Advanced Interconnect with Laser Assisted Bonding

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LASER

- Light Amplification by Stimulated Emission of Radiation

Absorption

Spontaneous emission

Stimulated emission

→ Light amplification

- Optical pumping
- Electron excitation
- Inelastic atom-atom or molecule-molecule collisions
- Chemical reaction

Resonator

Laser medium

Pumping

Laser output

- Solid
- Gas
- Liquid
- Semiconductor
LASER

• Laser Property
  - Directional
  - Monochromaticity
  - coherence
How Many LASER Applications?

- Laser Related Industry & Application

<table>
<thead>
<tr>
<th>Office</th>
<th>Medical</th>
<th>Entertain</th>
<th>Industry</th>
<th>Military</th>
<th>Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>LASER pointer</td>
<td>LASER Toning</td>
<td>SF Movies</td>
<td>Measurement</td>
<td>LASER Weapons</td>
<td>LASER Marking</td>
</tr>
<tr>
<td>LASER Mouse / Keyboard</td>
<td>LASER Depilation</td>
<td>Laser Show</td>
<td>Welding / Cutting</td>
<td>LASER LADAR</td>
<td>LASER SAW</td>
</tr>
<tr>
<td>LASER Beam projector</td>
<td>LASIK / LASEK</td>
<td></td>
<td>Heating</td>
<td>LASER Sensor</td>
<td>LASER Drilling</td>
</tr>
<tr>
<td>LASER Printer</td>
<td>Alzheimer Remedy</td>
<td>Laser Barcode Scanner</td>
<td>Defect Inspection</td>
<td>LASER Security</td>
<td></td>
</tr>
<tr>
<td>CD &amp; DVD Writer</td>
<td>Cancer Surgery</td>
<td>Marking</td>
<td>Communication s</td>
<td>Others</td>
<td>LASER Bonding</td>
</tr>
</tbody>
</table>
Introduction (Laser Assisted Bond)

IR Laser

1~2 sec Laser Emission

Die
Introduction (Laser Assisted Bond)

- Laser Assisted Bond (LAB) is the new interconnection technology using laser as a thermal energy for wetting between die bump and substrate pad and others.
- Key is to emit homogenized & die sized laser beam on Laser and this laser power heat up the die only.

(Side view) Laser Emission on Die

Homogenized & die sized laser
LAB Process Flow

- 1st application is to replace ‘Mass reflow’ process for Flip-chip devices.

1. Substrate Plasma
2. Flux dipping
3. Flip chip attach
4. LAB
5. Flux cleaning
6. Bake
7. Plasma

8. Underfill
9. Underfill Cure

To replace Mass Reflow

* Note: Difference in between conventional Mass Reflow and Laser Assisted Bond (LAB) is only reflow part. Therefore, LAB process is very easy to apply in matured process. However, there are big difference in thermal budget & related stress perspectives beneficially.
LAB (Laser Assisted Bond) vs MR (Mass Reflow)

• Key Process Comparison
  - MR (Mass reflow): High thermal budget, Higher warpage
  - LAB: Less thermal budget (1~2sec only), Less warpage
Process concept

• Low thermal stress
  - Limited die / PCB extension as applying optimized energy for interconnection
Process concept

- Fast bonding (Same UPH as Mass reflow)
  - 1sec bonding time / unit (2200uph for 56up strip fcCSP)

![Graph showing LAB profile & UPH](image-url)
MR vs. LAB – FCBGA 400um Core

- Test vehicle

<table>
<thead>
<tr>
<th>Body Size</th>
<th>Die Size</th>
<th>Die Thickness</th>
<th>Bump Type</th>
<th>UBM Size</th>
<th>Bump Height</th>
<th>Bump Pitch</th>
<th>Core Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>60mm</td>
<td>23x23mm</td>
<td>780um</td>
<td>Cu Pillar</td>
<td>80um</td>
<td>40(Pillar)/30(Cap)</td>
<td>130um</td>
<td>400um</td>
</tr>
</tbody>
</table>

- Bump Interconnection
  - Bump tearing at MR in 400um core thickness
    - Nominal MR(Mass Reflow) Process has its substrate warpage risk in thin core thickness
  - Good joint formation w/o bump tearing at LAB in 400um core thickness
    - Advantage of low thermal budget on substrate by short reflow time with customized beam(heating) area

<table>
<thead>
<tr>
<th>MR (T0)</th>
<th>LAB(T0)</th>
<th>MR (TCBx700)</th>
<th>LAB (TCBx1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bump tearing after MR</td>
<td>No issue after LAB</td>
<td>MR Fails</td>
<td>LAB Passes</td>
</tr>
<tr>
<td><img src="image1" alt="Bump tearing after MR" /></td>
<td><img src="image2" alt="No issue after LAB" /></td>
<td><img src="image3" alt="MR Fails" /></td>
<td><img src="image4" alt="LAB Passes" /></td>
</tr>
</tbody>
</table>
MR vs. LAB – FCBGA Coreless sub

- **Test vehicle**

<table>
<thead>
<tr>
<th>Body Size</th>
<th>Die Size</th>
<th>Die Thickness</th>
<th>Bump Type</th>
<th>UBM Size</th>
<th>Bump Height</th>
<th>Bump Pitch</th>
<th>Core Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>45mm</td>
<td>20x16mm</td>
<td>780um</td>
<td>Cu Pillar</td>
<td>70um</td>
<td>40(Pillar)/15(Cap)</td>
<td>150um</td>
<td>Coreless</td>
</tr>
</tbody>
</table>

- **Bump Interconnection**
  - Non-wet bump at MR in Coreless type
    - Encountered 33% of non-wet after chip attach reflow due to high substrate crying warpage
  - **Good joint formation w/o Non-wet at LAB in Coreless type**
    - Confirmed good interconnection and no non-wet bump after applying LAB
FCCSP (SAP & ETS pad)

• Purpose
  - To confirm LAB performance on SAP & ETS pad

• Result
  - Good interconnection on both SAP & ETS pad

<table>
<thead>
<tr>
<th></th>
<th>SAP</th>
<th>ETS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>mSAP</th>
<th>ETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Die size</td>
<td>10.3 x 10.7</td>
</tr>
<tr>
<td></td>
<td>UBM / Bump height (Cu/Ni/SnAg)</td>
<td>40x70um / 58um (35/3/20um)</td>
</tr>
<tr>
<td></td>
<td>Bump Pitch</td>
<td>90/180um</td>
</tr>
<tr>
<td>Package</td>
<td>Type</td>
<td>FC CSP</td>
</tr>
<tr>
<td></td>
<td>Size</td>
<td>14x14</td>
</tr>
<tr>
<td></td>
<td>Pad pitch</td>
<td>0.4mm</td>
</tr>
<tr>
<td>PCB</td>
<td>PCB type</td>
<td>mSAP(2L, 0.226T)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETS(3L, 0.172T)</td>
</tr>
</tbody>
</table>
### Molecular Energy Levels

- Types of energy levels and their transition wavelengths

<table>
<thead>
<tr>
<th>Level</th>
<th>Atoms</th>
<th>Molecules</th>
<th>Approximate $\lambda$ of most transitions</th>
<th>Energy transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic</td>
<td>Yes</td>
<td>Yes</td>
<td>Visible or ultraviolet</td>
<td>Atom / Molecular deformation</td>
</tr>
<tr>
<td>Vibrational</td>
<td>No</td>
<td>Yes</td>
<td>Near infrared</td>
<td>Medium heating</td>
</tr>
<tr>
<td>Rotational</td>
<td>No</td>
<td>Yes</td>
<td>Far infrared</td>
<td>Medium heating</td>
</tr>
</tbody>
</table>

- Electronic, Vibrational, and Rotational Levels for a hypothetical molecule
Laser application per power density

- 100W~300W/cm² Power density is POR for LAB process which is much less power density than Laser marking power density.

<table>
<thead>
<tr>
<th>LAB Power Density</th>
<th>Heating</th>
<th>Melting</th>
<th>Evaporation</th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>100~300 W/cm²</td>
<td>&lt;10⁵ W/ cm²</td>
<td>~10⁵ W/ cm²</td>
<td>~10⁷ W/ cm²</td>
<td>&gt;10⁹ W/ cm²</td>
</tr>
</tbody>
</table>

Energy Increase
LAB evaluation W/ Functional Device

**Purpose**
- To confirm Electrical performance & Reliability test after LAB

**Information & Result**

<table>
<thead>
<tr>
<th>PKG</th>
<th>BD size</th>
<th>Die size</th>
<th>Pitch</th>
<th>Si Node</th>
<th>Electrical test test</th>
<th>Reliability test test</th>
</tr>
</thead>
<tbody>
<tr>
<td>fcCSP</td>
<td>15x15mm m</td>
<td>12x12mm m</td>
<td>55/110um m</td>
<td>28nm</td>
<td>182/182 (100%)</td>
<td>MRT(L3) TCBx1500 HTS1500hrs</td>
</tr>
<tr>
<td>fcCSP</td>
<td>15x15mm m</td>
<td>10x10mm m</td>
<td>130um</td>
<td>16nm</td>
<td>40/40 (100%)</td>
<td>MRT(L3) TCBx1000 HTS1000hrs</td>
</tr>
</tbody>
</table>
LAB evaluation W/ Functional Device

- Interconnection state
  - No abnormality

<table>
<thead>
<tr>
<th></th>
<th>EOL</th>
<th>MRT(L3)</th>
<th>MRT(L3)+TCBx1000</th>
<th>HTS1000hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral</td>
<td><img src="Peripheral_EOL.png" alt="Image" /></td>
<td><img src="Peripheral_MRTL3.png" alt="Image" /></td>
<td><img src="Peripheral_MRTL3+TCBx1000.png" alt="Image" /></td>
<td><img src="Peripheral_HTS1000hrs.png" alt="Image" /></td>
</tr>
<tr>
<td>Core</td>
<td><img src="Core_EOL.png" alt="Image" /></td>
<td><img src="Core_MRTL3.png" alt="Image" /></td>
<td><img src="Core_MRTL3+TCBx1000.png" alt="Image" /></td>
<td><img src="Core_HTS1000hrs.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Laser effect on die active area

• Inspection method: FIB after Laser on die
• Device: 28nm Functional die (W/ Memory function)
• Condition

<table>
<thead>
<tr>
<th>Leg</th>
<th>Power (W)</th>
<th>Emission time (Sec)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Raw die</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>1</td>
<td>POR condition</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>1</td>
<td>Higher power</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>4</td>
<td>Higher power &amp; longer emission time</td>
</tr>
</tbody>
</table>

• Result: No abnormality on functional & metal / Low K layer
Laser effect on die active area

- **Result**
  - FIB result (Leg 1 – Raw die, Control unit)

<table>
<thead>
<tr>
<th>Core</th>
<th>Peripheral</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Core Image]</td>
<td>![Peripheral Image]</td>
</tr>
</tbody>
</table>
Laser effect on die active area

- **Result**
  - FIB result (Leg 2 – 200W / 1 sec)
  - No abnormality
Laser effect on die active area

• Result
  – FIB result (Leg 3 – 400W / 1 sec)
  – No abnormality
Laser effect on die active area

• Result
  – FIB result (Leg 4 – 400W / 4 sec)
  – No abnormality
LAB - LASER Assisted Bonding
Interconnection positioning

- UPH advantage
- Bump count
- Fine pitch availability
- Si Node
- Large die / Thin die
- Thermal stress

Legend:
- MrCuP
- QLR(TCCUF)
- TCNCP
- LAB
Appendix
PCB warpage

- 60mm BD & 400um Core
  - 40~50um PCB warpage on Die area @ 225°C HT

* Typical Max Warpage at 225 deg.C
Die warpage

- 12x12mm size / 100um thickness
- 50um die warpage (Smile type) @ 217°C HT
Light Transmission

\[ I(x) = I_0 \exp(-ax) \]

Where:
- \( I \) = light intensity at distance \( x \) into the Si
- \( I_0 \) = light absorbed by the back of the Si
- \( a \) = absorption coefficient 96 cm\(^{-1}\) at 980 nm

Light Transmission at 980 nm wavelength
- 100 um thick die: \( I/I_0 = \exp(-96/100 \times \text{cm}) = 0.382 = 38.2\% \)
- 760 um thick die: \( I/I_0 = \exp(-96/760 \times \text{cm}) = 0.0006782 = 0.07\% \)

Light Transmission at 1070 nm wavelength
- 100 um thick die: \( I/I_0 = \exp(-8/100 \times \text{cm}) = 0.932 = 93.2\% \)
- 760 um thick die: \( I/I_0 = \exp(-8/760 \times \text{cm}) = 0.544 = 54.4\% \)
The reflectivity of a polished silicon wafer is determined from the complex refractive index.
MR vs. LAB – FCBGA Coreless sub

- Coreless FCBGA W/ LAB
  - 52.5mm BD, 19.7x19.2mm Die, Eutectic, 160um pitch, Coreless 12+1 PCB
  - LAB : Good interconnection & stable joint height

<table>
<thead>
<tr>
<th>Position</th>
<th>Left</th>
<th>Center</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td><img src="left_top.png" alt="Image" /></td>
<td><img src="center_top.png" alt="Image" /></td>
<td><img src="right_top.png" alt="Image" /></td>
</tr>
<tr>
<td>Core</td>
<td><img src="left_core.png" alt="Image" /></td>
<td><img src="center_core.png" alt="Image" /></td>
<td><img src="right_core.png" alt="Image" /></td>
</tr>
<tr>
<td>Bottom</td>
<td><img src="left_bottom.png" alt="Image" /></td>
<td><img src="center_bottom.png" alt="Image" /></td>
<td><img src="right_bottom.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- Mass Reflow
  - 72.7um
  - 61.5um
  - 72.2um