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

February 14, 2018

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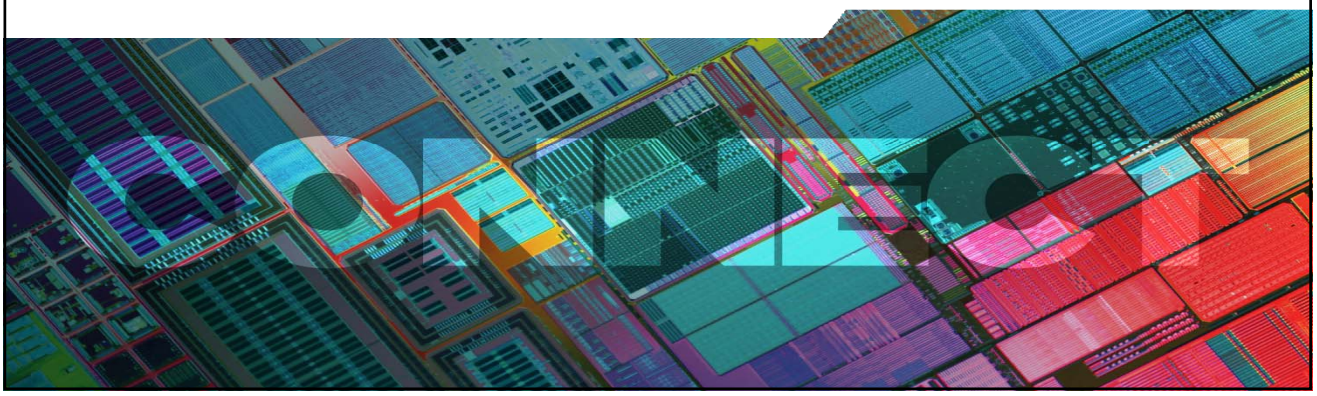
SEMI Industry Research & Statistics



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*

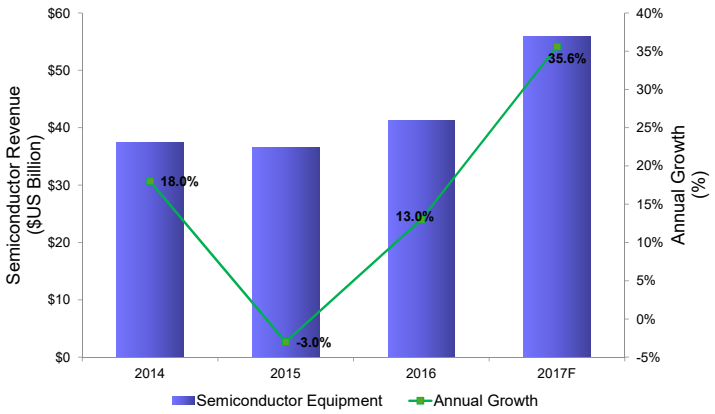
- *2017 is a record setting year for the industry*
  - *Semiconductor sales: **>$400B** for the first time*
  - *Fabless sales reach the **$100B mark** for the first time*

  - *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



Previous spending high was in $48B in 2000

Source: SEMI/SEAJ WWSEMS

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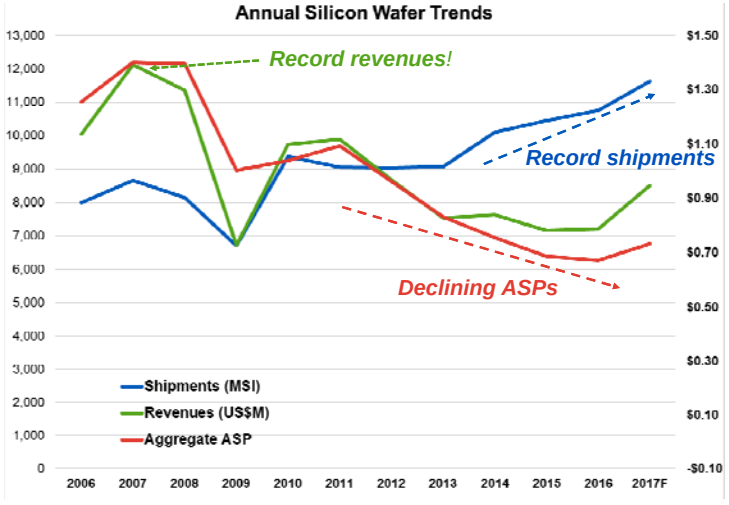
Silicon Wafer Market-

Recovery in Aggregated Average Selling Price



Source: SEMI

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

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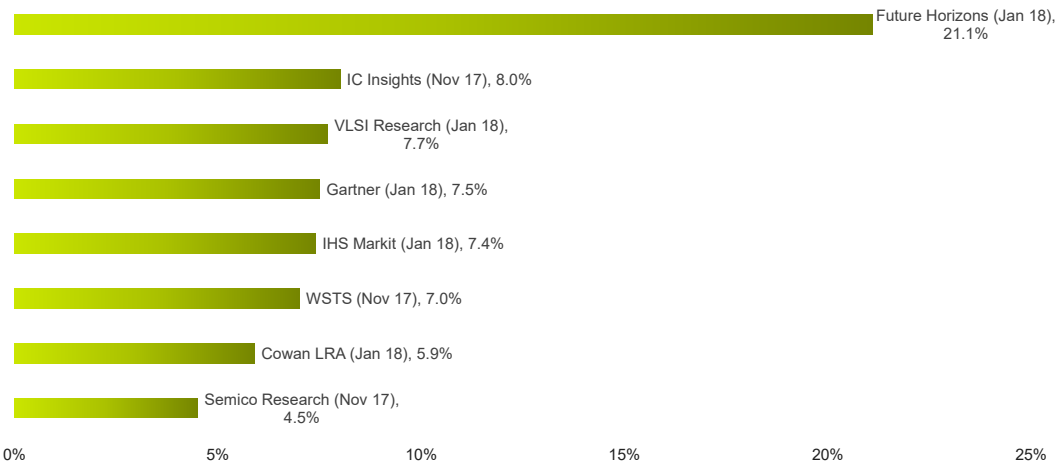
Semiconductor Industry Outlook and Market Drivers

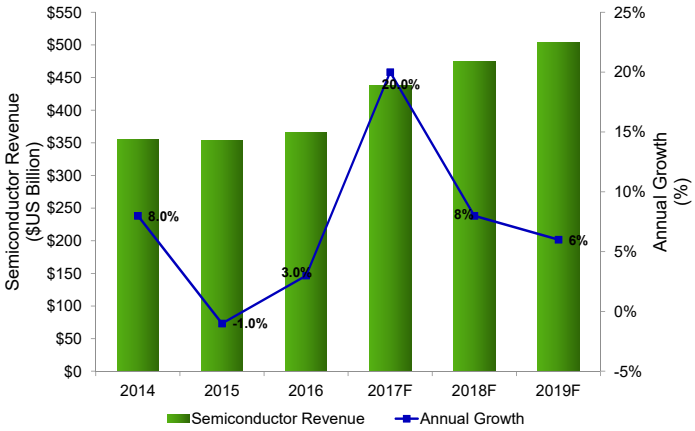
2018 Semiconductor Forecasts



Source: SEMI January 2018

Semiconductor Cycles-

Revenues to reach $500 billion by 2019

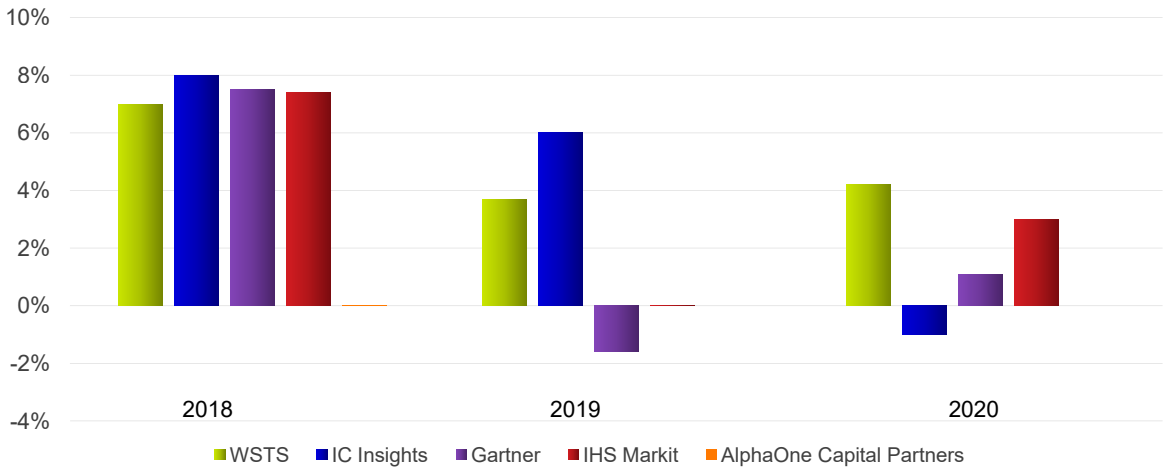


Source: IC Insights McClean Report, January 2018

Semiconductors are pervasive

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

Semiconductor Revenue Outlook Beyond 2018

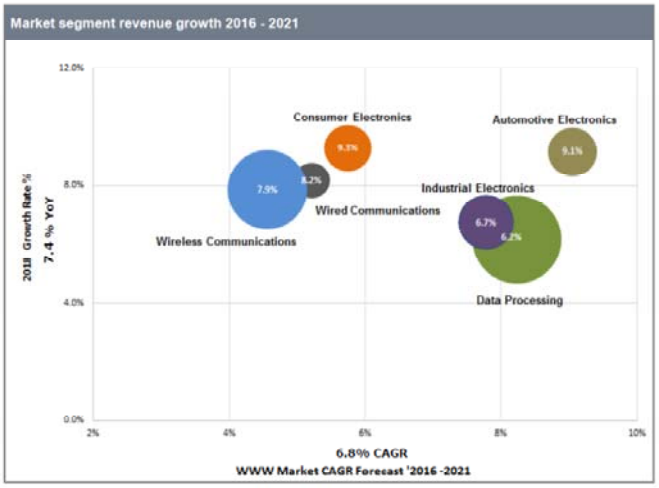


Source: SEMI January 2018

Industry Trends and Growth Drivers

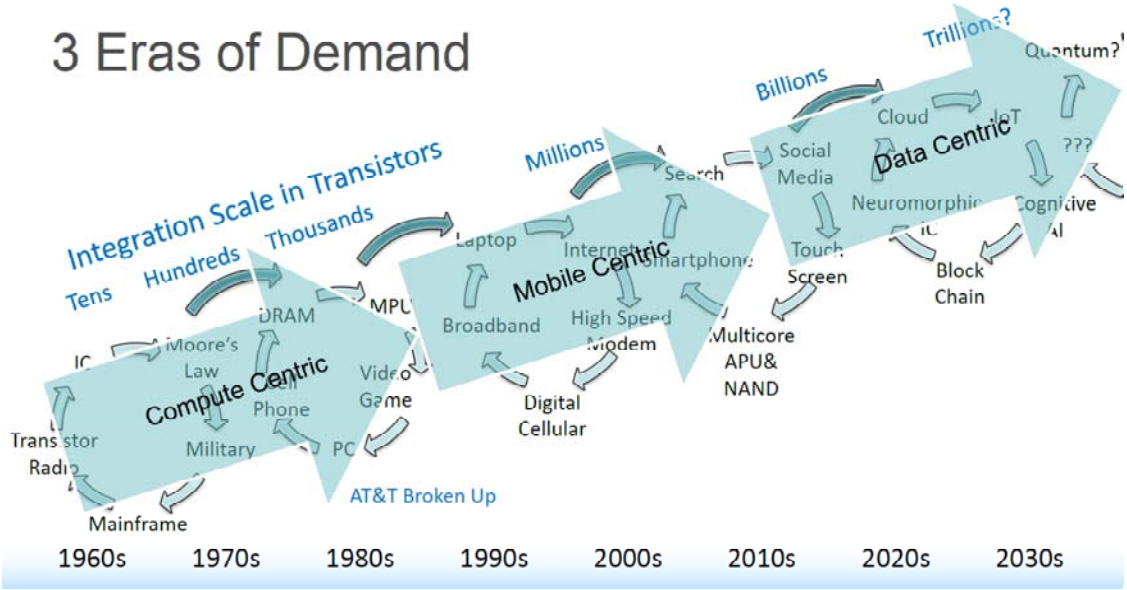
- Data Centers
  - Big Digital SoCs
  - Storage – Solid State Memory
- Gateways
  - Data Collection Hubs
- IoT Nodes
  - Sensors
  - Actuators
  - Imagers
  - Transmitters

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



Source: IHS Markit, presented at ISS US January 2018

3 Eras of Demand



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*

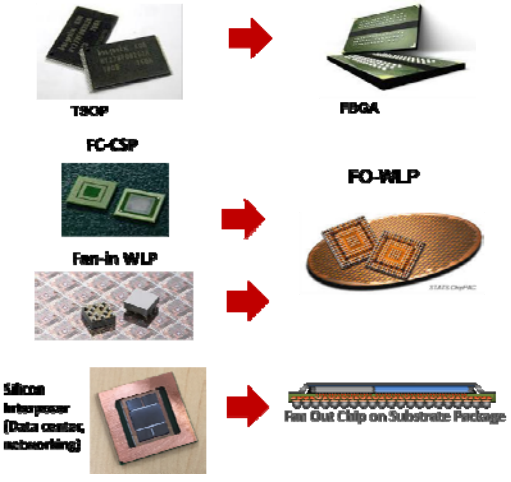


Image Source: TechSearch International

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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

Image Source: ASE

Image Source: Siliconware

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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

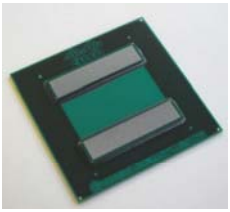

Image Source: Xilinx

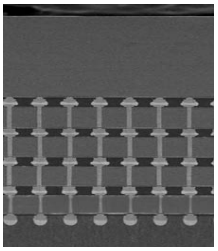

Image Source: SK Hynix

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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

Audio CODEC (4.25mm x 3.9 mm)

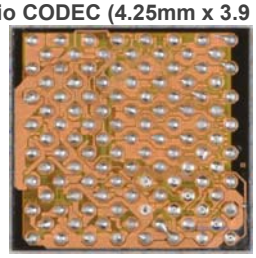
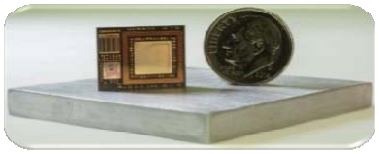


Image Source: TechInsights.

IoT Module



Source: Nepes

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Materials

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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

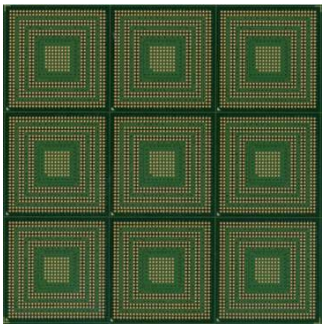

Image Source: Unimicron

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

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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)*

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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.

Image Source: Kyocera Chemical

Image Source: Towa Corp.

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

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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:

Flip Chip	Key Features	Current	2021 Estimate
Cu Pillar	Bump Pitch Bump Diameter	100 µm to 50 µm 40 µm	40 µm to 30 µm 25 µm

- Affordable Non-Conductive Film (NCF) underfill with higher throughput

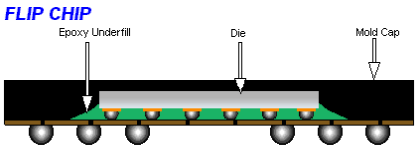

Image Source: Amkor

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

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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

Image Source: Shinko

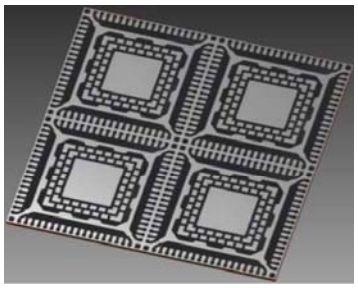

Image Source: Chang Wah Technology Co.

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

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Other Packaging Material Issues and Needs

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

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

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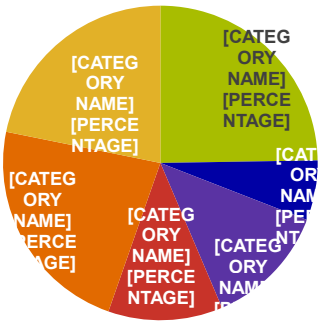
Semiconductor Packaging Materials Markets

4% Revenue Growth in 2017; 2% Growth Forecasted for 2018



2016 = $19.1 billion

Region	2017F $US B	2018F $US B
China	$5.11	$5.30
N. America/Europe	1.21	1.23
Japan	2.53	2.57
South Korea	2.26	2.35
SEA/ROW	4.45	4.50
Taiwan	4.24	4.29
Total	**$19.8**	**$20.2**

Totals may not add due to rounding

Source: SEMI Materials Market Data Subscription, January 2018

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China

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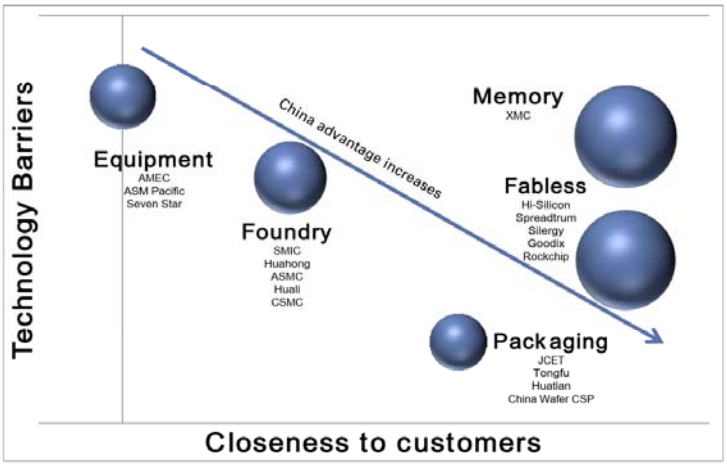
China IC Industry Faces Challenges and Opportunities



Source: Reuters, Goldman Sachs Global Investment Research, Gao Hua Securities Research

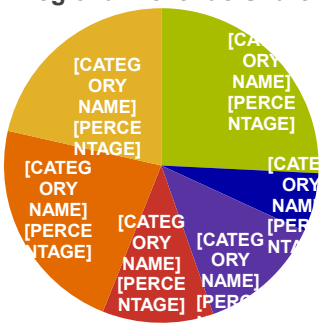
Packaging Opportunities in China

- 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

2017 Packaging Materials Regional Revenue Share



Source: SEMI Materials Market Data Subscription, January 2018

- 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

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

Source: CSIA,SEMI, December 2017

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*