Flexible Manufacturing Platform for High Volume TCB and High Density FOWLP

Tom Strothmann
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IEEE CPMT SCV Meeting

Agenda

- Advanced Packaging Market Trends
- Flexibility of the APAMA Bonder Systems
- High Accuracy Flip Chip Die Placement
- FOWLP Die Placement Capability for C2W
### Packages Using Stacked Die

- Two of the leading edge stacked memory products are currently assembled using TCB and drive the highest demand.
- **High Bandwidth Memory (HBM)** is used primarily for graphics applications:
  - JEDEC standard for high density parallel interface
  - Assembled on interposers to enable high-density routing
  - HBM uses Chip-to-Wafer (C2W) TC bonders
- **Hybrid Memory Cubes (HMC)** are used in high-performance computing:
  - High speed serial interface
  - Assembled on laminate with chip-to-substrate (C2S) TC bonders

Source: TechSearch International, Inc.
FOWLP Revenue Forecast
(source Yole Developpement)

K&S Semiconductor Assembly Equipment

K&S Offers the Full Range of Semiconductor Assembly Equipment
APAMA Advanced Packaging Platforms

- Wafer-Level Interface and Encapsulation
- Wafer-Level Electrical Redistribution
- Flip-chip & Wafer-Level Stacking and Integration

Source: Yole Development

APAMA Advanced Packaging Platforms

- C2S/C2W TCB
- C2W HD FOWLP
- C2S/C2W TCB
- C2W TCB
- C2S/C2W HA FC

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APAMA™ Thermocompression Bonders

- APAMA C2S TC Bonder
- APAMA C2W TC Bonder

- High Accuracy design of the APAMA TCB platforms enable high capability in adjacent markets
- Improved accuracy over existing die placement solutions
- C2S and C2W platforms can be adapted for High Accuracy Flip Chip die placement (HAFC)
- C2W platform can be adapted to FOWLP die placement
  - FOWLP die placement can be Face Up or Face Down

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Assembly Cost as a Function of Throughput TCB Compared to Mass Reflow

<table>
<thead>
<tr>
<th></th>
<th>Die</th>
<th>Subst.</th>
<th>C2/TC</th>
<th>Other Assem.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2-CUF</td>
<td>11.96</td>
<td>0.58</td>
<td>0.77</td>
<td>4.33</td>
<td>17.64</td>
</tr>
<tr>
<td>TC-CUF</td>
<td>11.96</td>
<td>0.58</td>
<td>0.84</td>
<td>4.29</td>
<td>17.67</td>
</tr>
<tr>
<td>TC-NCP</td>
<td>11.96</td>
<td>0.58</td>
<td>1.24</td>
<td>4.10</td>
<td>17.88</td>
</tr>
</tbody>
</table>

Results show very little difference between mass reflow and thermo-compression.

Higher costs for TC-NCP is due to high materials cost - Material cost will go down during HVM transition.

Savantsys Cost Model

High UPH TC Bonding (TC-NCF and TC-CUF)

- Optimize equipment design with guiding principals for movement efficiency
  - Bond head, die and target material movement during each cycle
- Maximize parallel functions in the process whenever possible
- Analyze and optimization of each program segment
- Reduce the range of temperature cycling required by the bond head
  - Temperature cycling is required for each die bond cycle
  - Reducing the range greatly improves the process UPH
  - Fast and linear heating (350°C/sec )
  - Slower and non-linear cooling (125°C/sec)
  - Consumes valuable process time
    - Conventional TC-NCF process ~30%

Today's TC Bonders Running in Production
Small cost difference at 1000 UPH

The Cost of TCB is Competitive at High UPH

Cooling Wait 31%
Heating
### TCB Local Reflow Process Options

<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>UPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-applied Underfill</td>
<td>• Die is underfilled during TCB&lt;br&gt;• Mature process</td>
<td>• Potential tool contamination&lt;br&gt;• Void-free underfill requires dwell&lt;br&gt;• Longer bond times to ensure curing</td>
<td>• Current 1000+&lt;br&gt;• Future 1500</td>
</tr>
<tr>
<td>Paste (NCP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-applied Underfill</td>
<td>• Die is underfilled during TCB&lt;br&gt;• Less chance for tool contamination than paste&lt;br&gt;• Hot transfer at 150°C is now possible for high UPH</td>
<td>• Void-free underfill requires dwell&lt;br&gt;• Large temperature changes required</td>
<td>• Current 1100+&lt;br&gt;• Future 2000+</td>
</tr>
<tr>
<td>Film (NCF)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dip Flux</td>
<td>• No chance of tool contamination&lt;br&gt;• Very short bonding process times&lt;br&gt;• Low forces even for high bump counts</td>
<td>• Requires flux cleaning&lt;br&gt;• Requires post-bond CUF&lt;br&gt;• More stress on bonds before CUF&lt;br&gt;• Cooling to &lt; 80°C at fluxing station</td>
<td>• Current 900+&lt;br&gt;• Future 1500</td>
</tr>
<tr>
<td>Substrate Flux</td>
<td>• Fluxing processes demonstrated&lt;br&gt;Very fast and very limited bond head temp changes per cycle</td>
<td>• Requires flux cleaning&lt;br&gt;• Requires post-bond CUF&lt;br&gt;• More stress on bonds before CUF</td>
<td>• Prototyped 1000+&lt;br&gt;• Future 2500+</td>
</tr>
</tbody>
</table>

High UPH process capability has been demonstrated for both NCF and Substrate Flux processes.

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### Improving NCF Throughput

- NCF has been limited to a die transfer temperature <80°C to avoid handling damage to the film when it becomes tacky.
- New handling techniques have been developed to allow the NCF to be transferred at 150°C.
- This improvement enables NCF to become one of the highest throughput options for stacked die TCB or die on interposer processes.
UPH NCF Hot Transfer Process

- Process without intermediate dwells achieves a UPH over 1700
- UPH is improved by 500 over the same process with an 80°C transfer temperature
- Assumes 80 die/strip (10 sites x 8 die stack)

High speed NCF with excellent void performance and metallurgy

Substrate Fluxing for TC-CUF

- Dip fluxing TCB (thermocompression bonding) is a slow process for HVM
  - Die dipping in flux requires temperatures around 80°C requiring bond head temperature excursions >200°C.
  - Die dipping process is sequential to pick and bond adding >500ms to process.
  - Process demonstrated with as low as 6.9 sec cycle per unit equaling a UPH of ~1000

- Substrate fluxing is a fast process enabling a breakthrough for TCB
  - Without die flux dip the temperature excursion of bond head is limited to ~120°C
  - Demonstrated a process with as low as 4.8 sec cycle per unit equaling a UPH of >1500
  - Potential to exceed 2500 UPH with higher temperature touch down
Substrate Fluxing UPH Improvement

- Flux application to the substrates has been validated with a unique printing method developed by Kulicke & Soffa
- Method applies the flux immediately prior to bonding and enables patterned flux printing
- Similar flux volume to that used in a conventional flux dip process
  - Limited flux volume ensures effective flux cleaning after bonding
- Process capability has been verified thorough SEM cross-section and bump metallurgy for several key factors in the process.
  - Flux volume applied to the substrate
  - Contact temperature of the die to the substrate
  - Die time at temperature prior to contact
  - Substrate time at temperature prior to bonding
- Two factors improve TC-CUF process UPH
  - Removing the sequential flux dip process
  - Enabling higher die transfer temperature

APAMA FACTS

Mitigate Uncertainty of Technology Shifts & Protect Your Investments

Flexible
- Highly Configurable Core Design
- TCB C2S
- TCB C2W
- HA FC
- FOWLP
- HA DA

Adaptable
- Adapt to Your Transforming Environment
- FOUNDRY
- OSAT
- IDM
- R&D

Capable
- Quality and Output Performance
- Best UPH @ High Accuracy
- Best in Class process monitors & Integrated Metrology
- Best cost performance ratio

Transformable
- An Evolutionary Core Machine that Protects Customer Investments
- TCB to FOWLP to HAFC
- Risk free solution
- Time to MFG

Scalable
- K&S Global Infrastructure with Coverage for Sales/Service/MFG
- Repair/refurbishment & warranty support
- Global support presence
- Supply ramp capacity
**APAMA C2W Conversion Diagram**

- **Low Mass/Force Bond Head**
  - Flux Dip
  - Select
  - Die Flip

- **Convertible**

- **High Mass/Force Bond Head**
  - Flux Dip
  - Select
  - Die Flip

- **Field Conversion Possible – Secure Investment**
  - Conversion is possible between process capabilities
  - 70% CAPEX reduction compared to new equipment purchase
  - Reduced CAPEX risk as market demands change

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**C2W HAFC Die Placement**

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APAMA Platform Flexibility – HAFC
Extending Mass Reflow Capability

- Market is developing for High Accuracy Flip Chip placement (no TCB)
  - Accuracy of ± 3um (3500 UPH), ± 5um (4500 UPH)
  - Paired with mass reflow (MR) or laser reflow (LR – local reflow)
- Both C2W and C2S can be adapted to HAFC (reduced risk for capex)
  - Increased throughput is targeted to 4500 UPH
  - Active program for C2S with demo machines in application labs
- Demonstrated capability for C2W HAFC

Si to Si 30um Pitch TV MR (3200 I/O)
Cross-section Inspection

- Accurate placement of die enables self-alignment during the reflow process
- Example is silicon to silicon so CTE is matched
- Assembly onto laminate needs to account for CTE mismatch
### HAFC Key Specifications (C2S or C2W)

<table>
<thead>
<tr>
<th>Process Requirements</th>
<th>Specification HAFCH</th>
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</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>±3μm (3σ)</td>
</tr>
<tr>
<td>Thin die handling</td>
<td>&gt;30 μm</td>
</tr>
<tr>
<td>Die thickness</td>
<td></td>
</tr>
<tr>
<td>UPH</td>
<td>4500</td>
</tr>
<tr>
<td>Die Size</td>
<td>0.5 – 38.0mm</td>
</tr>
<tr>
<td>Substrate Size</td>
<td>310x160mm</td>
</tr>
<tr>
<td>Wafer Size</td>
<td>330mm</td>
</tr>
<tr>
<td>Maximum Force</td>
<td>150N</td>
</tr>
<tr>
<td>Yield and Metrology</td>
<td>Die crack detection</td>
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<tr>
<td></td>
<td>Post bond overlay</td>
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<td>IR Align NCF</td>
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*Risk mitigation for fine pitch Cu pillar assembly*

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### C2W FOWLP Die Placement

![C2W FOWLP Die Placement Image](image_url)

*Image of C2W FOWLP Die Placement*
APAMA C2W for FOWLP

- Dual head placement
- Face-down and Face-up die placement
- Global Alignment Capability

APAMA Platform Flexibility - FOWLP

- Demonstrated capability for C2W for FOWLP
  - Market requirement for both face up and face down die placement with higher accuracy
  - eWLB process face down (Infineon process)
  - TSMC InFO (and others) face up
  - 4500 UPH possible (linked to accuracy)
- Tools in evaluation with multiple Taiwanese customers

Face-up FOWLP Demonstration

Wafer Info:
- Wafer type: glass
- Wafer size: 300mm
- Wafer thickness: 700mm
- Die spacing: 250um
Placement of Glass Die on Glass Wafer

- Validation of global alignment accuracy
- 15 x 15mm glass die
- 55 die placed over 255mm diameter

3σ = 2.5µm
3σ = 3.0µm
3σ = 11mdeg

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Chip to Wafer Bonder
Summary

- K&S has developed the next generation thermocompression bonder to enable cost-effective, high performance packaging
- High accuracy inherent in the equipment design enables use of the equipment for HAFC and FOWLP processes
- Equipment with the flexibility for field conversion reduces capex risk
- HAFC demonstrated for mass reflow of 30mm pitch Cu pillars
- Accurate FOWLP die placement is possible with APAMA C2W system
  - Global alignment capability
  - Face up or Face down defined by recipe