Retarding the Cu-Sn and Ag-Sn Intermetallic Compounds in Cu/Sn-3.5Ag/Cu-15Zn Microbumps in 3D-IC Technologies

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Abstract

This study investigates the evolution of interfacial microstructures in Cu/Sn-3.5Ag/Cu and Cu/Sn-3.5Ag/Cu-15Zn (wt %) microbumps. Due to the small size of microbumps, Cu-Sn intermetallic compounds (IMCs) rapidly form from the Cu pads. These brittle IMCs occupy the entire joint and weaken joint reliability. Moreover, Ag₃Sn tends to precipitate inside the solder in large plates, which results in the accumulation of thermal stress due to a CTE mismatch between Ag₃Sn and β-Sn. It is demonstrated that doping Zn into one of the Cu substrates effectively suppresses the growth of Cu-Sn and Ag₃Sn IMCs. Owing to the effective suppression of Cu-Sn and Ag-Sn IMCs, Cu/Sn-3.5Ag/Cu-15Zn microbumps are potentially useful in strengthening the interconnections of novel 3D-IC technologies.

Experimental procedure

Morphology and Microstructure

In Cu/Sn-3.5Ag/Cu microbump:
- After reflow for 10 min, Cu₆Sn₅ and Cu₃Sn formed on both sides.
- Cu-Sn IMCs became thick after long-time reflow.
- Large Ag₃Sn plates formed randomly in the solder matrix.

In Cu/Sn-3.5Ag/Cu-15Zn microbump:
- After reflow, only Cu₆(Sn,Zn)₅ (no Cu₃Sn) formed on both side.
- No large Ag₃Sn was found in the solder matrix.
- Lots of small Ag₃Sn precipitated in the solder near Cu-Zn side.

Ag Distribution in the solder matrix

- Ag accumulated in a plate between the Cu₆Sn₅ layers.
- Ag remained more evenly distributed near the Cu-15Zn side.

Mechanical properties of IMCs

2. The Cu₆(Sn,Zn)₅ fracture toughness is 54% higher than the Cu₆Sn₅ one.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Composition (at.%)</th>
<th>Hardness (GPa)</th>
<th>Young's modulus (GPa)</th>
<th>Fracture toughness (MPa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu₆Sn₅</td>
<td>54.1 45.9</td>
<td>6.5 ± 0.2</td>
<td>130.2 ± 6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Cu₆(Sn,Zn)₅</td>
<td>55.1 42.2 2.7</td>
<td>5.4 ± 0.1</td>
<td>110.1 ± 15.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Conclusions

- A novel Cu-Zn UBM can solve reliability issues in 3D-IC.
- Fast growth of Cu-Sn compounds and Kirkendall voids were retarded by Zn effects.
- Large Ag₃Sn plates were inhibited by Zn.
- Cu₆(Sn,Zn)₅ enhanced the bonding strength due to the higher toughness.

Acknowledgements

The financial support from National Science Council, Taiwan, under the Contract No. NSC-97-2221-E-007-021-MY3 is gratefully acknowledged.