Introduction - 3D Integration & Through Silicon Via (TSV)

Through silicon via (TSV)

- Vertical electrical interconnection passing through the silicon

Why TSV for 3D integration?

- Pad area for wire bonding
- Long looped Au wire

< 3 chips + 2 interposers stack with wire bonding>

< 3 chips stack with TSV >

- Smaller package size
- Short interconnect length
Introduction - Former TSV Interconnection Methods & Limits

**<Cu-Sn Metal bonding>**

- TSV
- Metal bump
- Chip
- Substrate chip

**<Cu-Cu Metal/polymer hybrid bonding>**

- TSV
- Metal bump
- Chip
- Dielectric polymer
- Substrate chip

- Long bonding time (< minutes)
- Repeat of under-fill
- Void trap during under-fill

- Long bonding time (30min)
- Additional polymer patterning
- Semi-solid state after polymer patterning

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Introduction - Why TSV Conducting Adhesives (TCAs)/Solder Joint?

- What is TCA?

TSV + Conducting + Adhesive

- Substitution of underfill
- No need of patterning

- Bonding process with TCA

TSV & bumped wafer

Silicon wafer

Si chip with TCA

Pressure & temperature

*Patent issued: US6518097

*Wafer-level lamination of TCA on the wafer

Dicing of TCA-applied wafer

Chip to wafer bonding using TCA/solder joint

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Introduction - Why TCA/solder Hybrid Joint?

Features of TCAs

- No need of underfill & patterning
- Gap filling by resin flow
- Short bonding time
- Curing temperature
  - Joint stability
- Viscosity
  - Joint formation

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Experiments – Test Vehicles (TSV simulated SnAg coated Cu post bump)

Micro-bumped chip

- Substrate chip design
  - Dimension: 13 mm X 13 mm
  - Pads: 5 daisy resistance & 4 joint resistance circuits

- Bonding chip design
  - Dimension: 6 mm X 6 mm
  - Bump
    - Material: Cu/SnAg2.5
    - Height: 10/10 μm
    - Diameter: 40 μm
    - Pitch: 80 μm

Single Bump Joint resistance At the corner
Daisy resistance

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Experiments – TCAs Formulation

➢ Resin system

Curing agent + Thermosetting epoxy + Thermoplastic resin + Curing accelerator

Curing temperature

Thermo-mechanical properties

Viscosity

Curing speed

➢ TCA formulation

<table>
<thead>
<tr>
<th></th>
<th>TCA1</th>
<th>TCA2</th>
<th>TCA3</th>
<th>TCA4</th>
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</thead>
<tbody>
<tr>
<td>Curing temperature (°C)</td>
<td>160</td>
<td>185</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>Min. viscosity (Pa·s)</td>
<td>450</td>
<td>90</td>
<td>3000</td>
<td>600</td>
</tr>
<tr>
<td>(°C)</td>
<td>(130°C)</td>
<td>(160°C)</td>
<td>(130°C)</td>
<td>(120°C)</td>
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<tr>
<td>Curing speed @250°C(sec)</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>10</td>
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</tbody>
</table>

*Tg : 100 ~ 140 °C
Results - Effects of Curing of TCAs

- Real time viscosity & resistance change during the bonding

- Bonding with TCA1
  (160 °C, 450 Pa·s @ 130 °C)

- Bonding with TCA2
  (185 °C, 90 Pa·s @ 160 °C)

- TCA/solder hybrid joints were interconnected with the viscosity of 600 Pa·s.

Bonding condition
Pressure: 16.32 MPa
Temperature: 40~250 °C (5 °C/s)

Nano Packaging & Interconnect Lab.
Results – Effects of Viscosity of TCAs

- Real time viscosity & resistance change during the bonding

- Bonding with TCA1
  - (160 °C, 450 Pa·s @ 130 °C)
    - No bump interconnection

- Bonding with TCA3
  - (160 °C, 3000 Pa·s @ 130 °C)

- TCA/solder hybrid joints with high viscosity TCA were interconnected preby the softening of the TCA resin.

Bonding condition:
Pressure: 16.32 MPa
Temperature: 40~250 °C (5 °C/s)
Results - Joint Interconnection during the Bonding

➢ Bonding with TCA1

(160 °C, 450 Pa·s @ 130 °C)

Before bonding

Physical contact of the bumps

<Before bonding>

Metallurgical bonding

Increase of the contact area

<Metallurgical bonding>

No bump interconnection

Viscosity (|K|)

Daisy resistance (Ω)

Temperature (°C)

Bonding condition
Pressure: 16.32 MPa
Temperature: 40~250 °C (5 °C/s)
Result – 40 μm Fine Pitch Capability of TCA/solder Joints

➢ TCAs bonding with 40 μm pitch test vehicles

✓ Chip specification
  • Bump
    Material: Cu/SnAg
    Height: 10/10 μm
    Diameter: 20 μm
    Pitch: 40 μm

✓ Joint resistance

<table>
<thead>
<tr>
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<th>40 μm</th>
<th>80 μm</th>
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</thead>
<tbody>
<tr>
<td>Contact resistance (mΩ)</td>
<td>1.18</td>
<td>2</td>
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</table>

Successful bonding of 40 μm pitch TCA/solder hybrid joints in 10 sec!
Result – Humidity Test

85 °C/85 %RH test

No failure was found until 300 h of the humidity test for TCA/solder hybrid joints.
Conclusion & Ongoing Works

➢ Conclusion

1. TCA/solder hybrid joint was demonstrated for TSV interconnection using new TCA materials.
2. TCA material properties was designed for joint interconnection.
   - Curing temperature → joint stability
   - Viscosity → joint interconnection @ 600 Pa·s
3. 40 μm fine pitch capability was demonstrated in 10s bonding time.

➢ Ongoing works

1. Void elimination
2. Optimization of the TCA materials
   - Curing agent, epoxy, & thermo-plastic polymers
3. 3D TSV chip stacking using TCAs
   - Process & TCA properties optimization

**TCA/solder** as a new solution for the 3D-TSV vertical interconnection