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New package solutions for automotive optical sensors

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Automotive optical sensors, including cameras, image sensors, and light detection and ranging (LiDAR) components, are fundamental to the operation of advanced driver assistance systems (ADAS). These sensors play a crucial role in detecting and interpreting the vehicle's surroundings, supplying high-precision data necessary for ADAS functionality. With the evolution of autonomous driving technology, particularly the transition from the Society of Automotive Engineers (SAE) SAE J3016 Level 2 autonomy to Levels 4 and 5, the number of cameras and optical sensors integrated into each vehicle is expected to rise substantially. Industry projections, including those from SAE, suggest that future vehicles could be equipped with 8 to 10 or more cameras per unit.

The widespread adoption of ADAS by automotive manufacturers has significantly enhanced driving safety. These systems provide real-time assistance to drivers, reducing the likelihood of accidents and improving overall road safety. Key ADAS features include adaptive cruise control, lane departure warning, and automatic emergency braking, which have become standard in modern vehicles. As the industry progresses towards increased vehicle automation, the integration of ADAS technologies is accelerating, driving rapid advancements in sensor technology.

Beyond conventional camera-based applications, a range of innovative optical sensor technologies is emerging, further augmenting vehicle performance, safety, and user experience. For instance, ambient light sensors are increasingly integrated into vehicle systems to enhance both safety and comfort. These sensors adjust in-car lighting—including dashboard and console illumination—by detecting external light intensity, thereby improving visibility. They also regulate headlight activation in response to surrounding light conditions, ensuring optimal illumination in low-light environments. With ADAS requiring precise visual feedback, ambient light sensors contribute to a more adaptive, efficient, and user-friendly in-cabin experience.

This article introduces the development of a new optical ball grid array (OBGA) packaging platform designed for automotive applications, with a focus on platform development and compliance with the Automotive Electronics Council (AEC) AEC-Q100 Grade 2 reliability standard. The proposed packaging solution extends beyond traditional cavity OBGA packages, which have been primarily utilized for microelectromechanical systems (MEMS) and sensor applications as illustrated in **Figure 1**.

The cavity OBGA platform, depicted in **Figure 2**, represents a well-established and mature technology that is currently in production for consumer electronics. The introduction of this new OBGA package marks a strategic expansion into automotive optical sensors. This initiative strengthens the company's competitive edge by aligning with the increasing

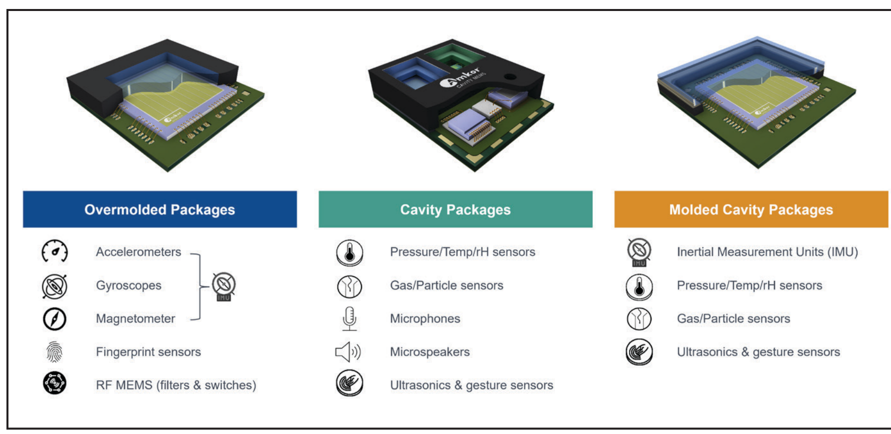


Figure 1: MEMS and sensor packages and applications.

Figure 2: Imaging, optical MEMS and sensing packages and applications.

demand for advanced sensor integration in modern vehicles.

The new OBGA packaging aims to expand the current portfolio by enhancing performance and reliability. Two key technological advancements drive innovation in this packaging platform. The first involves the adoption of glass-on-sensor (GoS) technology, which facilitates the evaluation of clear die attach film (DAF) transmittance while ensuring automotive-grade reliability. This approach enables the package structure to meet the stringent performance and durability requirements demanded by the automotive sector. The second advancement introduces the glass-on-mold (GoM) design, replacing traditional metal or liquid crystal polymer (LCP) lids commonly used in MEMS packaging. This modification eliminates the need for venting holes, effectively mitigating particle contamination in the sensor region. As a result, the optical sensor's reliability and performance are significantly improved.

Designed specifically for automotive optical sensor products, the new OBGA package has undergone comprehensive feasibility studies and rigorous reliability testing. These assessments confirm its structural robustness and suitability for demanding automotive environments, ensuring that the package can withstand extended operational lifecycles and harsh environmental conditions. To address these challenges, advanced toolbox and open tooling capabilities are leveraged to ensure that design for cost (DFC) and design for manufacturability (DFM) considerations are integrated from the initial stages of product development. Prioritizing manufacturing efficiency and scalability allows the delivery of high-performance optical sensor packaging solutions that meet the evolving requirements of the automotive industry.

New package development

To overcome the challenges associated with existing packaging solutions, the new OBGA package integrates advanced molding and lid placement technologies commonly employed in MEMS cavity products. The proposed OBGA package serves as an alternative solution designed to provide enhanced mechanical robustness, accommodating larger sensor sizes anticipated in next-generation automotive applications.

The new OBGA package leverages extensive expertise in cavity MEMS packaging, combined with a proven track record in managing high-end consumer digital camera product lines. This synergy results in a highly reliable and manufacturing-efficient package that meets the stringent performance and durability requirements of the automotive industry. The integration of these advanced technologies ensures that the package maintains structural integrity and optical performance, even under harsh environmental conditions typical of automotive applications.

Two distinct OBGA package variants are shown in **Figure 3**, each designed to address specific application needs. The first variant, GoS, features a compact footprint and is derived from consumer optical fingerprint sensor (FPS) technology. This solution utilizes an established material set and incorporates film assisted molding (FAM) technology, which has been successfully implemented in the existing product portfolio. The second variant, GoM, represents a completely new design, developed from the ground up to meet the specific demands of automotive optical sensor applications. This innovative structure offers enhanced performance and greater integration capabilities, ensuring long-term reliability and optimal functionality within ADAS and autonomous vehicle ecosystems.

Glass-on-sensor development

The glass-on-sensor configuration involves laminating a transparent die attach film with glass and directly stacking the glass onto the sensor die. A critical characteristic of this structure is the absence of any gap between the sensor and the DAF, ensuring seamless optical transmission. Given the importance of optical clarity in sensor performance, evaluating the material properties of DAF for optimal transmittance and thermal stability is a crucial step in the development process.

Optical transmittance and thermal durability of DAF materials are essential for optoelectronic applications, including automotive sensors, display technologies, and optical coatings. The development process assessed transparent die attach films used in GoS packaging, with particular emphasis on their transmittance characteristics and long-term stability under thermal stress.

Three candidate materials—Material A, Material B, and Material C—were selected for evaluation. Film thickness and thermal curing conditions were evaluated for their influence on optical performance. Key parameters, including transmittance across the visible light spectrum (400–700nm) and stability after thermal aging, were analyzed. A detailed summary of the material properties and corresponding performance data is presented in **Table 1**.

Identifying materials capable of maintaining high optical transmittance while withstanding prolonged thermal stress is a critical requirement for applications demanding long-term reliability and performance. To simulate assembly process operating conditions, the selected materials underwent thermal aging at 175°C for 8 hours. This process was designed to assess their ability to sustain optical integrity and performance stability under extended high-temperature exposure.

The experimental procedure began with the lamination of DAF onto glass substrates at 65°C, followed by an initial optical transmittance evaluation within the 400–700nm wavelength range. The materials were then subjected to thermal aging at 175°C for 8 hours and transmittance measurements were conducted again to analyze any degradation or shifts in optical performance after thermal treatment. These tests were performed on materials with two distinct film thicknesses—10µm and 20µm—to assess how thickness variations influence transmittance retention and thermal stability.

Table 2 presents the transmittance results for the different materials across various wavelengths following thermal aging at 175°C for 8 hours. Among the evaluated materials, Material A demonstrated superior transmittance across nearly all wavelengths, outperforming the other candidates. Additionally, the results indicate that thinner films (10µm) exhibited higher transmittance compared to thicker films (20µm), confirming the influence of film thickness on optical efficiency.

Both Material A and Material B maintained excellent optical transmittance, consistently exceeding 90% in the 400–700nm wavelength range after undergoing thermal aging. This high retention of transmittance highlights their robust optical stability under extended heat exposure—a critical requirement for automotive optical sensor applications.

Following the material selection process, Material B was chosen for further development due to its balance of high transmittance, thermal stability, and process workability. As detailed in **Table 3**, the next phase involves assembly process optimization and verification of AEC-Q100 Grade 2 reliability, ensuring its suitability for automotive qualification while maintaining manufacturing feasibility and maturity.

The reliability testing phase was conducted to evaluate the performance and durability of the GoS OBGA package under stringent automotive stress conditions, ensuring compliance with AEC-Q100 Grade 2 standards. The assessment included moisture sensitivity level 3 (MSL3), temperature cycling (TC), high-temperature storage (HTS) testing, and unbiased highly-accelerated stress testing (uHAST) to validate the package's environmental resilience and long-term reliability (see **Figure 4**).

The TC test subjected the package to extreme thermal fluctuations from -55°C to 125°C for 1000 cycles—testing its ability to withstand repeated thermal expansion and contraction. The HTS test—conducted at 150°C for 1000 hours—confirmed the package's long-term thermal stability. Additionally, uHAST was performed at 130°C and 85% relative humidity (RH) for 168 hours, assessing the package's resistance to moisture-induced degradation.

All samples successfully passed open/short circuit and scanning acoustic tomography (SAT) tests, with no failures or degradation observed. These results confirm the GoS OBGA package's suitability for automotive applications, demonstrating strong mechanical and optical reliability, as well as excellent resistance to environmental stress factors.

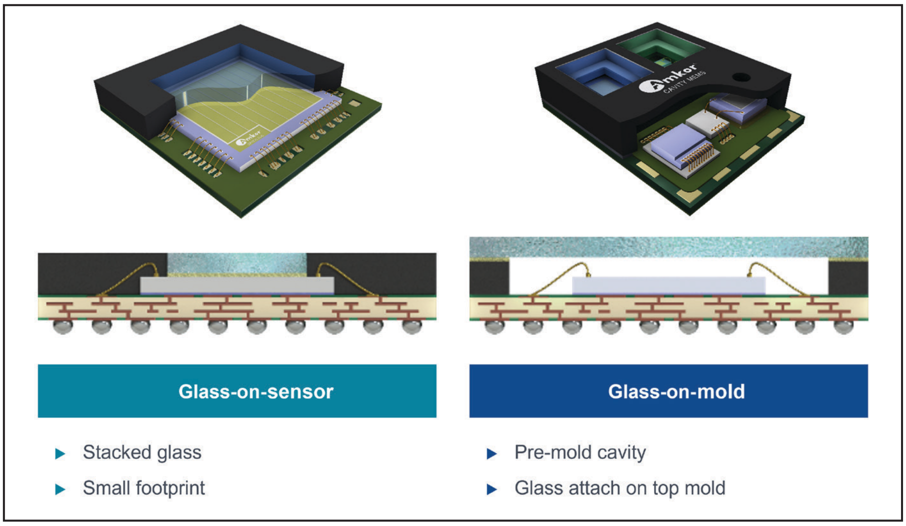


Figure 3: New package structures for automotive optical applications.

Material	Thickness	Tg	CTE	Film Type	Appearance
A	10 µm	41	81	Silica	Transparent (>90%)
B	20 µm	62	75	Silica	Transparent (>90%)
C	20 µm	15	49	Silica	Transparent (>90%)

Table 1: Technical property data.

Wavelength (nm)	Material A	Material B	Material C
Red (610–700)	99.99%	99.44%	94.6%
Orange (590–610)	99.71%	99.28%	93.2%
Yellow (570–590)	99.58%	98.28%	92.4%
Green (500–570)	99.45%	97.97%	90.7%
Blue (450–500)	98.45%	95.65%	90.2%
Purple (400–450)	96.34%	91.33%	88.9%

Table 2: Transmittance results after thermal cure at 175°C for 8 hours.

Glass-on-mold development

The experimental phase of development involved simulating various package configurations and materials to optimize the GoM OBGA package. The feasibility study focused on several key parameters, including glass attach process parameters, bond line thickness (BLT) and glass tilt management. These parameters were evaluated through a series of design of experiments (DOE) and simulations.

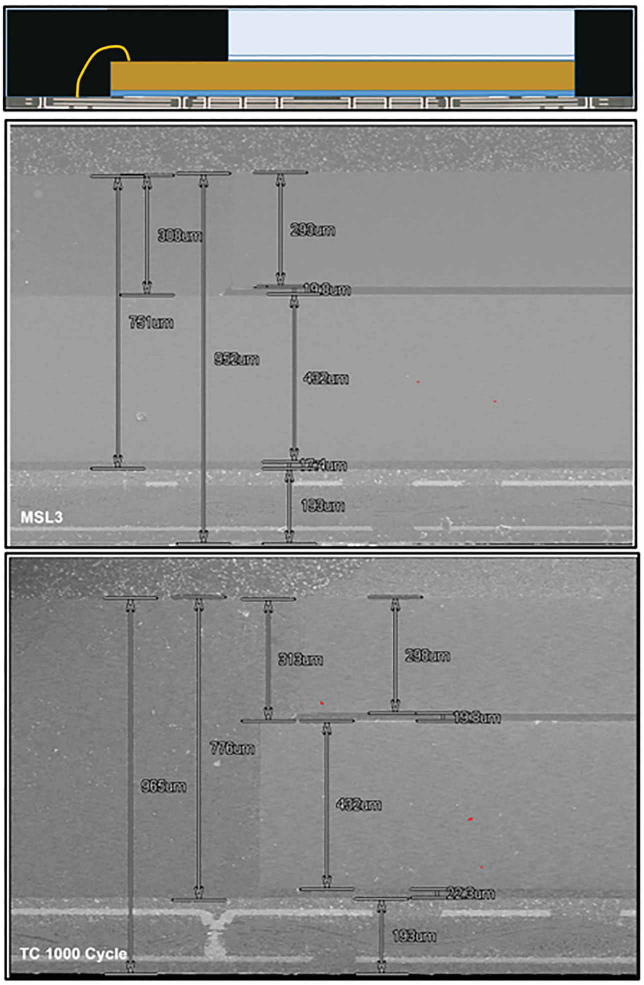
Several equations were used to guide the design process, including Boyle's Law, Charles's Law and Gay-Lussac's Law. These laws helped to understand the relationships between pressure, temperature and volume, which are critical for designing the cavity volume and controlling the process temperature.

The first step in the experiment was to identify preliminary design rules and package configurations that refer to MEMS's product initially. This involved creating study legs to run simulations and narrow down the package development scopes. The simulations considered factors such as bond line thickness of the glass adhesive and the contact width of the glass and glass adhesive material selection.

The simulation analyzed stress and design factors, such as the bill of materials and levels. The preliminary package configuration was reviewed based on the end application requirements, and a simulation DOE was conducted to evaluate different package sizes, glass adhesive materials, and bond line thickness levels.

The simulation results revealed two major weaknesses: the interface between the glass and glass adhesive layer, and the stress between the mold and solder resistance on the substrate. These weaknesses were addressed by optimizing the bond line thickness of the glass adhesive and its contact width, resulting in reduced glass stress and improved reliability.

The feasibility study involved a series of tests to determine the optimal package configuration and process parameters.



Reliability Results	
MSL 3	12.4 x 8. 6.9 x 7.6 mm
TC (-55~125°C)	500 cycles: Open/Short Passed 1000 cycles: Open/Short Passed
HTS (150°C)	500 hrs: Open/Short Passed 1000 hrs: Open/Short Passed
uHAST (130°C/85%RH)	96 hrs: Open/Short Passed 168 hrs: Open/Short Passed

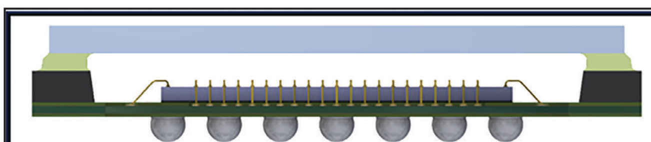
Figure 4: Reliability results for a GoS package.

Package	Glass-on-Sensor OBGA Test Vehicle
Body Size	12.4 x 8.8 mm
Mold Cap	Film Assist Mold
Die Thickness	Sensor: 425 µm Glass: 300 µm
Film Type	Standard & Material B
EMC Type	Standard
Wire Type	18 µm (0.7 mil) Au
PCB Thickness	2 Layers/0.19 mm

Table 3: Package configuration for the GoS OBGA test vehicle.

The DOE for the feasibility study was structured based on simulation data and included four legs with different glass contact widths and bond line thicknesses.

The key process optimizations identified during the feasibility study included die attach, wire bonding, solder ball attach, and package singulation. The wire bonding process,



Package	GoM OBGA Test Vehicle
Body Size	12.4 x 8. 6.9 x 7.6 mm
Mold Cap	Transfer Mold
Die Thickness	Senser: 200 µm Glass: 400 µm
Die Adhesive	Standard
EMC Type	OMC-2
Wire Type	25 µm (1.0 mil) Au
PCB Thickness	4 Layers/0.6 mm
Reliability Results	
MSL 3	SAT & Open/Short test Passed
TC (-55~125°C)	500 cycles: Open/Short Passed 1000 cycles: Open/Short Passed
HTS (150°C) w/o pre-con	500 hrs: Open/Short Passed 1000 hrs: Open/Short Passed
uHAST (130°C/85%RH)	96 hrs: Open/Short Passed

Figure 5: Reliability results for a GoM package.

for example, was optimized to ensure reliable connections between the die and the substrate.

The glass attach process was a critical focus of the feasibility study. Three major metrics were evaluated: water infiltration, bond line thickness, and glass tilt. These metrics were essential for ensuring a completed sealed cavity to protect the sensor component and fulfill the flatness requirements for optical performance.

After process optimization, the GoM OBGA package underwent a series of rigorous reliability tests to ensure its performance for automotive applications, including TC, HTS testing, and uHAST (see **Figure 5**). The package was subjected to -55°C to 125°C for 1000 cycles, 150°C for 1000 hours, and 130°C/85% RH for 96 hours—all of which tested its resistance to thermal, humidity, and moisture stress. All samples passed the open/short and SAT tests, demonstrating no degradation or failure. These results confirm that the GoM OBGA package exhibits exceptional reliability, making it suitable for automotive applications that demand long-term stability, high performance, and environmental resistance.

To ensure package robustness, an integrity check was conducted to verify the interface between the glass-to-glass adhesive, mold top surfaces, and mold compound to substrate. The results confirmed no abnormalities after undergoing MSL3 preconditioning, 1000 cycles of TC, and 1000 hours of HTS, as shown in **Figure 6**.

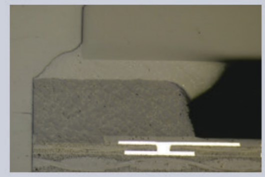
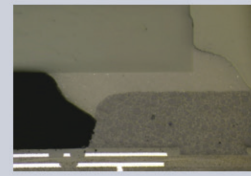
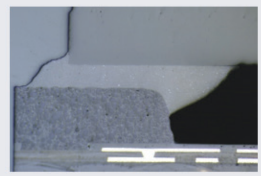
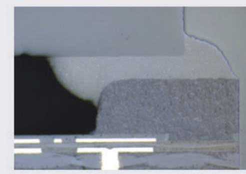
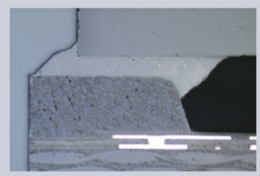
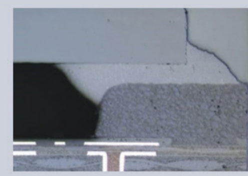
Reliability	Cross section		Remark
MSL3			No abnormality
TCB 1000X			No abnormality
HTS 1000H			No abnormality

Figure 6: Package cross section after reliability testing of the GoM package.

Future development

The new GoM OBGA package provides a reliable, high-performance solution for automotive optical sensors. However, further enhancements can optimize its performance and miniaturization for next-generation applications. One key development focus is reducing package size by applying glass adhesive material over the wire and utilizing film-assisted molding technology. This approach can achieve greater compactness while maintaining performance and reliability.

Another avenue involves multi-chip or sensor integration, requiring collaboration with customers to design system in package (SiP) solutions that incorporate radar, LiDAR, or artificial intelligence (AI)-enabled processors to make possible intelligent sensor capabilities for autonomous vehicles.

Summary

GoS and GoM OBGA packages offer reliable, high-performance solutions for automotive optical sensors, addressing key challenges in thermal stability, optical performance, and manufacturability. The new OBGA package platform enhances miniaturization and manufacturing efficiency while maintaining flexibility for sensor fusion integration. Having a broad packaging portfolio that supports high-speed computing chips, power management devices, memory, network components, and MCU controllers, enables further evolution into SiP solutions, as well as sensor fusion integration. This packaging addresses the current and future demands of ADAS and autonomous vehicle technologies.

Biographies

Weilung Lu is a Sr. Director, MEMS and Sensor BU at Amkor Technology, Inc., Tempe, AZ. He joined Amkor in 2015 and is currently responsible for Optical Sensor products business and package development. Prior to joining Amkor, he worked for Siliconware Precision Industries Co., Ltd. (SPIL) as a technical program manager supporting key US customers and in R&D developing wirebond and flip-chip products. Weilung is a Doctor of Engineering Management from the George Washington U. Email: Weilung.Lu@amkor.com

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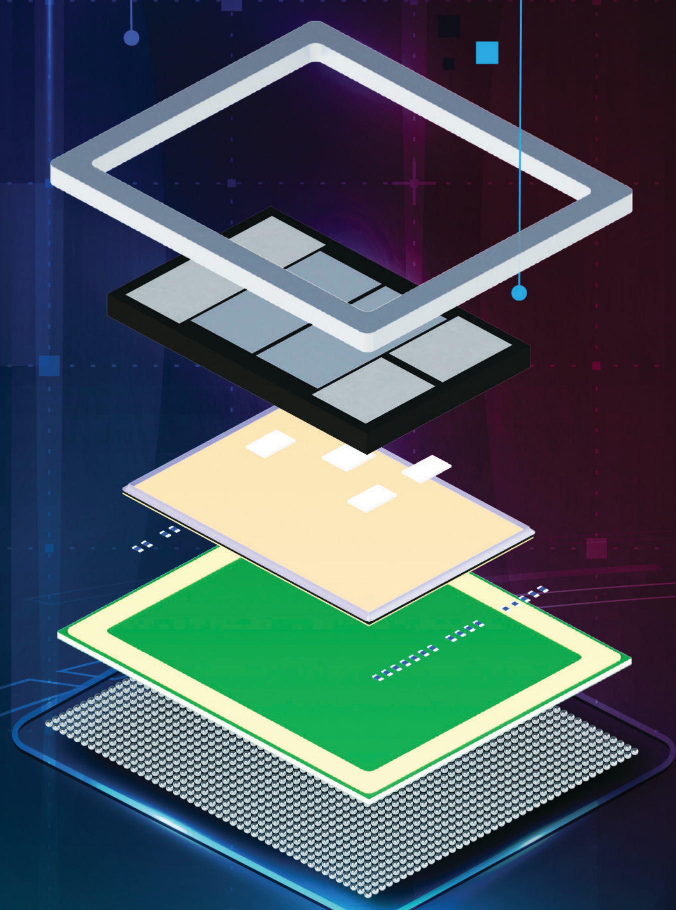

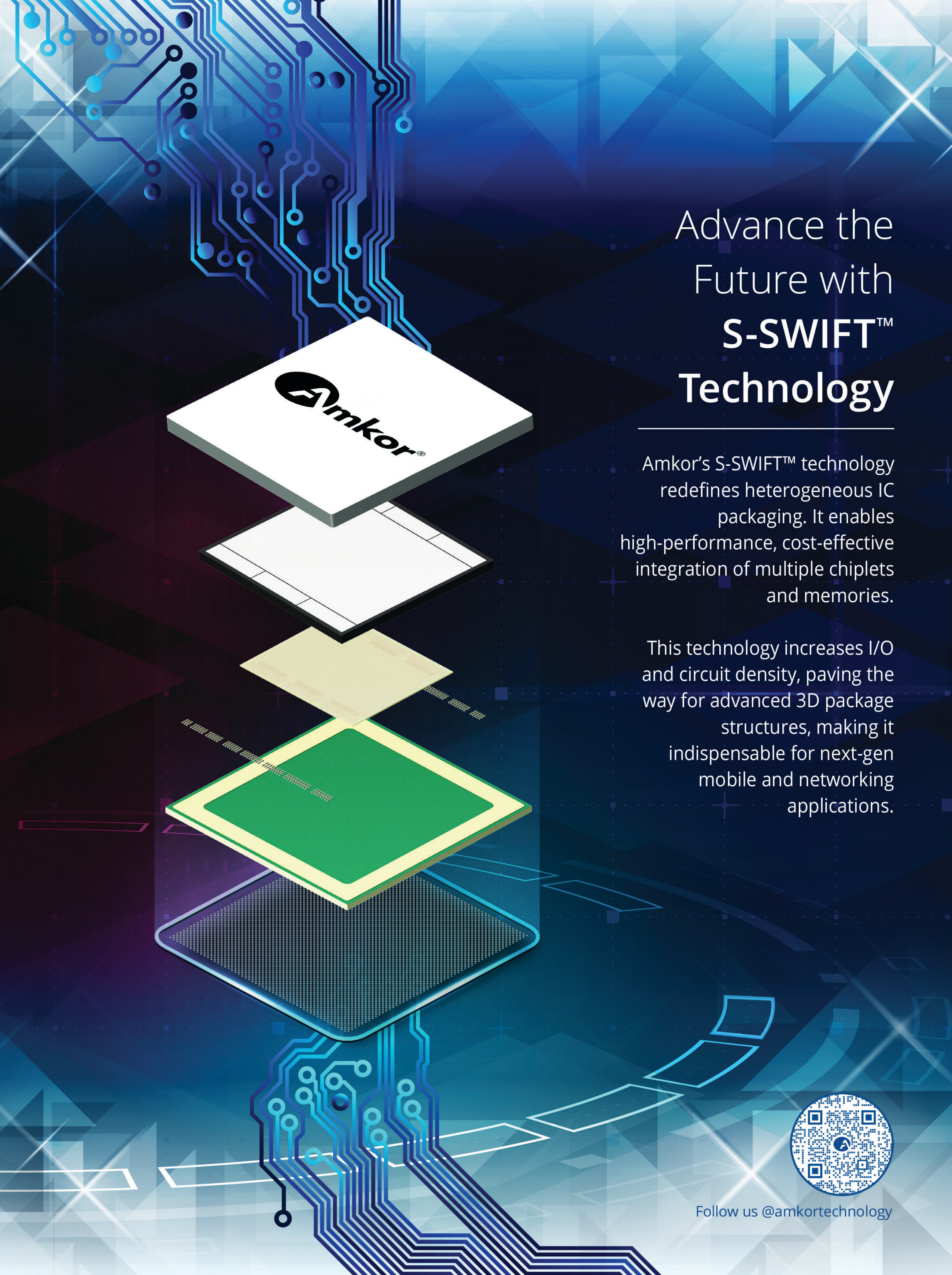
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