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The Future of Semiconductor Packaging

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Challenges in automotive packaging technologies

By Emilie Jolivet [Yole Développement] and Prasad Dhond [Amkor Technology, Inc.]

Four main trends are driving innovation in the automotive industry: electrification, autonomous driving, connectivity and comfort. Due to environmental considerations, governments want to decrease carbon dioxide (CO₂) emission levels by promoting electric cars and developing clean energy consumption. While safety has always been a major factor in modern vehicles, with the expansion of autonomous vehicles, a lot of investment has been made to develop even safer cars. With advanced driver assistance systems (ADAS) in cars and robotic vehicles, passengers' comfort and entertainment are also becoming a nice "must have" for in-cabin options.

Today, the automotive industry is looking more and more to the semiconductor industry and expectations for the coming years are getting higher. The car industry represents US\$2.3 trillion with a compound annual growth rate (CAGR) of +2.7% over the next five years. Automotive electronics accounts for US\$142 billion with a CAGR of +7% (Figure 1) [1]. The amount of electronics in a car has increased by 2.5 times since the 90s. Driven by the adoption of more electronics components in end-products, the semiconductor industry is growing strongly.

Although the automotive market has a greater inertia to change compared to the consumer market, advanced packaging technology will become more and more overriding (see Sidebar). As a result, the packaging market is projected to grow from US\$3.7 billion in 2017 to almost US\$7 billion in 2023 [1]. Also, regulations and qualification needs are getting more specific for this industry. To respond to the demand and reduce production costs, original equipment manufacturers (OEMs) and Tier 1 suppliers have started subcontracting more from outsourced semiconductor assembly and test (OSATS) companies.

On one hand, packages need to be simple, reliable and affordable. On the other hand, some modules are including more chips with a higher level of

Electronic megatrends: 2021 market values

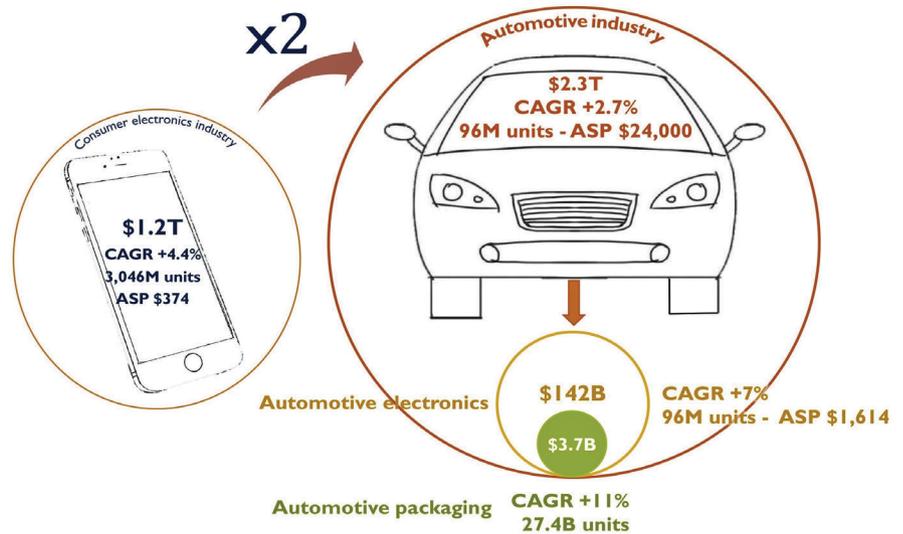


Figure 1: The automotive industry's need for advanced technologies continues to drive increasing electronics content. SOURCE [1]

2017-2023 Packaging revenue breakdown by the 4 market drivers for the automotive industry

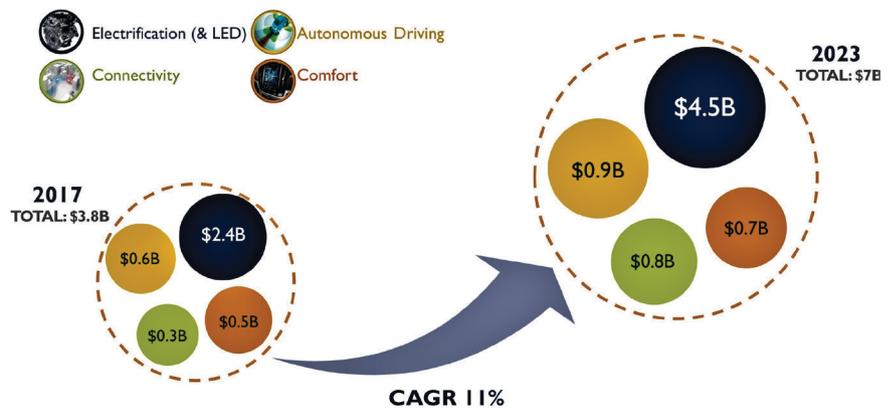


Figure 2: 2017-2023 Packaging revenue breakdown by the four market drivers for the automotive industry. SOURCE [1]

integration and a higher added value. With these varied requirements, OSATS are being given the opportunity to address these needs. This has been made possible because OSATS' manufacturing

technologies are getting more sophisticated, thereby enabling them to handle higher levels of complexity. In the span of a few years, OSATS' market share in automotive packaging has grown

and reached 38% in 2017. As safety and comfort have to be increasingly implemented in ADAS cars and robotic vehicles, the number of sensors is increasing by 21% CAGR from 2017 to 2023 (Figure 2). By 2025, camera, light detection and ranging (LIDAR) and radar sensors will equip all of the high-end vehicles and a large portion of the middle range cars. With the augmentation of sensitive sensors for safety applications, chip performance needs to be optimum. To meet those stringent requirements, chip packages need to evolve. For example, for CMOS image sensors (CIS), there are two types of setups, some are packaged with organic materials and others with ceramic materials. Both types of packages will grow due to a significant increase in the number of camera sensors per car. Radar sensors were originally packaged in wire bond packages. Now, they are slowly moving to fan-out (FO) designs with more chips integrated per package thanks to flip-chip technology. With larger systems, such as multi-dies and wafer-level chip-scale packaging (WLCSP), the objective is to cut costs.

To enter the automotive market, components have to pass qualification tests depending on the grade associated with their application. Each grade level from the Automotive Electronics Council (AEC) merely provides a reference of what the device or system has to withstand at its operating conditions. Some packages are already qualified for automotive standards, but for the most aggressive grades, some improvements are expected. Reliability and high-temperature resistance are key. To qualify a new package, quality checks are longer and more demanding than for other industries.

Investing in new types of packages for sensors in the automotive industry is a way to add value. Thanks to flourishing integration of infotainment and entertainment applications in cars, technologies from the consumer market are being adapted to the automotive market. In fact, the car is becoming an extension of the driver's smart phone or smart home. By adapting consumer products to the automotive world, their packages are getting automotive qualified for use in vehicles, helping OSATS and integrated device manufacturers (IDMs) to reduce development time—if minimal or no modifications are required.

Package opening - From front side

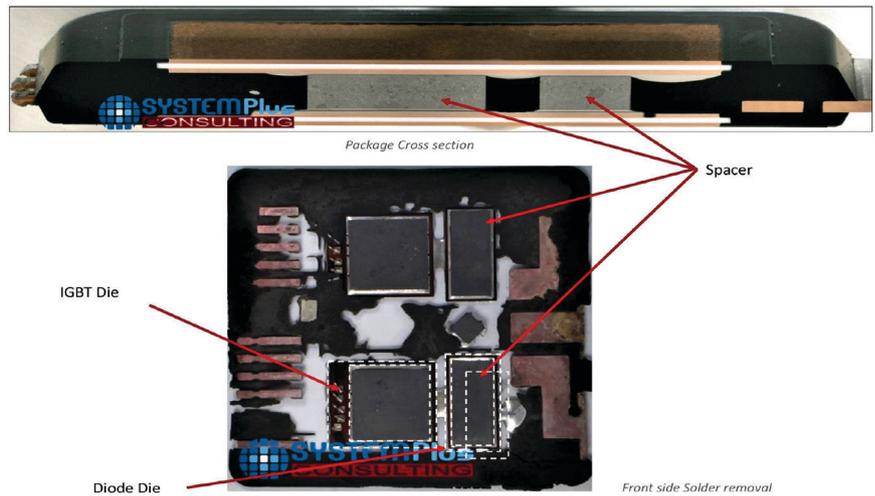


Figure 3: Infineon FF400R07A01E3 Double Side Cooled 700V 400A IGBT Module – multiple cross sections. SOURCE [2]

Driven by in-cabin safety, more and more equipment is implemented in the cockpit that could also be used for infotainment and entertainment. Gesture and speech recognition are the next way to interact with the central cluster and the on-board system. Cameras could be used for driver monitoring, but also for gesture recognition and man-machine interaction. Those systems will use artificial intelligence (AI) and will require powerful processing hardware. Those new applications will take advantage of the ADAS computing platform built in for autonomous driving computing. Packaging these new systems is also a challenge. Today, there is no automotive standard for these advanced chips, so most of the OEMs use expensive and powerful chips from Nvidia, Renesas or Kalray. Those platforms use graphics processing units (GPUs) that are currently packaged on an interposer with stacked memory, and still not yet optimized for the automotive market.

Following the trend towards more electrification, power conversion applications are the strongest driver for automotive packaging innovation with 18% CAGR. While talking about power conversion, one of the main issues is thermal management. To provide better cooling solutions without expanding the footprint, improved packaging techniques must be implemented. With double-side cooled, card-like modules, copper clips

and side-to-side chips in quad flat no-lead (QFN) packages, the degree of integration gets higher, requiring better thermal power dissipation (Figure 3). To achieve better thermal management, new types of heat dissipation materials must be used. As a result, the industry is searching for ceramic-less substrate solutions as an alternative to organic substrate materials. This year, it has been made public that Tesla was the first high-class car manufacturer to integrate a full silicon carbide (SiC) power module. This new module is made by STMicroelectronics and multiple modules are integrated in the new Tesla Model 3. Each module contains two SiC MOSFETs with an innovative die attach solution and connected directly onto the terminals with copper clips, and thermally dissipated by copper baseplates.

Acknowledgments

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1. “Trends in Automotive Packaging 2018” report, Yole Développement, 2018.
2. “Infineon FF400R07A01E3 Double Side Cooled IGBT Module” report, System Plus Consulting, 2018.

Automotive OSAT challenges

By Prasad Dhond [Amkor Technology, Inc.]

Automotive is one of the fastest growing segments in the semiconductor industry. Due to their long lifecycle, automotive applications provide a stable volume base and higher returns on investment (Figure S1). However, the automotive business is also tough and has high barriers to entry. Suppliers must support long lifecycle products to ensure business continuity. Automotive customers are looking for suppliers that have the highest levels of experience, technical capability and quality.

The shift towards advanced packaging in automotive

Although 80% of automotive packaging still uses wire bond technology, the trend is towards advanced packaging. Flip-chip ball grid array (FCBGA) is the most popular advanced package for processors used in advanced driver-assistance systems (ADAS). The high I/O count, thermal and electrical performance requirements of these processors are best supported using FCBGAs (Figure S2).

Low-density fan-out (LDFO) technology is used for packaging mmWave radar transceivers to achieve superior electrical performance. Flip-chip chip-scale packaging (fcCSP) is also used for radar transceivers and high-performance microcontrollers (MCUs) that were previously packaged in wire bond BGAs.

Infotainment applications use processors in system-in-package (SiP) form factors. These SiPs combine the

processor, memory and other support components together in a standard form factor such as FCBGA. A modular SiP approach speeds up time to market and provides flexibility to car original equipment manufacturers (OEMs) to upgrade processors without making changes to the surrounding circuitry.

Wire bond packages in automotive

A majority of analog integrated circuits (ICs) and MCUs that are sprinkled all over the car still use wire bond packages. Wire bond packages have a long history in automotive electronics, and will continue to play a crucial

part in powertrain, body, and chassis applications. The focus for automotive wire bond packages has been to improve reliability performance using enhanced material sets. Almost all new automotive wire bond products now use copper wire. To achieve higher automotive reliability, there are many variations of copper wire being tested. Lead frame packages use lead frames that undergo treatments such as roughening for better adhesion with interfaces to prevent delamination. For some packages, epoxy molding compounds (EMCs) with lower sulfur content are used to enhance the reliability with copper wire in automotive applications.

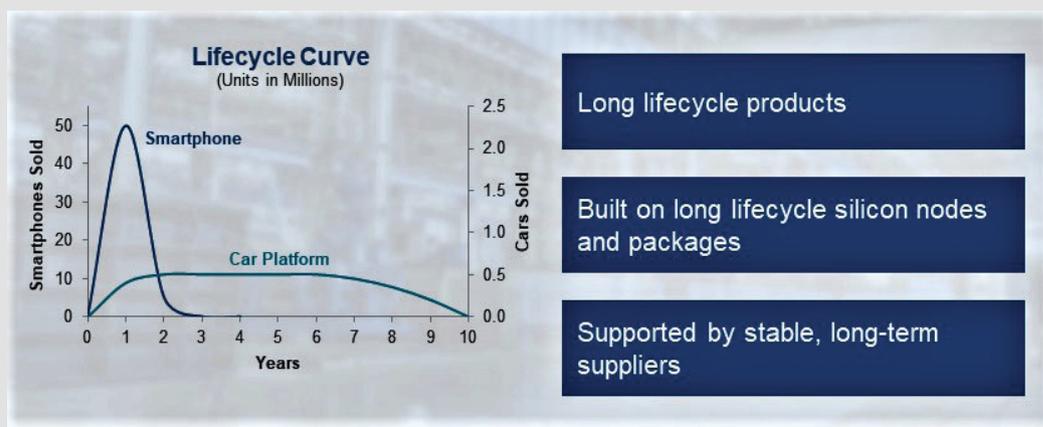


Figure S1: Automotive product requirements provide a challenge to any supplier.

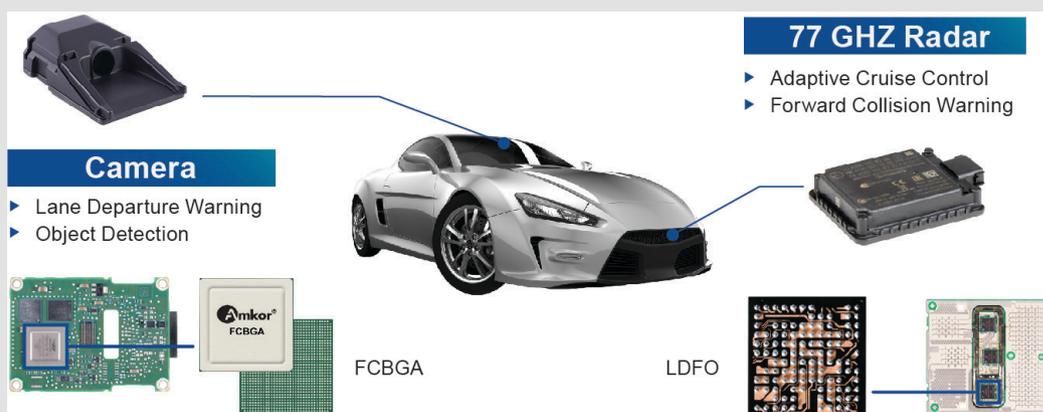


Figure S2: Emerging applications in cars require different types of advanced packages: SOURCE: IHS Markit Teardown

Quad flat no-lead (QFN) packages with plated-end-lead (PEL) designs are popular in automotive applications. Automotive customers require solder joint inspection of IC packages mounted on printed circuit boards (PCBs). However, solder joints of leadless QFN packages are not visible and require the use of expensive X-ray inspection. The PEL option for QFN packages forms visible solder fillets that can be inspected using standard automated optical inspection (AOI) equipment (**Figure S3**).

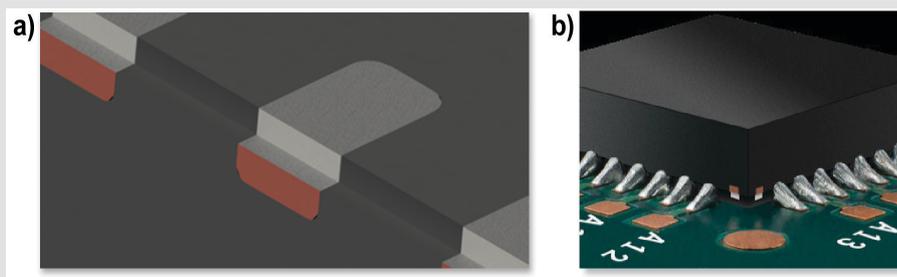


Figure S3: Plated-end-lead QFN packages provide a visible solder fillet when mounted on a PCB: a) (left) Saw-singulated QFN bottom view, b) (right) Mounted on board.

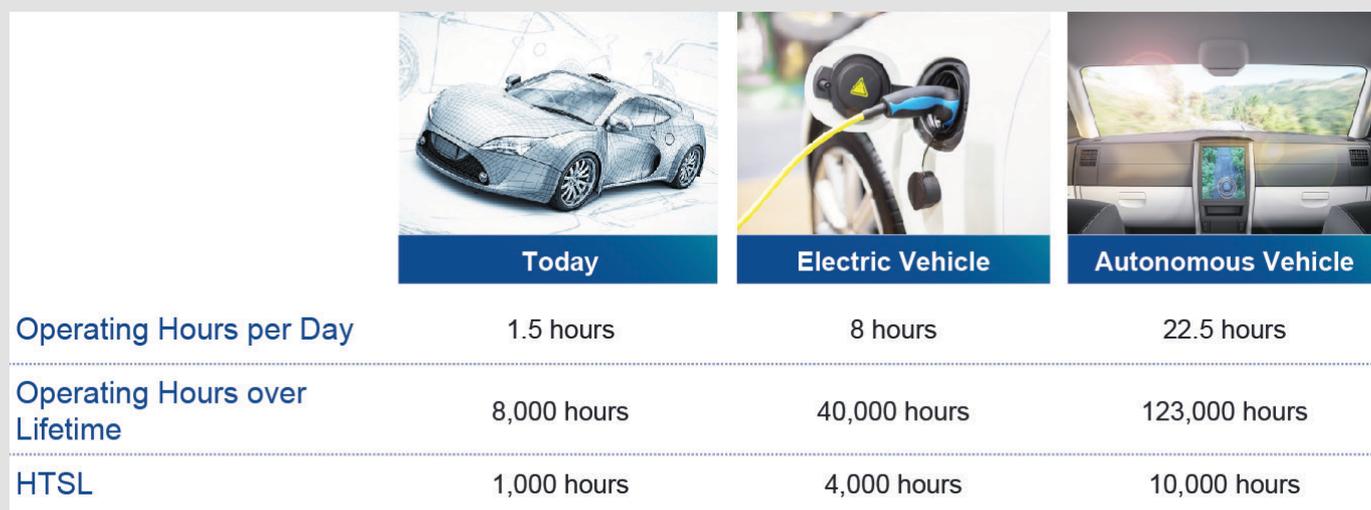


Figure S4: Automotive lifetime requirements dictate rigorous qualifications tests.

The use of electric vehicles is growing and power semiconductor suppliers, including OSATS need to provide reliable, efficient and cost-effective solutions. Sub-systems such as traction inverters, DC-DC converters and on-board chargers for xEV vehicles use power semiconductors in different form factors such as:

1. Discrete packages: Standard power packages such as TO263, TO247 and their derivatives are popular in automotive applications.
2. Modules: Modules house multiple components used as switches for power stages. For example, Si insulated-gate bipolar transistors (IGBTs) with free-wheeling diodes; or SiC metal-oxide semiconductor field-effect transistors (MOSFETs) with Schottky barrier diodes. In

addition, the modules provide cooling mechanisms such as double-sided cooling (**Figure 3**, main article).

New challenges for automotive packaging

There are several automotive trends that impact the semiconductor and packaging industry:

1. Leading-edge technology nodes are being used in ADAS processors. For example, Intel’s Mobileye EyeQ5 is planned to be developed on a 7nm FinFET process [SR1]. There is limited field experience with advanced nodes that require different techniques to assess reliability of the silicon and packaging.
2. The mission profiles of cars are changing. For example,

components in electric cars have longer operating hours on account of the additional charging time. This translates into higher requirements for reliability tests such as high-temperature storage life (HTSL) (**Figure S4**). The requirements specified in documents such as the Automotive Electronics Council’s (AECs) AEC-Q100 standard are often extended or modified to closely match the actual mission profiles of specific applications.

The “multiplier effect” is the main challenge in automotive semiconductor reliability. Even a 1 part per million (ppm) failure at the component level will multiply to a 1% defect rate in the vehicle. For the highest reliability, the goal is zero defects. This challenge is even more pronounced with the

rising electronic content in cars. In spite of this, quality expectations have never been higher, and customers now measure defects in “number of quality incidents” instead of ppm.

Certifications and standards

Suppliers to the automotive industry must have International Automotive Task Force IATF16949:2016 Quality Management System (QMS) certification. The suppliers must also be compliant with or support other Automotive Industry Action Group (AIAG) standards/requirements such as advanced product quality planning (APQP), failure modes and effects analysis (FMEA), Production Part Approval Process (PPAP), statistical process control (SPC) and measurement systems analysis (MSA). Process audits must be conducted using VDA 6.3 checklists.

Qualification and reliability testing are conducted using AEC standards. The standard varies by the type of component, such as AEC-Q100 for integrated circuits, AEC-Q101 for discrete components, and AEC-Q104 for multi-chip modules.

Beyond certifications and standards

Achieving certifications and standards compliance is a good start, but only the minimum requirements for a successful automotive supplier. There are other controls and best practices that must be implemented for automotive products, such as:

- Automotive products should be manufactured using designated equipment that is operated by automotive trained operators.
- Automotive material sets and process flows must be developed to achieve higher reliability. Automotive control plans must be established for enhanced monitoring and tighter SPC control.
- Design rules must be established to improve reliability and manufacturability of automotive packaging construction.
- A reliable and high-quality supply chain must be established and maintained. This supply chain must be managed with enhanced practices such as using VDA 6.3 checklists for audits and establishing more stringent material inspection criteria.
- A higher level of automation must be used in automotive factories to eliminate human error and minimize variations in production.
- Automotive suppliers must use best known 5S (a Japanese method to sort, set in order, shine, standardize and sustain) practices to maintain a cleaner manufacturing environment for automotive products.
- A safe launch process must be used to ramp automotive products successfully to high-volume production.

Suppliers must be financially sound to support long life-cycle applications. They should have a strategic focus on the automotive market that is backed up by investments in automotive quality initiatives. Automotive OEMs and Tier 1 suppliers are looking for stable partners that can support them in the long-term. An increasing number of automotive applications are moving to advanced packages that require packaging partners with technology expertise.

Quality remains the most important factor in automotive applications. Automotive suppliers must go beyond basic certifications and standards. They must provide intelligent package design, automotive materials and processes, tighter controls and automotive-certified personnel that help manufacture consistently high-quality products. This creates an automotive culture and mindset at the supplier that is necessary to achieve the zero defects goal.

Sidebar reference

SR1. The Evolution of EyeQ, Mobileye’s website, <https://www.mobileye.com/our-technology/evolution-eyeq-chip/>



Biographies

Emilie Jolivet is Director of the Semiconductor & Software Division at Yole Développement, part of the Yole Group of Companies, where her specific interests cover package and assembly, semiconductor manufacturing, memory and software and computing fields. Based on her valuable experience in the semiconductor industry, Emilie manages the expansion of the technical and market expertise of the Semiconductor and Software Team. She holds a Master’s degree in Applied Physics specializing in Microelectronics from INSA (Toulouse, France). After an internship in failure analysis at Freescale (France), she was an R&D engineer for seven years in the photovoltaic business where she co-authored several scientific articles. Enriched by this experience, she graduated with an MBA from IAE Lyon and then joined EV Group (Austria) as a Business Development Manager in 3D & Advanced Packaging before joining Yole Développement in 2016. Email: jolivet@yole.fr



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