Material based challenge and study of 2.1, 2.5 and 3D integration

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Packaging Solution Center
R&D Headquarters
Hitachi Chemical Co., Ltd.,
Outline

1. Hitachi Chemical Activity - Open Lab.-
2. Cu fine line fabrication regarding 2.1/2.5D
3. In-plane collective bonding with BFL film
4. Study of Vertical collective bonding
5. Summary
HC Production Lineup

- Materials for Buffer Coating
- Interlayer Dielectric Materials
- CMP Slurry for Cu/Barrier Metal
- CMP Slurry for STI
- Photo Sensitive Dry Film
- High Density Interposer
- Printed wiring boards
- Dicing Tape
- Underfill Material
- Epoxy Molding Compounds
- Die Bonding Film
- QFN Support tape
- Die Bonding Paste
- Liquid Encapsulant
- Solder Resist
- Build-up Materials
- Package Substrate
Activities of Packaging Solution Center

**Customers**

- Customer demands
- Propose the total solution

**Hitachi Chemical**

Packaging Materials

- Material Properties
- Reliability Evaluation
- Structure Analysis
- Package Assembly

**Hitachi Chemical Packaging Solution Center**

- / Adhesion
- / Elastic modulus
- / CTE etc.
- / Reflow resistance
- / TCT resistance
- / Warpage etc.
- / Stress Simulation
- / Warpage
- FEM: Finite Element Method
- / Wafer dicing
- / D/B, TCB bonding
- / Mold (Transfer / Compression)

**SEMICON Taiwan 2016**
Activity of Open Laboratory

Supports a materials & process in cooperation with customers

Conventional Process

New Process (Open Lab.)

Material Presentation

Submission of Sample (Interaction)

Customer’s Evaluation

Customer’s approval

Our Sample

Offered customer’s Device

Assemble test in Open Lab.

Fix the process condition & Propose the new materials combination / process with customer

Customer’s approval
Ex. Assembly Scheme in Open Lab.

/ Flip-chip, 3D, FO-WLP

- **Wafer (12inch)**
  - BG (Back grind)
  - DC (Blade Dicing)

- **Chip**
  - FC (Flip chip)
  - TCB (Thermal compression bonding)
  - R/F (Reflow)
  - UF (Underfill)

- **PCB (Printed circuit Board)**
  - MCL/DFR/SR

- **High Accuracy Analyze**
  - FC bonder (COW/TCB acceptable)

- **FO-WLP (300 mm Wafer)**
  - Compression Mold
  - UF EMCRM

- **Ex. Assembly Scheme in Open Lab.**
High Accuracy Analysis Equipment

**IR Microscope**  
Void Observation  
Spec  
- Magnification: < X 1,000  
- Resolution: 0.65 μm  
- 300 / 200 mm wafer

**3D X-rays**  
Bump Connection  
Spec  
- Resolution: < 0.10 μm  
- Magnification: < X 2000  
- Sample: 508 x 444 mm

**Shadow Moire**  
Warpage & CTE Evaluation  
Spec  
- Sample: 400 X 400 mm  
- Resolution: 3 μm  
- XYZ axis strain and CTE calculation

**SAM**  
Delamination Observation  
Spec  
- Sample: 350 x 350 mm  
- Resolution: 0.5 μm  
- Scan: 1,000 mm / sec

**SEM**  
X-section  
Spec  
- Resolution: 3.0 nm  
- Magnification: X 5 ~ X 300,000

**Strain Measuring Equipment**  
Strain Evaluation  
Spec  
- Magnification: < X 1,000  
- Sample size: φ 50 mm  
- Sample Thickness: 10 mm  
- Temperature: -100 ~ 420 °C
### Table. Evaluation examples for each advanced PKG in Open Lab.

<table>
<thead>
<tr>
<th>No.</th>
<th>Items</th>
<th>Specification</th>
<th>Hitachi chemical materials</th>
<th>TEG Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ultra-fine pitch FC PKG (2.1D/2.5D/3D PKG)</td>
<td>/Silicone &amp; Organic interposer / L/S=2/2 (w/customer) / Chip to Wafer to Substrate (CoWoS) / Bump pitch ; Min. 40 um / Ultra-low CTE core (CTE : &lt;2ppm) / Dry film resist of fine-pitch (L/S=2/2) / High Tg Solder resist (Liquid/Film)</td>
<td>/ Low stress underfill / RDL (Redistributed dielectrics) (Fine patterning, Low Dk type)</td>
<td>Top 4 stacked  Bottom die Substrate</td>
</tr>
<tr>
<td>2</td>
<td>Thin stacked PKC (Coreless PKG)</td>
<td>/ Die thickness : Min. 15 umt / DAF thickness : Min. 3 umt / Coreless prepreg : Min. 15 umt / Max. 32 Die stacked</td>
<td>/ Prepreg (Min. thickness : 15um) / Low CTE &amp; High modulus / Solder resist film / Thin DAF (Thickness : Min. 3-5um)</td>
<td>32 Die Stack</td>
</tr>
<tr>
<td>3</td>
<td>WLP (Fan out, Fan in type)</td>
<td>/ 12 inch / Panel size : Max. 640 x 495mm / RDL first &amp; RDL last process</td>
<td>/ Mold (Powder, Liquid, Film) / Temporary bonding film / RDL (Liquid, Film)</td>
<td>Panel mold (640x495) Chip (1564 chip)</td>
</tr>
<tr>
<td>4</td>
<td>Wearable PKG</td>
<td>/ Flip-chip assembly to FPC / Bendable &amp; Expandable</td>
<td>/ Low modulus mold materials (Liquid, Film &amp; High transparency) / Low stress underfill / Low temp. curable conductive paste (Paste, Film : 150°C bonding)</td>
<td>LED Flip chip</td>
</tr>
</tbody>
</table>
1. Hitachi Chemical Activity - Open Lab.

2. Cu fine line fabrication regarding 2.1/2.5D

3. In-plane collective bonding with BFL film

4. Study of vertical collective bonding

5. Summary
Fine line organic interposer technology is required.
Evaluation specification of Cu fine line

Structure of the test vehicle

Cu wiring was prepared by Semi-additive process

Si substrate

Organic substrate

AS-500HS: Low loss dielectric material

Multi Layer structure

Primer layer

New high-functional resin system

Material properties

<table>
<thead>
<tr>
<th>Items</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg (TMA)</td>
<td>201 ºC</td>
</tr>
<tr>
<td>CTE (30-120ºC) / (200-250ºC)</td>
<td>18 / 42 ppm/ºC</td>
</tr>
<tr>
<td>Elastic modulus (40ºC)</td>
<td>11.0 GPa</td>
</tr>
<tr>
<td>Dk / Df (5GHz)</td>
<td>3.3 / 0.0034</td>
</tr>
</tbody>
</table>
Cu fine line fabrication on Si & Organic Sub.

<table>
<thead>
<tr>
<th>Test vehicle</th>
<th>Comb electrode</th>
<th>L/S-2/2 (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si substrate</td>
<td><img src="image1" alt="Comb electrode image" /></td>
<td><img src="image2" alt="L/S-2/2 image" /></td>
</tr>
<tr>
<td>Organic substrate</td>
<td><img src="image3" alt="Comb electrode image" /></td>
<td><img src="image4" alt="L/S-2/2 image" /></td>
</tr>
</tbody>
</table>
Cu fine line fabrication results on Si (Cross section)

<table>
<thead>
<tr>
<th>L/S (μm)</th>
<th>X250</th>
<th>x1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>3/3</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>5/5</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>7/7</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td>10/10</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
</tr>
</tbody>
</table>
Cu fine line fabrication results on Si (Top view)

<table>
<thead>
<tr>
<th>L/S=2/2 μm</th>
<th>L/S=3/3 μm</th>
<th>L/S=5/5 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="x1000" alt="Image" /></td>
<td><img src="x1000" alt="Image" /></td>
<td><img src="x1000" alt="Image" /></td>
</tr>
<tr>
<td><img src="x5000" alt="Image" /></td>
<td><img src="x5000" alt="Image" /></td>
<td><img src="x5000" alt="Image" /></td>
</tr>
</tbody>
</table>
Laser via drilling and b-HAST evaluation results

Top view of via

Cross section of filled via

Laser : 355 nm
Via diameter: 83 μm (Top)
77 μm (Bottom)

b-HAST evaluation results of L/S=2/2 μm

Microscopic observation results after b-HAST

Degradation of insulation wasn’t observed at 130°C / 85%Rh for 200 hours.
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5. Summary
Status of 2.5/3D technology

2.5/3D technology has been adopted only for high end products.

Productivity enhancement of 2.5/3D may contribute to expand the market.

3D die stacking usually uses TCB (Thermal Compression Bonding).

- TCB has many advantages in flip chip bonding,
- The productivity isn’t high enough.

Source: Yole D
Bonding technology for 2.5/3D

Thermal compression bonding (TCB) is used for 2.5/3D die stacking

- TCB process for flip chip bonding.

<table>
<thead>
<tr>
<th>Item</th>
<th>TCB process</th>
<th>Mass reflow process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine pitch interconnection</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Warped die assembly</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Productivity</td>
<td>Poor</td>
<td>Good</td>
</tr>
</tbody>
</table>

C4: Mass Reflow Process

TCB: Compression Bonding

Line process

One by one process

Improvement of the low productivity is important to meet the various demands of the advanced packages like 2.5 and 3D multi die stacking.
## How to enhance TCB productivity?

### One die bonding by one process vs. Plural die bonding by one process

<table>
<thead>
<tr>
<th>Bonding type</th>
<th>Process image</th>
<th>Concern</th>
<th>Material solution</th>
</tr>
</thead>
</table>
| In-plane collective   | ![Process Image](image1.png) | ➢ Height deviation of bump and pad  
➢ Substrate topology | BFL (bonding force leveling)  
Film                                    |
| Vertical collective   | ![Process Image](image2.png)   | ➢ Temperature deviation among dies      | High thermal conductive material    |
| 3D collective         | ![Process Image](image3.png)   | ➢ Height deviation of bump and pad  
➢ Substrate topology  
➢ Temperature deviation among dies | Combination of above 2 ?               |
Improvement of productivity in TCB process

◆ Conventional TCB process

- Die by die sequential process steps
  - Die pick up
  - Pre-bonding
  - Main bonding
  - Head cooling

◆ In-plane collective bonding

- Die by die sequential process steps
  - Die pick up
  - Pre-bonding
  - Multi dies main bonding
There are unevennesses of bump height and pad thickness, unflatness of substrate surface and unparallelism of bonding head to the stage. Those may cause the die shift and the less bonding force.
The new film inserted between the head and the dies can level the applied bonding force among the multi pre-placed dies.
Items
Evaluation of leveling performance of insertion film by smashed Au bump.

Model
Die size: 7.3 mm x 7.3 mm
Die thickness: 300 μm
Bump: Plated Au
Bump count: 544
Bump pitch: 50 μm (peripheral)
Bump height: 16 μm

Method & condition
Analysis method: FEM analysis
Elastic-plastic Simulation

The head was inclined to one corner which was 10 μm lower than the diagonal corner.

Bonding force: 0 - 100N (vertical direction)
Head (Rigid body)
Film
Die  Si E=183 GPa
Au bump E=75 GPa (Yield stress=180 MPa)

Various types of the films were evaluated.
### Simulation Results of leveling performance

<table>
<thead>
<tr>
<th>Film</th>
<th>Without film</th>
<th>Thermoplastic resin film</th>
<th>Thermosetting resin film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of film</td>
<td>-</td>
<td>500 MPa</td>
<td>1.0 GPa</td>
</tr>
<tr>
<td>(at 25 °C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model of Contact</td>
<td>Head</td>
<td>Head</td>
<td>Head</td>
</tr>
<tr>
<td></td>
<td>Die</td>
<td>Film</td>
<td>Film</td>
</tr>
<tr>
<td>Deformation of Au bump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The maximum difference</td>
<td>7.8 μm</td>
<td>7.0 μm</td>
<td>1.9 μm</td>
</tr>
</tbody>
</table>

- The position of head was inclined to one corner which was 10 μm lower than the diagonal corner.

- The thermosetting resin film insertion was very effective to the leveling of the bonding force.
Function thermosetting BFL film

The BFL film is set up between the head and the dies which are pre placed on the substrate.

Firstly, the compensating the height difference among the dies where the thermosetting resin layer melts and flows, and then cured.

Next, the multi die bonding where the bonding force is applied through the cured resin layer to change the shape of the resin to fit each die height.
The bonding force leveling effect by BFL film

* The film less press reflects the incline of the head to the bump height.
* The insertion of BFL film made the bump height deviation smaller than that of PTFE film.

Die size: 7.3 mm x 7.3 mm
Die thickness: 300 μm
Bump: Au plated
Bump pitch: 50 μm (peripheral)
Bump height: 16 μm

Bonding head was inclined to one corner which was 10 μm lower than the diagonal corner.*1

<table>
<thead>
<tr>
<th>Film</th>
<th>Without film</th>
<th>PTEF film</th>
<th>BFL film (Thermosetting resin layer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smashed bump height</td>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>9.3 μm</td>
<td>7.1 μm</td>
<td>3.5 μm</td>
</tr>
</tbody>
</table>
The effect of the elastic modulus of thermosetting resin layer on BFL

5 types of the cured BFL film which had different elastic modulus

Die size: 7.3 mm x 7.3 mm
Die thickness: 300 μm
Bump: Plated Au
Bump pitch: 50 μm (peripheral)
Bump height: 16 μm

Die was forced by the head to the stage at 260 °C for 5s.

Observed difference of bump height = A - B
(The density of Au bump is different from A in B)

- Elastic modulus of the cured thermosetting resin layer has higher bonding force leveling performance.
In-plane collective bonding experiment

- **Bonding condition**

<table>
<thead>
<tr>
<th>Methods of Bonding</th>
<th>Pulse heat</th>
<th>Constant heat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Die placement</td>
<td>Multi bonding</td>
</tr>
<tr>
<td></td>
<td>1st step</td>
<td>2nd step</td>
</tr>
<tr>
<td>Bonding force</td>
<td>N/die</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>5</td>
</tr>
<tr>
<td>Bonding temperature</td>
<td>°C</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>5</td>
</tr>
<tr>
<td>Stage temperature</td>
<td>°C</td>
<td>80</td>
</tr>
</tbody>
</table>

- **Equipment**

  Die placement: LFB-2301 (Shinkawa Ltd.)
  Multi dies main bonding: HTB-MM (Alpha Design Co., Ltd)
  
  - Bonding head temperature: max. 450°C (Pulse heating)
  - max. 300°C (Constant heating)
  - Bonding force: 100 N - 5000 N
  - Head size: 60 mm x 70 mm (Pulse heating)
  - 100 mm x 100 mm (Constant heating)
Set up of in-plane collective bonding

- Die size: 7.3 mm x 7.3 mm
- Die thickness: 100 μm
- Bump: Cu pillar
- Bump pitch: 80 μm (Peripheral) + 300 μm (Core area)
- Bump height: 45 μm

- Cu trace of substrate: 15 μm
- Substrate thickness: 0.36 mm

1. **5 singulated die and substrate**

   - Pulse heating

2. **15 dies on a single substrate**

   - Constant heating

---

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### In-plane collective bonding with BFL film

<5 dies of singulated test vehicles>

<table>
<thead>
<tr>
<th>Item</th>
<th>Without film</th>
<th>PTFE film</th>
<th>BFL film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy chain test (NG/Total)</td>
<td>0/5</td>
<td>0/5</td>
<td>0/5</td>
</tr>
<tr>
<td>Die shift of the bonding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of die shift</td>
<td>14.0 μm</td>
<td>11.1 μm</td>
<td>3.1 μm</td>
</tr>
<tr>
<td>C-SAM observation of die A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **The BFL film shows good performance not only in the daisy chain test, but also die shift and C-SAM observation.**

---

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In-plane collective bonding with BFL film

<15 dies on a single substrate>

<table>
<thead>
<tr>
<th>Item</th>
<th>Without film</th>
<th>PTFE film</th>
<th>BFL film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy chain test (NG/Total)</td>
<td>14/15</td>
<td>7/15</td>
<td>0/15</td>
</tr>
<tr>
<td>Die shift of the bonding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average of die shift</td>
<td>29.4 μm</td>
<td>26.6 μm</td>
<td>5.3 μm</td>
</tr>
<tr>
<td>C-SAM observation of die A</td>
<td>×</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

- The BFL film suppressed the die shift more effectively than the others at 15 dies collective bonding.
- The throughput of the process based on the main bonding condition was calculated to be 2700 UPH.
Thank you for attention!
The entry contents of these data based on the results of our experiment done until April 2016 do not guarantee their characteristic values. The contents may be revised according to new findings if necessary. Please examine the process and the condition carefully and confirm before mass production.