

**Microstructure**

- β-Sn dendrites [2]
- Brittle IMCs form during annealing
  - Cu₅Sn₆
  - Ag₅Sn
- Bi addition strengthens for concentrations up to 2%
  - Reduces IMC formation

**Results**

- Bright, Bi precipitates
- IMC sediment ~0-75 μm above the interface
- Directional β-Sn dendrites
- IMC sediment ~0-50 μm above the interface

**Ball Shear**

- SAC305 + 3 wt% Bi possessed greatest shear strength
  - Fast shear (5 mm/s)
  - Slow shear (0.5 mm/s)
  - Linear increase in strength until 2 wt% Bi
  - x = ± 3 ± standard deviation

**Discussion**

- Average shear strength in different Bi %Bi from literature [8]
- Our shear strength data match with the literature

(a) - Large Ag₅Sn IMC plates with Bi matrix in solid solution of β-Sn at 1.5wt%Bi
(b) - Finer Ag₅Sn IMC plates, Bi precipitates at 3wt% [8]

**Material Properties**

- Stress-strain curves at elevated temperatures for SAC305 (a) and SAC_Q (Sn-3.4Ag-0.5Cu-3.3Bi) (b) showing experimental data and Anand model fit [9]
- Bi-containing alloys have higher yield strength compared to similar alloys with no Bi due to solidification strengthening and Bi precipitates.

- Fatigue behavior-aged SAC305(a), SAC_Q(b) [10]
- Bi-containing alloys tolerate higher stresses, longer aging without degrading cyclic fatigue properties

**Future Work**

- Bulk solder creep/tensile testing
- Comprehensive ball shear / microhardness testing
- Optical/BSE SEM microstructural imaging

**Summary**

Based on a review of ball shear data and literature, the team recommends the alloy SAC305 +2%Bi due to its improved mechanical properties over SAC305. The team recommends further testing of microhardness, ball shear performance, and bulk creep properties of this composition both aged and as-reflowed to better characterize the mechanical behavior.

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