"Trends, Transitions, and Inflection Points in Semiconductor Packaging"

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Dan Tracy, Sr. Director
SEMI Industry Research & Statistics

Outline

• Quick 2017 Overview

• Semiconductor Industry Outlook and Market Drivers

• Packaging Market Trends
  • Business and Technology
  • Material Segments
  • China

• Summary
2017 Overview

2017- A Record Setting Year

• 2017 is a record setting year for the industry
  – Semiconductor sales: >$400B for the first time
  – Fabless sales reach the $100B mark for the first time

  – Investments
    • All-time high for CAPEX by single company (Samsung)
    • Equipment spending in Korea will smash previous regional spending record
    • Worldwide equipment billings: ~$56B

  – Silicon shipments
    • Also, a rebound in wafer pricing
Semiconductor Equipment Cycles-
Revenues to approach $56 billion, a new annual spending record

![Graph showing semiconductor revenue trends]

Previous spending high was in $48B in 2000

Source: SEMI/SEAJ WWSEMS

Silicon Wafer Market-
Recovery in Aggregated Average Selling Price

- Peak revenues back in 2007
- Several year period of declining ASPs while shipments increased
- 2017 rebound in ASPs to propel +17% revenue growth

Source: SEMI
Semiconductor Industry Outlook and Market Drivers

2018 Semiconductor Forecasts

- IC Insights (Nov 17), 8.0%
- VLSI Research (Jan 18), 7.7%
- Gartner (Jan 18), 7.5%
- IHS Markit (Jan 18), 7.4%
- WSTS (Nov 17), 7.0%
- Cowan LRA (Jan 18), 5.9%
- Semico Research (Nov 17), 4.5%
- Future Horizons (Jan 18), 21.1%

Source: SEMI January 2018
Semiconductor Cycles - Revenues to reach $500 billion by 2019

Semiconductors are pervasive
- Key drivers in 2018 are high-performance computing, IoT, and automotive

Semiconductor Revenue Outlook Beyond 2018

Source: IC Insights McClean Report, January 2018

Source: SEMI January 2018
Industry Trends and Growth Drivers

- Data Centers
  - Big Digital SoCs
  - Storage – Solid State Memory
- Gateways
  - Data Collection Hubs
- IoT Nodes
  - Sensors
  - Actuators
  - Imagers
  - Transmitters

Source: Mentor, A Siemens Business, presented at ISS US January 2018

Source: IHS Markit, presented at ISS US January 2018

3 Eras of Demand

Integration Scale in Transistors


Source: VLSI Research, presented at ISS US January 2018
Packaging Market Trends

Business and Technology
Packaging Trends and Transitions

- Wire bond is not dead, but industry evolving to increased packaging and assembly at the wafer level
- Memory inflection point:
  - Leadframe to organic substrate packages
  - WB to FC
- FO-WLP is a disruptive technology
- Traditional model:
  - Wafer is processed in fab then sent to assembly facility for singulation, assembly, and test
- New model:
  - Some wafers stay at the foundry for packaging and assembly
  - Some OSATs install wafer processing (“like”) equipment to create package on the wafer

Emergence of Outsource Packaging

Today:
- >50+% of packaging revenues
- Leading new packaging development…Cu pillar, FO-WLP, SiP, and more…

2005:
- ~40% of packaging revenues
- Fabless companies grow; IDMs shift to outsourcing

1995:
- ~18% of packaging revenues
- Emergence of leading Taiwanese and Korean OSAT companies

1985:
- ~5% of packaging revenues
- Manufacturing focus in the Philippines
- PDIP & Transistors

Source: Gartner and SEMI
Packaging and Assembly Trends

- SiP remains a hot topic
  - Drivers remain the same…miniaturization #1
  - Heterogeneous integration drives this into high-performance applications
- Silicon interposer finally moved into volume production (but small volumes)
  - FPGA with homogeneous and heterogeneous solution
  - GPU + stacked memory
  - Network systems
  - Artificial intelligence
- Still waiting for the big TSV market, but we have production volume
  - DRAM with TSVs for servers
  - HMC
  - HBM

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Trends Driving Heterogeneous Integration

- As the industry moves to the next silicon nodes (10nm, 7nm, etc.) new packaging solutions are need to achieve the economic advantages that were previously met with silicon scaling
- Heterogeneous integration is considered the answer and is taking various forms:
  - Silicon interposers
  - Alternatives such as Intel’s EMIB or Fan-out on Substrate
  - Future organic interposers

Requires collaboration across the entire supply chain

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Growing Number of FO-WLP Applications

- Baseband processors
- Application processors
- RF transceivers, switches, etc.
- Power management integrated circuits (PMIC)
- Audio CODECs
- Connectivity modules
- Radar modules (77GHz) for automotive
- Microcontrollers
- Sensors
- Logic + memory for data centers and cloud servers

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Materials
Laminate Substrates

- ~$7B market
- Stable supply base
- Wire bond CSP and BGA are declining; while flip chip CSP and BGA are seeing some increase
- Flat growth in PC; slowing growth in mobile
- Some substrate suppliers have reduced production with the transition to FO-WLP
- Some customers relaxing extensive price pressure on suppliers
- China suppliers increasing capabilities

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)

Wafer Level Dielectrics

- ~$200M market currently
- Numerous suppliers currently in the market
- New RDL formulations still in development, especially for multi-layer applications
- Low cure temperatures a must
- WLP dielectrics with good adhesion to metal (Cu) layers and epoxy (in the case of FO-WLP reconstituted wafer) without delamination
- Low stress WLP dielectric (to match the CTE of the chip) and/or low modulus (for less wafer bow)

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)
Mold Compounds

- ~$1.3B market
- Stable supply base with Japanese suppliers maintaining strong market position
- Formulations to pass Moisture Sensitivity Level 1 (MSL1) for small packages.
  - Critical for board-level reliability
- Need smaller fillers and narrower particle size distribution for better warpage control. Especially critical in FOWLP.
- Clear compounds for optical devices: limited material available as warpage and adhesion issues need to be addressed.

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)

Underfill

- >$200M market for flip chip (higher if under package is included)
- Stable supply base led by Japanese suppliers
- Capillary applications challenged with void-free filling for finer pitched Cu pillar
- Flip chip dimensions:

<table>
<thead>
<tr>
<th>Flip Chip</th>
<th>Key Features</th>
<th>Current</th>
<th>2021 Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu Pillar</td>
<td>Bump Pitch Bump Diameter</td>
<td>100 µm to 50 µm</td>
<td>40 µm to 30 µm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 µm</td>
<td>25 µm</td>
</tr>
</tbody>
</table>
- Affordable Non-Conductive Film (NCF) underfill with higher throughput

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)
Leadframes

- ~$3.1B market
- Copper alloy supply constraints affecting lead-times
- Growing etch capacity and capabilities for surface treatments
- Routable QFN/MIS to increase I/O count
  - Currently limited sources/supply
- Pre-molded QFN is a new technology
  - Improved handling, though needs to provide attractive cost-down benefit
- RF and analog expected to switch from QFN to WLCSP

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)

Other Packaging Material Issues and Needs

<table>
<thead>
<tr>
<th>Material Segment</th>
<th>Need/Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plating</td>
<td>Higher throughput for Cu pillar</td>
</tr>
<tr>
<td>Panel Fan-out</td>
<td>Driven by desire for a lower cost solution</td>
</tr>
<tr>
<td></td>
<td>Need big product volume to drive the economics</td>
</tr>
<tr>
<td></td>
<td>Need standards (equipment companies waiting for standards to “fully” support initiatives)</td>
</tr>
<tr>
<td></td>
<td>&lt;10µm/10µm lines and spaces may be difficult to achieve with multiple layers with high yield</td>
</tr>
<tr>
<td>Dicing/Grinding</td>
<td>Dicing and Grinding for thin wafers: 80µm in production, developing 50µm, looking at 30µm and below</td>
</tr>
<tr>
<td></td>
<td>Non-blade techniques need to get Cost of Ownership equal to blade processing</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Sustainability—recycle and reuse—is a major issue. Also pertains to shipping and packing materials used for packaged devices</td>
</tr>
</tbody>
</table>

Source: SEMI/TechSearch International, Global Semiconductor Packaging Materials Outlook (to be published 1Q 2018)
Semiconductor Packaging Materials Markets
4% Revenue Growth in 2017; 2% Growth Forecasted for 2018

<table>
<thead>
<tr>
<th>Region</th>
<th>2017F $US B</th>
<th>2018F $US B</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>$5.11</td>
<td>$5.30</td>
</tr>
<tr>
<td>N. America/Europe</td>
<td>1.21</td>
<td>1.23</td>
</tr>
<tr>
<td>Japan</td>
<td>2.53</td>
<td>2.57</td>
</tr>
<tr>
<td>South Korea</td>
<td>2.26</td>
<td>2.35</td>
</tr>
<tr>
<td>SEA/ROW</td>
<td>4.45</td>
<td>4.50</td>
</tr>
<tr>
<td>Taiwan</td>
<td>4.24</td>
<td>4.29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$19.8</strong></td>
<td><strong>$20.2</strong></td>
</tr>
</tbody>
</table>

Source: SEMI Materials Market Data Subscription, January 2018
China IC Industry Faces Challenges and Opportunities

Packaging Opportunities in China
- Lowest barriers to success and is poised for growth and technical advancement
- Closeness to customer
  - Large electronics manufacturing base there
- Technology barriers
  - Lower capex requirements (compared to wafer fabrication)

China Packaging Market

China is the largest market consuming packaging materials
- Packaging is a mature industry in China
  - 45% of bonding wire shipments are to China
- 150+ package & assembly plants located in China
  - 80+ OSAT Plants
  - 17 Bumping Facilities
- China OSAT companies mainly focused on traditional packaging, though are increasing capabilities and offerings of advanced packaging solutions
## Domestic Packaging Materials Suppliers in China

<table>
<thead>
<tr>
<th>Category</th>
<th>Company</th>
<th>Est. Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leadframes</td>
<td>Kangqiang, Hualong, Trinity Sanjia, Others</td>
<td>11% Revenue Share WW Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~30% Revenue Share of China Market</td>
</tr>
<tr>
<td>Substrates</td>
<td>Shennan Circuits, Zhuhai Yueya, AKM</td>
<td>N/A</td>
</tr>
<tr>
<td>Bonding Wire</td>
<td>Doublink, Kangqiang, Yes/No, Youk Wire, (Many, many) Others</td>
<td>10% Shipment Share WW Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20% Shipment Share of China Market</td>
</tr>
<tr>
<td>Encapsulation Resins (including LED applications)</td>
<td>Sinopaco, HHCK, ANPIN Silicone, BJKMT, Darbond, Others</td>
<td>~6% Revenue Share WW Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~20% Revenue Share of China Market</td>
</tr>
<tr>
<td>Die Attach</td>
<td>Darbond, Others</td>
<td>N/A</td>
</tr>
<tr>
<td>Ceramic Packages</td>
<td>Zhongwei, Yixing</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Source: CSIA, SEMI, December 2017

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**Summary**


Summary

- 2017 was record setting year for the industry
  - Record fab investments; All-time high for total equipment spending
  - Spending in Korea will smash previous regional spending record

- Significant packaging transitions underway as function of mobility, connectivity, and performance

- Need to address materials challenges pertaining to package performance and reliability, e.g. warpage, adhesion, interfacial/surface interactions, etc., for 3D, SiP, and Heterogenous Integration

- Packaging will continue to grow rapidly in China
  - Domestic companies increasing capabilities; demand for locally produced materials to grow