Semiconductor packaging trends: an OSAT perspective

By David Clark [Amkor Technology, Inc.]

While supply chain issues, including severe shortages, occupied much of the visibility for semiconductors in 2021, semiconductor manufacturers and their outsourced semiconductor assembly and test suppliers (OSATS) have continued to make technical progress in many areas. These technology improvements address the advanced packaging requirements of leading-edge applications in key market segments. Before going into specifics, let's look at the overall market outlook.

Market outlook

The semiconductor packaging market continues to show a prosperous outlook and is forecast to grow to $96B by 2026 (3.8% compound annual growth rate (CAGR) from 21-26) (**Figure 1**). This market is typically divided into mainstream and advanced packaging segments with the latter being expected to exceed the mainstream segment for the first time by 2026.

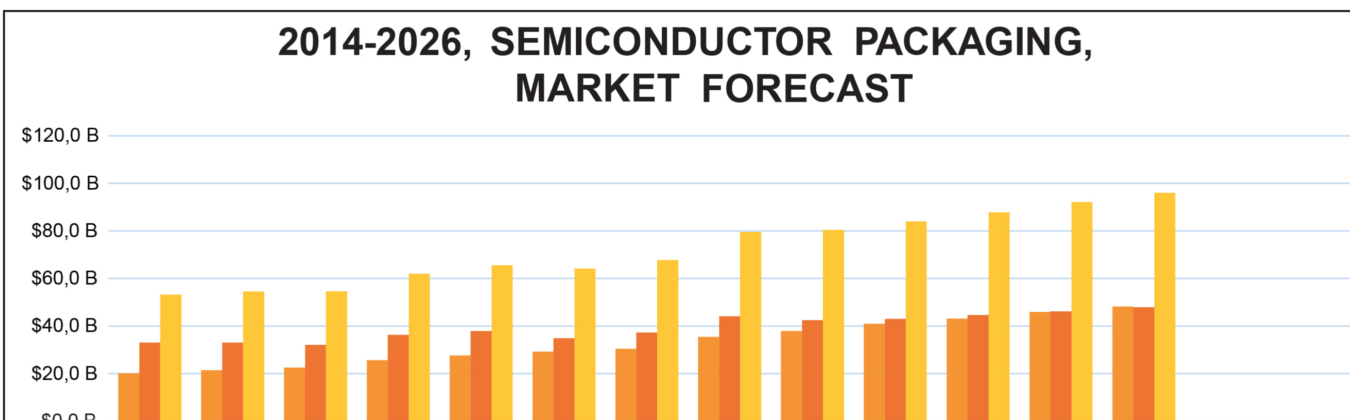
The market is underpinned by general trends in increasing manufacturing outsourcing, functionality and semiconductor content. Notable growth drivers come from multiple market segments such as 5G connectivity, automotive, data center, artificial intelligence (AI) and networking. 5G forms the backbone of many connected devices and services. While 5G is primarily a wireless connectivity growth opportunity, it also is an enabler for many adjacent markets generating further semiconductor content growth.

Despite industry-wide supply chain constraints since 2020 and expected to continue into 2022, many OSATS were still able to generate record revenues. Well reported shortages in IC foundry capacity, together with a constrained substrate supply chain, made for a challenging 2021. With newly publicized investments in these areas for capacity expansion, it is hoped that lead times will slowly reduce, and the industry will stabilize in 2022, however, substrate challenges will persist through 2023.

Mobile packaging trends

Many of the market growth drivers require increasing levels of system integration to meet the ever-increasing demand on performance, power and cost. As the OSAT supplier becomes an increasingly integral part of the overall system solution, it is in the advanced packaging segment where continued innovation in the areas of system in package (SiP), 2.5 and 3D packaging architectures are most apparent.

Cellular connectivity continues to drive advancements in radio frequency (RF) SiP technologies. With the rise of 5G, cellular frequency bands have increased considerably, requiring innovative solutions for the packaging of RF front-end modules for smartphones and other 5G-enabled devices. Amkor's double-sided molded



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	CAGR 2014-2026	CAGR 2020-2026
AP	$20,2 B	$21,5 B	$22,5 B	$25,7 B	$27,6 B	$29,3 B	$30,4 B	$35,5 B	$37,9 B	$41,0 B	$43,2 B	$45,9 B	$48,2 B	7,5%	8,0%
Other	$33,0 B	$33,0 B	$32,1 B	$36,3 B	$38,0 B	$34,9 B	$37,3 B	$44,1 B	$42,5 B	$43,0 B	$44,6 B	$46,2 B	$47,9 B	3,2%	4,3%
Total	$53,2 B	$54,5 B	$54,6 B	$62,0 B	$65,6 B	$64,1 B	$67,7 B	$79,5 B	$80,4 B	$84,0 B	$87,8 B	$92,1 B	$96,1 B	5,1%	6,0%

Figure 1: Advanced packaging vs. traditional packaging market forecast (2014-2026). SOURCE: [1]

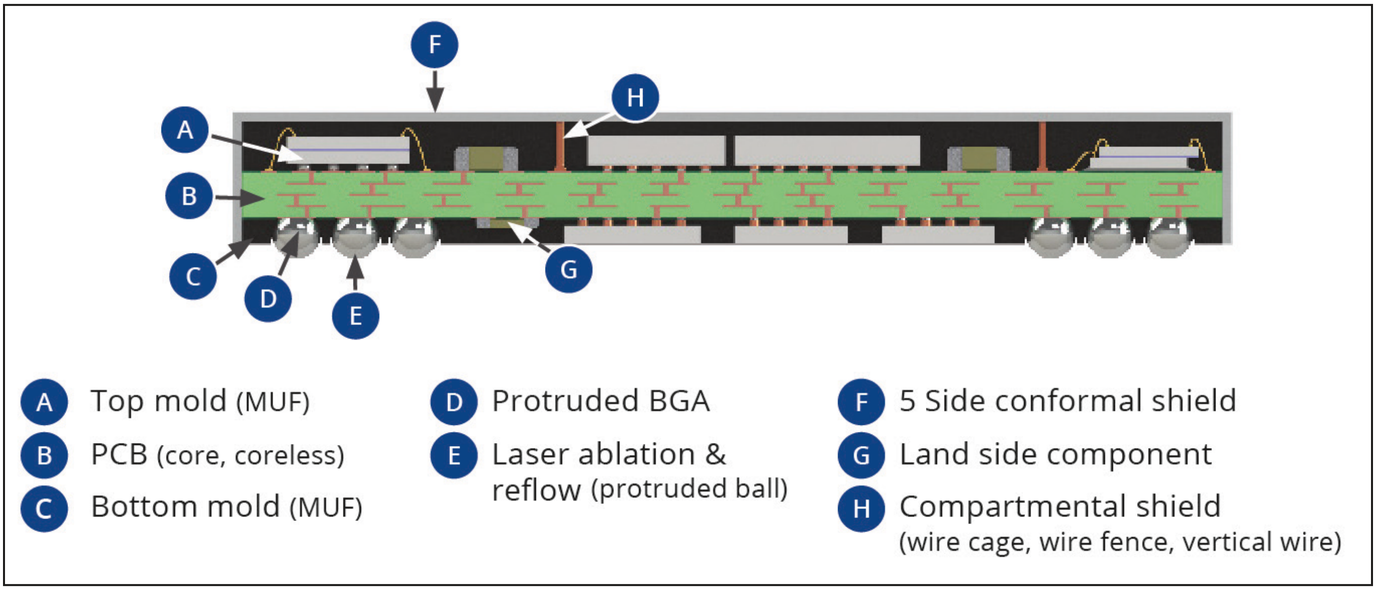


Figure 2: A double-sided molded ball grid array (DSMBGA) package.

ball grid array (DSMBGA) is the leading example of such solutions (**Figure 2**).

With the arrival of 5G networking, there has been a change in frequencies, adding frequency bands above 3GHz in FR1 and millimeter wave (mmWave) range in FR2. This growing number of new frequencies combined with the variety of multiplexing methods significantly increases the complexity of the RF front end. Integration using SiP allows customers to design, tune and test RF subsystems allowing for a reduction in design iterations and an accelerated time-to-market. Our double-sided packaging technology has vastly increased the level of integration for RF front-end modules used in smartphones and other mobile devices.

For 5G smartphones and other mmWave applications, antenna integration, either through antenna in package (AiP) or antenna on package (AoP) technologies, simplifies the challenges associated with designing products that operate at these high frequencies. A variety of AiP/AoP design methodologies provide the required form, fit and function for these applications and can include more than one antenna or antenna array. Today's AiP/AoP technologies can be implemented through standard, as well as custom, SiP modules to achieve a complete RF front-end (RFFE) subsystem.

In addition to a reduced size required for handheld and other small mmWave devices, AiP/AoP provides improved signal integrity with reduced signal attenuation and addresses the range and propagation challenges that occur at higher frequencies.

Automotive packaging trends

In the automotive area, advanced driver assistance systems (ADAS), electrification, and concepts such as the virtual cockpit, offer significant new opportunities for advanced packaging and innovation. These areas of new innovation are contributing to positive automotive semiconductor growth whereby the market is projected to grow from $38.7 billion in 2020 to almost US$82.6 billion in 2025 [2]. Implementing safety and comfort levels within ADAS-enabled vehicles result in an expectation for increased sensor deployment with the number of sensors increasing by 9.2% CAGR from 2020 to 2025 [2]. By 2026, the majority of high and some mid-range vehicles will integrate camera and radar, as well as light detection and ranging (LIDAR) sensors.

Multiple sensing techniques are being deployed to cover a vast array of range, environmental and accuracy requirements. Integration is a key focus to reduce the form factor and improve sensitivity levels. Sensor packaging platform development and re-use of mature assembly processes are key to controlling cost. For example, in

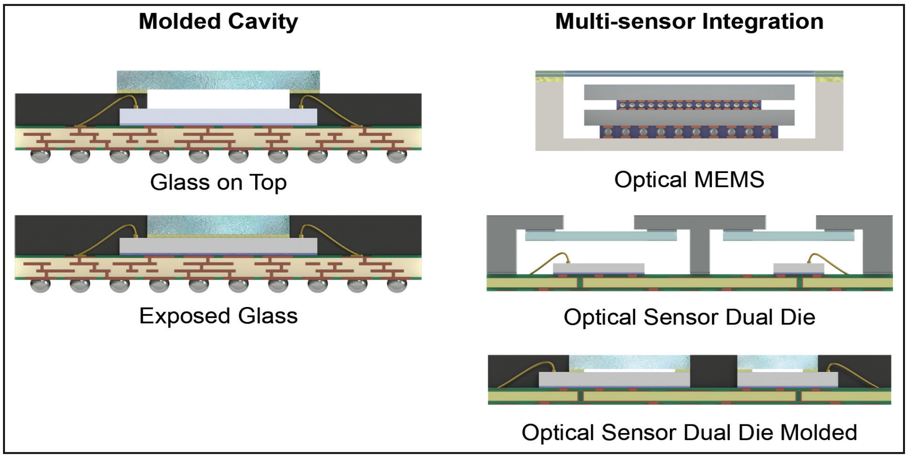


Figure 3: Molded cavity and multi-sensor integration optical sensor packages.

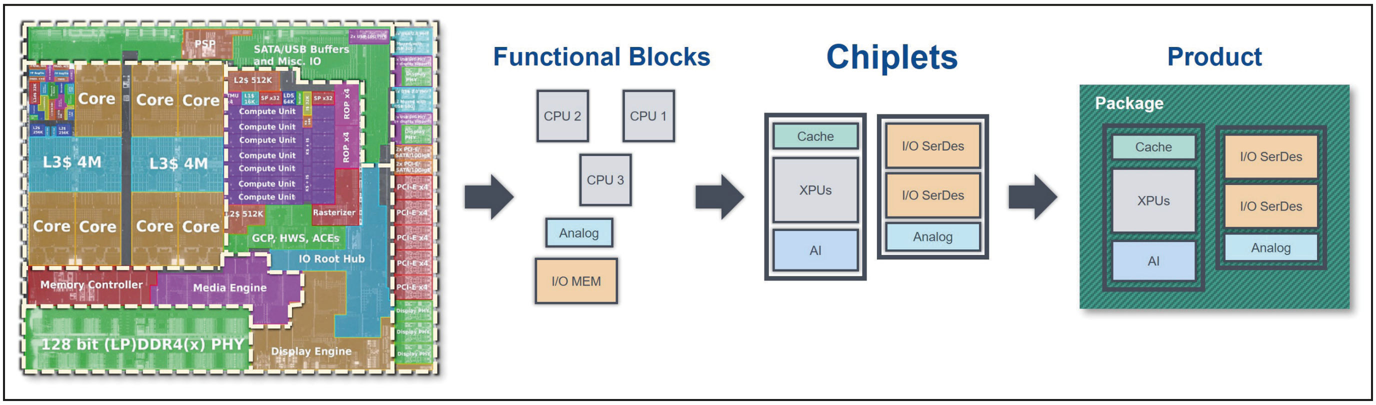


Figure 4: A heterogeneous integration platform for chiplets.

the area of optical sensing, such as the time of flight (ToF) and contact image sensor (CIS), molded single and multi-cavity microelectromechanical systems (MEMS) packaging solutions are now being deployed and qualified for these optical sensing applications (**Figure 3**).

The ADAS system-level augmentation of the sensor functions noted above will drive the need for higher levels of in-vehicle compute capability. In this area, OSATS are leveraging many years of experience emanating from the high-performance compute and network sectors. With further development of specific automotive-rated material systems, these single and multi-chip central processing units (CPUs) can be qualified to the automotive AEC Q-100 grade requirements.

We anticipate the accelerated adoption of advanced silicon technology nodes with 5nm designs being introduced by automotive original equipment manufacturers (OEMs) later in this decade. Furthermore, SiP technology then offers automotive customers a platform to integrate these advanced CPU chips with complementary functions such as Serializer/Deserializer (SerDes), power management integrated circuits (PMICs), memory and more.

Data center and networking packaging trends

Cloud and edge computing, storage and networking form the backbone of today's connected living. The demand on voice and data traffic is driving major innovations in system architectures and fueling the partitioned chiplet trend (package-level integration) to find the ultimate, optimized balance in power, performance and cost (**Figure 4**). As these processing demands increase, transistor densities are increasingly challenging. Combined with effects like heat and noise, they are forcing designers to leverage heterogeneous architectures with specialized accelerators and memories, either on a single die or in an advanced package.

2.5 and 3D packaging solutions offer a heterogeneous integration platform for chiplets. Consequently, foundries are expanding their 3D packaging portfolios. To date, OSATS have offered complementary heterogeneous packaging and supply chain solutions, such as Amkor's SWIFT® and S-Connect technologies (**Figure 5**). Many of these approaches, whether a foundry or OSAT, die-first or die last, with or without interposer and other options, aim to quench the desire to extend Moore's Law and provide more effective package-level alternatives.

The technical challenges extend beyond the ability to co-package chiplets, so chip-package co-design is critical. When partitioning a floor plan, one needs to think carefully about where to place components within the package. Some components need to be placed very close together physically to maintain signal and power integrity. Key questions are

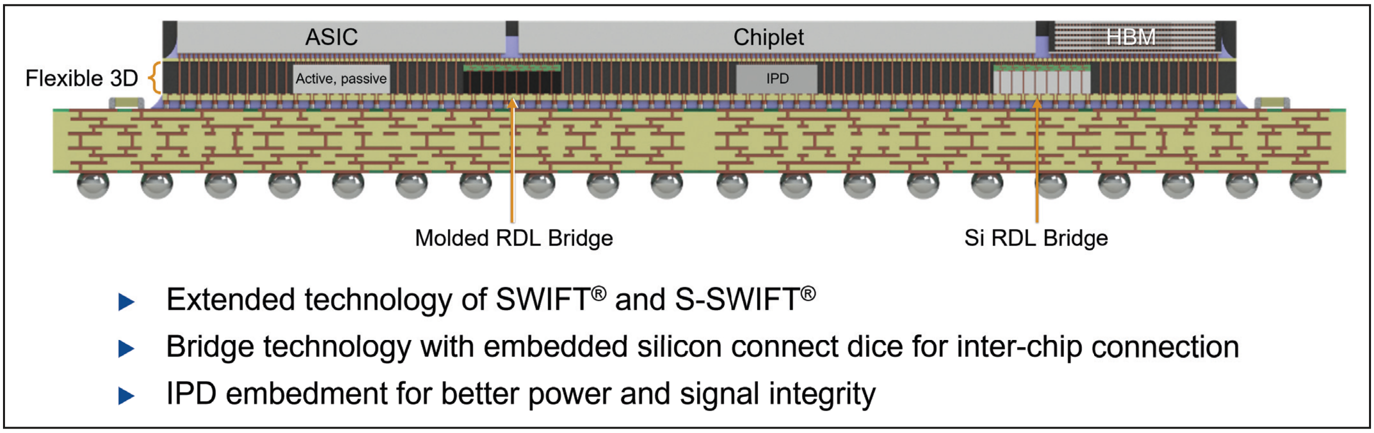


Figure 5: Amkor's S-Connect technology.

where and what to partition, what is the workload and what silicon nodes are optimal in terms of cost and yield for each function. With this added system design freedom, the OSATS's role is increasingly important in the system-level design, chip-chip I/O routing, power distribution, thermal optimization, and more.

Today, the chiplet era is in its infancy. The way systems are designed to date has been based upon historic approaches to moving data. A more pioneering approach to the movement of data to support a metaverse future will redefine how next-generation systems are configured. Concepts such as co-packaged optics (CPOs) that are currently in the research phase are among the future package design possibilities.

Summary

To satisfy the application needs in leading markets and meet growth projections, several different advanced packaging technologies are required. For continued OSATS', as well as semiconductor manufacturers' success, a few key criteria must be satisfied. Semiconductor original equipment manufacturers (OEMs) and OSAT suppliers must continue to improve their collaboration during the design phase to make sure the right problems are being solved early in the innovation process. To minimize footprints, effectively manage power and continuously improve performance, the technology investments by OSATS must occur with financial stability as a goal. With the right packaging concepts, success is demonstrated through capability to scale up to satisfy volume requirements in these growing markets. This is essential to avoid future supply chain issues.

Acknowledgments

SWIFT is a registered trademark of Amkor Technology, Inc.

References

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Biography

David Clark, Sr. Director, Amkor Technology, Inc. is responsible for Product Marketing and strategic business development in Europe. Prior to joining Amkor, David held various business development and engineering positions at FlipChip International (FCI), Leica Microsystems and Agilent Technologies. He has been granted 5 patents in Optoelectronics and Device Packaging and holds a BEng Honors Degree in Electronic, Electrical and Optoelectronic Engineering from the U. of Glasgow. Email: david.clark@amkor.com