Semiconductor Packaging and Assembly Trends: Outlook for 2022

Presented at the MEPTEC-IMAPS Semiconductor Industry Speaker Series Feb 2, 2022

E. Jan Vardaman, President and Founder

- TRACK INNOVATION
- IDENTIFY TRENDS
- ANALYZE GROWTH
- INFLUENCE DECISIONS

RELEVANT, ACCURATE, TIMELY
2021: Surviving the Chip Crunch

• Covid-19 disrupted global production and resulted in out-of-cycle demand for laptops and tablets, wearables, and server growth

• Covid-19 lockdowns disrupted production

• Winter weather and accidents resulted in lost production
  – Texas winter storm
  – Renesas fire in Japan

• Auto industry saw dramatic decline in 2020 and demand rebounded faster than anticipated in 2021
  – Companies did not place orders early enough
  – Has been operating in “just-in-time” mode
  – Shortages of microcontrollers and sensors

• Trade dispute between U.S. and China resulted in some disruption of supply chain

• Semiconductor shortage not expected to improve till after 2022
  – Demand continues for laptops, servers, and smartphones
Continued Semiconductor Industry Growth for 2022

- Semiconductor market growth 6.8% in 2020
  - Market expanded only 6.8% in 2020
  - 25.6% in 2021 (largest increase since the 2010 31.8% increase 11 years ago)
  - Projected 8.8% growth in 2022

<table>
<thead>
<tr>
<th>Autumn 2021</th>
<th>Amounts in US$M</th>
<th>Year on Year Growth in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2020</td>
<td>2021</td>
</tr>
<tr>
<td>Americas</td>
<td>95,366</td>
<td>118,835</td>
</tr>
<tr>
<td>Europe</td>
<td>37,520</td>
<td>47,126</td>
</tr>
<tr>
<td>Japan</td>
<td>36,471</td>
<td>43,581</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>271,032</td>
<td>343,419</td>
</tr>
<tr>
<td>Total World</td>
<td>440,389</td>
<td>552,961</td>
</tr>
<tr>
<td>Discrete Semiconductors</td>
<td>23,804</td>
<td>30,100</td>
</tr>
<tr>
<td>Optoelectronics</td>
<td>40,397</td>
<td>43,229</td>
</tr>
<tr>
<td>Sensors</td>
<td>14,962</td>
<td>18,791</td>
</tr>
<tr>
<td>Integrated Circuits</td>
<td>361,226</td>
<td>460,841</td>
</tr>
<tr>
<td>Analog</td>
<td>55,658</td>
<td>72,842</td>
</tr>
<tr>
<td>Micro</td>
<td>69,678</td>
<td>79,102</td>
</tr>
<tr>
<td>Logic</td>
<td>118,408</td>
<td>150,736</td>
</tr>
<tr>
<td>Memory</td>
<td>117,482</td>
<td>158,161</td>
</tr>
<tr>
<td>Total Products</td>
<td>440,389</td>
<td>552,961</td>
</tr>
</tbody>
</table>

Source: WSTS.
SEMI Reports Major 300mm CAPACITY Expansion

Total 300mm Capacity & Count of Fabs
(Volume Semiconductor Fabs, Probability >50%)

Capacity in 300mm WPM thousand

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Count of Fabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>179</td>
<td></td>
</tr>
</tbody>
</table>

300mm Fab Outlook to 2024, 4Q21 Update, Published by SEMI
Semiconductor Foundry Expansions

- **Intel plans to spend >$24 billion**
  - 2 new fabs in AZ, (1 for Intel Foundry Services)
  - Expansion in New Mexico, Fab plans for Europe
  - New fab in Columbus, Ohio

- **TSMC spending $100 billion for overseas expansion through 2023**
  - Arizona fab for 5nm technology with a capacity of 20,000 wafers per month by 2024
  - Announced plan to build a fab in Japan, primarily to serve Sony and other Japanese clients (22nm and 28nm node for image sensors and microcontrollers)
  - Considering a plant in Germany

- **GF ~$5 billion**
  - New 300mm fab in Singapore, New fab in U.S.

- **SMIC $8.87 billion**
  - Plans to invest $8.9 billion in a new Shanghai 300mm fab

- **Samsung will expand U.S. semiconductor production**
  - Plans to build a new $17 billion Texas facility (51.7 million sq. ft., 4X size of Austin plant)
Government Semiconductor Spending: The New Arms Race

• U.S. proposes to spend $52 billion in semiconductor production in U.S.
  – Only 12% of global semiconductor manufacturing capacity in U.S.

• EU is considering building an advanced semiconductor fab in Europe
  – EU “European Chips Act” calls for manufacturing up to 20% of all leading-edge semiconductors in the world by 2030 (discussions with TSMC about fab location)
  – France aims to boost semiconductor production by 2030 with €6 billion
  – About 10% of world’s semiconductor manufacturing facilities are in Europe
  – EU Commission’s European Innovation Council selected 65 start-ups and small companies to receive €363 million in funding (grant financing and equipment investment) for healthcare, digital technologies, energy, biotechnology, space, and other

• China is investing >$150 billion in semiconductors from 2014-2030
  – Accounts for only 7.6% of total global semiconductor sales with foundries focused on more mature nodes

• India is pushing to establish semiconductor production as part of “Made in India”
  – Finalizing an incentive package of >$10.2 billion to attract semiconductor manufacturing, display, design, and packaging (gov’t will put up 50%) over next 6 years
Automotive Market Growth

- Demand increased in 2021 (as much as 11% over 2020)
  - Adoption of safety features continues
  - Cameras, radar, ultrasonic, and LiDAR

- Requirement for compute function increases
  - Increased use of AI

- Electric vehicles expected to see growth
  - U.S. goal of ½ all vehicles sold in 2030
  - EV account for small % of sales (2% in U.S.)
  - Average car has $330 of semiconductor content, hybrid EV has up to 3,500 chips with a value of $1,000 (according to U.S. International Trade Commission)
  - Increased demand for charging stations
  - Creates demand for SiC and power packages

Source: Physicsworld.com.
Semiconductor Shortages Impacts Auto Industry

- **Semiconductor shortages continue, especially in auto industry**
  - Auto demand increased 11% in 2021
  - IPC survey shows >50% of companies expect shortage to last until at least Q2 2022

- **Auto industry expected to have revenue loss of $210 billion in 2021**
  - Ford, GM, Nissan, Daimler, BMW, Renault, and Toyota
  - Component shortages include microcontrollers and sensors
  - Renesas Electronics, NXP Semiconductor, and Infineon working on increasing output
  - Renesas 200mm Kyushu fab and 300mm Naka fab at full capacity, Renesas orders six microcontrollers (40nm node) from TSMC for every one it makes
  - TSMC will build fab in Japan to support image sensor and microcontroller production
  - Shortage of 200mm wafer fab capacity
  - SEMI reports that 200mm fab capacity will increase by 950,000 wafers (17%) from 2020 to 2024 to reach a record high of 6.6 million wafers put month
Smartphone Growth

• IDC projects smartphone shipments growth of 5.3% this past year (1.35 billion)
  – Slightly lower growth in Q3 because of component shortages and logistics issues

• IDC projects 3.5% 5-year CAGR for smartphone segment (lower than previous forecast)

![Worldwide Smartphone Shipments and ASP Forecast, 2021Q3](chart.png)

Source: IDC 2021
**Apple iPhone 12 Pro vs. 13 Pro**

<table>
<thead>
<tr>
<th></th>
<th>iPhone 12 Pro</th>
<th>iPhone 13 Pro</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiPs</td>
<td>33</td>
<td>35</td>
<td>+6%</td>
</tr>
<tr>
<td>WLPs</td>
<td>103</td>
<td>92</td>
<td>-11%</td>
</tr>
<tr>
<td>Total Packages</td>
<td>185</td>
<td>176</td>
<td>-5%</td>
</tr>
<tr>
<td>Total Die</td>
<td>310</td>
<td>292</td>
<td>-6%</td>
</tr>
</tbody>
</table>

Source: TechSearch International, Inc. teardown.

- **Apple iPhone 12 Pro contains 310 die in 185 packages, iPhone 13 Pro with 176 packages**
  - Many of the packages are SiP (33), with 35 in the iPhone 13
  - SiP examples include MEMS and sensors, RF and connectivity, and power management
  - 103 WLPs (2 FO-WLPs) in the iPhone 12 vs. 92 in the iPhone 13 (fewer voltage regulators, ESD protection diodes, and magnetic sensors)
**Slower PC Growth**

- PC shipments forecast to reach 344.7 million units, representing 13.5% growth this past year.
- IDC forecast PC shipments to have a 3.3% 5-year CAGR.

**Worldwide PC and Tablet Forecast, 2021Q3**

Source: IDC 2021
Server Growth Continues

- Global server shipments of ~17 million units in 2021
  - Driven by pandemic demand and large scale cloud service purchases
  - Projected to reach ~18 million units in 2022
  - Concerns with component shortages and substrate shortages
- Drives new package solutions
  - Chiplets

Source: Datacenterknowledge.com.

Source: Intel.

Sapphire Rapids
Intel’s 1st CPU with chiplets

Source: AMD.
New Era of Semiconductor Packaging

• Chiplets will be a key enabler for next 10-20 years

Source: Overclock3d.net.
Die Size Growth: Major Driver for Adoption of Chiplets

- Die sizes continued to increase over time for server CPU and GPU
  - nVIDIA’s 826 mm$^2$ die, fabricated at TSMC, is one of the largest in production today
  - Samsung reports die sizes of 750 mm$^2$

- Performance requires more transistors, but industry needs a new, more economical approach
  - Smart packaging, including heterogeneous integration and chiplets becomes the answer

Source: AMD internal analysis.
What’s a Chiplet?

• A chiplet is an integrated circuit block specifically designed to work with other chiplets to form a larger more complex system that often makes use of reusable IP blocks
  – A chiplet can be created by partitioning a die into functions that are more cost effectively fabricated (smaller die, higher yield, and less advanced nodes)
  – A chiplet is a hard IP block
  – Functions with other chiplets, so design must be co-optimized and silicon cannot be designed in isolation
  – Made possible by communication using chiplet interface (proprietary today)

• Differs from SiP or traditional MCM in that it is a new design, not just a combination of different “off-the-shelf” chips

• Chiplet is not the package, it’s the design philosophy
  – Change from “silicon centric thinking” to “system-level planning” and “co-design of IC and package”
  – The industry has to think about chip design in a new way
  – Same impact as when the industry moved from a peripheral chip layout to area array!
Chiplet ≠ Package: Many Package Options

- **MCM (Organic substrate)**
- **Embedded bridge in laminate**
- **Fan-out on Substrate with embedded bridge**
- **3D stack**
  - μbump
  - Hybrid bonding
- **Silicon interposer**

Intel’s EMIB

Source: Intel by TechInsights.

AMD V-Cache with TSMC’s SoIC

AMD Elevated Fanout Bridge EFB)

AMD’s MCM

Source: Intel by TechInsights.

Xilinx FPGA on CoWoS
AMD Multiple Chiplet Product Introductions

- Multiple generations of desktop and server products using chiplets with organic (laminate) substrate
  - Split out analog functions from advanced 7nm logic
  - Chiplets can be binned and speed-sorted before assembly on the substrate
  - Better memory access
  - Minimize local latency
  - Power efficiency improvement
  - 1, 2, 4 or 8 CPU chiplets plus an I/O chiplet are attached to an organic interposer

Intel’s Data Center CPU with EMIB

- Intel’s Sapphire Rapids will be Intel’s first CPU server for data centers using chiplets
  - All 4 chiplet die will access shared cache and are connected using the modular die fabric (MDF)
  - Any core can talk to other cores on the 4 die and access the shared cache across all 4 quadrants as well as I/O across 4 quadrants
  - Uses organic substrate with embedded silicon bridge (Intel’s EMIB)

EMIB size compared to grain of Basmati rice

Source: Intel.
AMD’s Elevated Fanout Bridge (EFB)

• AMD’s EFB provides better performance than bridge embedded in substrate
• Intel’s Foveros 3D technology chiplets stacked with ~50µm pitch micro bumps (going to 36 µm)
  – Base chip can include power management features, voltage regulators, DC/DC converters (design flexibility to mix & match IP)

• Used in the Samsung Galaxy Note S (Mobile PC), advantages include
  – 1/10 standby power, 50% graphic performance, 40% core board area decrease, 40% height reduction

Source: Intel.
Samsung X-Cube™ is first generation of 3DIC ("X" stands for extended interconnection density and extended functionality in 3D)

First versions with μbump connections
- Text vehicles with 9mm x 9mm SRAM die with TSVs and 25μm bump pitch stacked on 9.5mm x 9.5mm logic die, mold compound filled around SRAM, then mounted on a 12mm x 12mm laminate substrate with 125μm Cu pillar

Future use of hybrid bonding
**TSMC SoIC™ Technology**

- **Bond pad pitch <10 µm allows higher density, improved electrical performance**
- **Takes place just after wafer fab in front-end, not BEOL**
  - SoIC is not a package, but it goes into a package
- **First commercial product with hybrid bonding in 2022 for AMD**
AMD 3D V-Cache Structure

- AMD’s V-Cache is 3D IC with hybrid Cu-to-Cu bonding
- Solves thermal problem by designing the structure so that the memory and the cores are not placed on top of each other

Source: AMD.
Challenges

- All packages discussed for chiplets use a laminate build-up substrate
- Substrate shortage
  - Laminate build-up substrates required to support all packages are in short supply
  - Situation will be worse this year than last year
  - A lot of capacity is being added, but it takes time
  - By 2025 and 2026 the situation improves as long as body size is constrained
  - Yield improvements help

Source: TechSearch International, Inc.
Watch China

• China’s growth is slowing
  – Government needs to stabilize growth for next year

• Major debt problem
  – Housing speculation

• Closed border policy to keep COVID under control
  – Expected to remain closed through 2022

Source: National Bureau of Statistics of China, Bloomberg surveys of economists
Conclusions

• Semiconductor industry growth will continue in 2022
  – WSTS forecast 8.8% growth in 2022
  – Much lower than the 25.6% growth in 2021

• Industry may experience overcapacity in 2023-24
  – Semiconductor industry cycles continue

• Demand returns to more normal growth rates for electronics products
  – PCs
  – Smartphones

• Economic growth can be derailed by
  – Aggressive monetary policy
  – Increased trade friction
  – Political instability
Thank you!

TechSearch International, Inc.
4801 Spicewood Springs Road, Suite 150
Austin, Texas 78759 USA
+1.512.372.8887
tsi@techsearchinc.com

RELEVANT, ACCURATE, TIMELY

TechSearch International, Inc.
4801 Spicewood Springs Road, Suite 150
Austin, Texas 78759 USA
+1.512.372.8887
tsi@techsearchinc.com

RELEVANT, ACCURATE, TIMELY
COPYRIGHT NOTICE

The presentation in this publication was presented at the MEPTEC– IMAPS Semiconductor Industry Speaker Series. The content reflects the opinion of the author(s) and their respective companies. The inclusion of presentations in this publication does not constitute an endorsement by MEPTEC, IMAPS, or the sponsors.

There is no copyright protection claimed by this publication. However, each presentation is the work of the authors and their respective companies and may contain copyrighted material. As such, it is strongly encouraged that any use reflect proper acknowledgement to the appropriate source. Any questions regarding the use of any materials presented should be directed to the author(s) or their companies.

www.meptec.org