Packaging trends for automotive LIDAR applications

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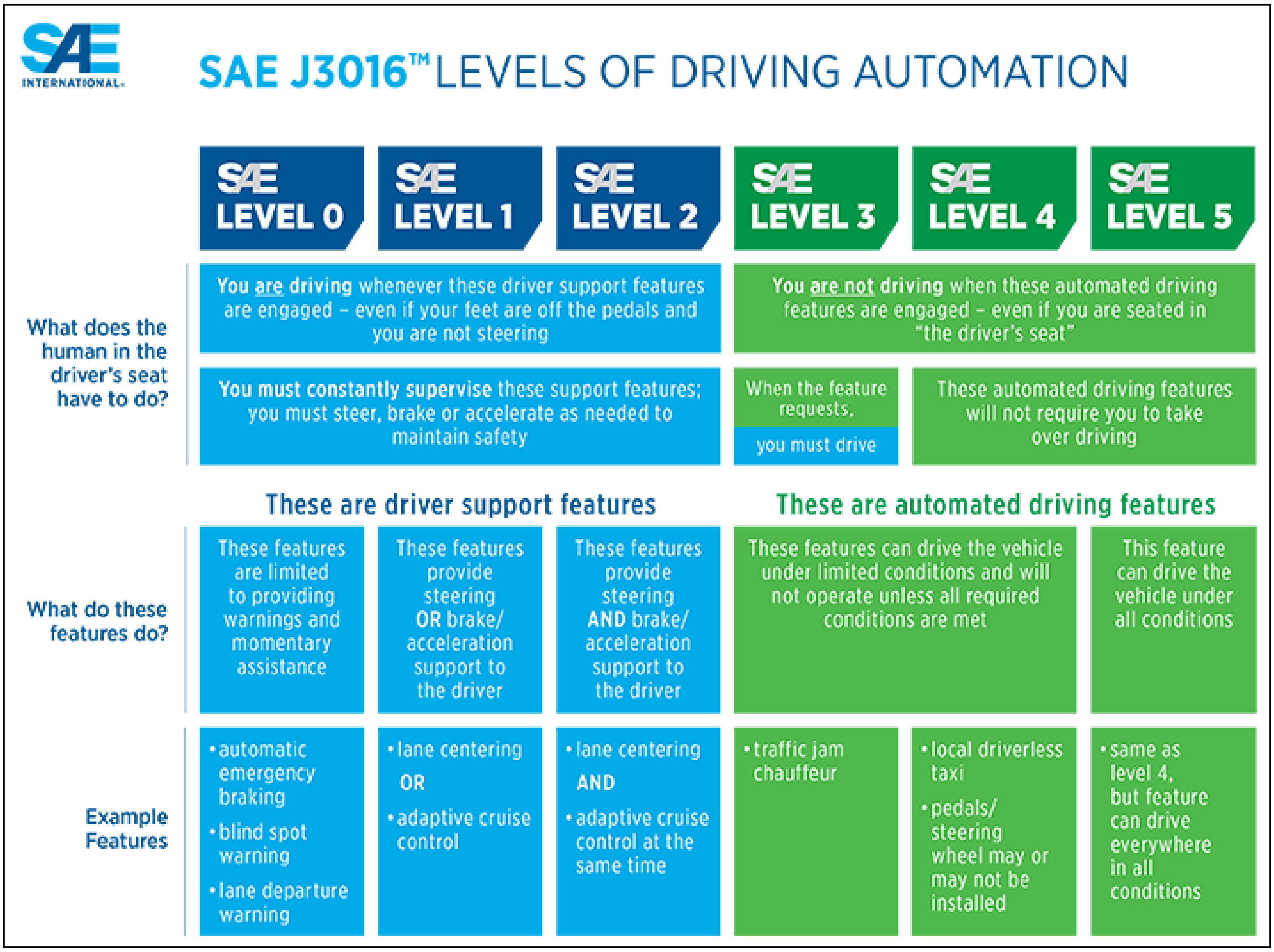
Revolutionizing the safety of the modern car will reduce road traffic fatalities and associated costs. Each year, approximately 1.35 million people die due to road traffic crashes worldwide. And, these accidents cost most countries 3% of their gross domestic product [1]. Human error is the leading cause for a majority of these traffic fatalities. According to the National Highway Traffic Safety Administration's (NHTSA) annual report for 2018 (published in 2020), nearly 34,000 crashes resulted in fatalities in the United States; additionally, 1.9 million crashes resulted in injury and 4.8 million crashes resulted in property damage [2]. While automotive car manufacturers (original equipment manufacturers [OEMs]) have integrated the modern car with a suite of sensors, such as radio detection and ranging (radar), cameras, inertial measurement units (IMU), and an anti-lock braking system (ABS), continued improvements will further automate driving tasks.

In recent years, light detection and ranging (LIDAR) technology has gained viability for applications such as advanced driver assistance systems (ADAS) and autonomous driving (AD). As the automotive industry pushes the safety envelope of the newer vehicles with ADAS and AD capabilities, the variety of state-of-the-art solutions is promising. Most OEMs and system (Tier 1) suppliers believe a combination of LIDAR, radar and cameras is essential for a robust safety platform.



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/acceleration support to the driver	These features provide steering **AND** brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 1: SAE autonomous driving levels. SOURCE: SAE International

Industry trends

According to SAE International (formerly the Society of Automotive Engineers [SAE]), the automated driving capabilities of vehicles can be defined from Level 0 to Level 5. The general description and guidelines of various levels, according to the SAE J3016 standard, are seen in **Figure 1**. Some of the key driver assistance features each of these levels enable are discussed below. For example, Level 1 includes automatic emergency braking (AEB) and lane departure warning system (LDWS) features, while Level 2 further enables safety options such as lane keeping assist (LKA) and adaptive cruise control (ACC). For some extended periods of time, a driver can take his/her hands off the steering wheel and foot off the pedals in Level 2 vehicles, enabling partial automation. Though Level 2 features can intervene in certain driving scenarios, the driver is expected to remain attentive on the driving environment. As such, bigger challenges remain in enabling Level 3 as vehicles migrate from partial to conditional automation.

Vehicles with Level 3 will enable features such as traffic jam assist (TJA) and driver monitoring system (DMS) as the driver-to-machine transition occurs. Unlike Level 2, Level 3 places the burden of monitoring the surroundings on the vehicle's sensor suite. However, the shift from Level 2 to Level 3 has been granular, as the industry defined an intermediate level called 2+. Level 2+ is empowered by high-definition maps with foresight of the horizon in both optimal and sub-optimal driving conditions. Essentially, Level 2+ heightens a vehicle's understanding of its path, especially during absence of lanes and unfamiliar driving destinations. Beyond Level 3, ADAS Levels 4 and 5 will include autopilot (AP) on highways and everywhere else, with high and full automation capabilities that are a must for robotic vehicles.

Most vehicles manufactured today are Level 0, however, it is expected that the adoption of Level 1 and above will increase as shown in **Figure 2**. For example, in 2019 one in every six cars sold was equipped with Level 2 and above capability. However, towards the end of the decade, nearly one in two cars is expected to be at Level 2 and above capability. The typical approach of most OEMs has been to design Level 2 using multiple radar and camera sensors. While this has been acceptable so far, relying on just radar and camera sensors may not be sufficient to enable Level 3 and higher levels. Other sensors such as LIDAR are gaining attention because of their complementary nature to radar and cameras. **Figure 3** shows a comprehensive view of how each of these sensors compares against each other under similar measurement conditions.

Figure 2: Light vehicle forecast and ADAS levels. SOURCES: Yole, IHS Markit

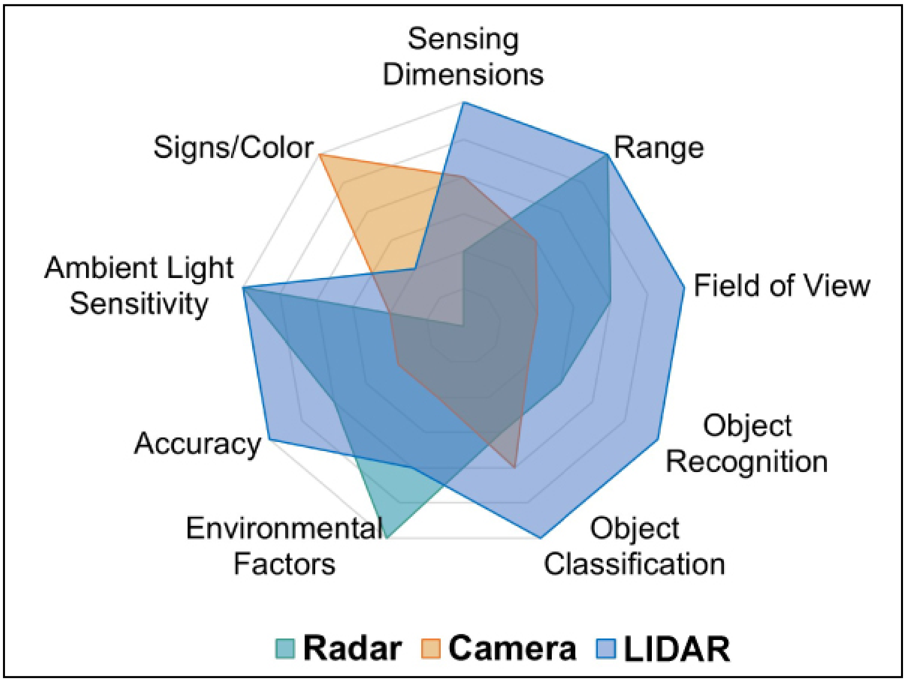
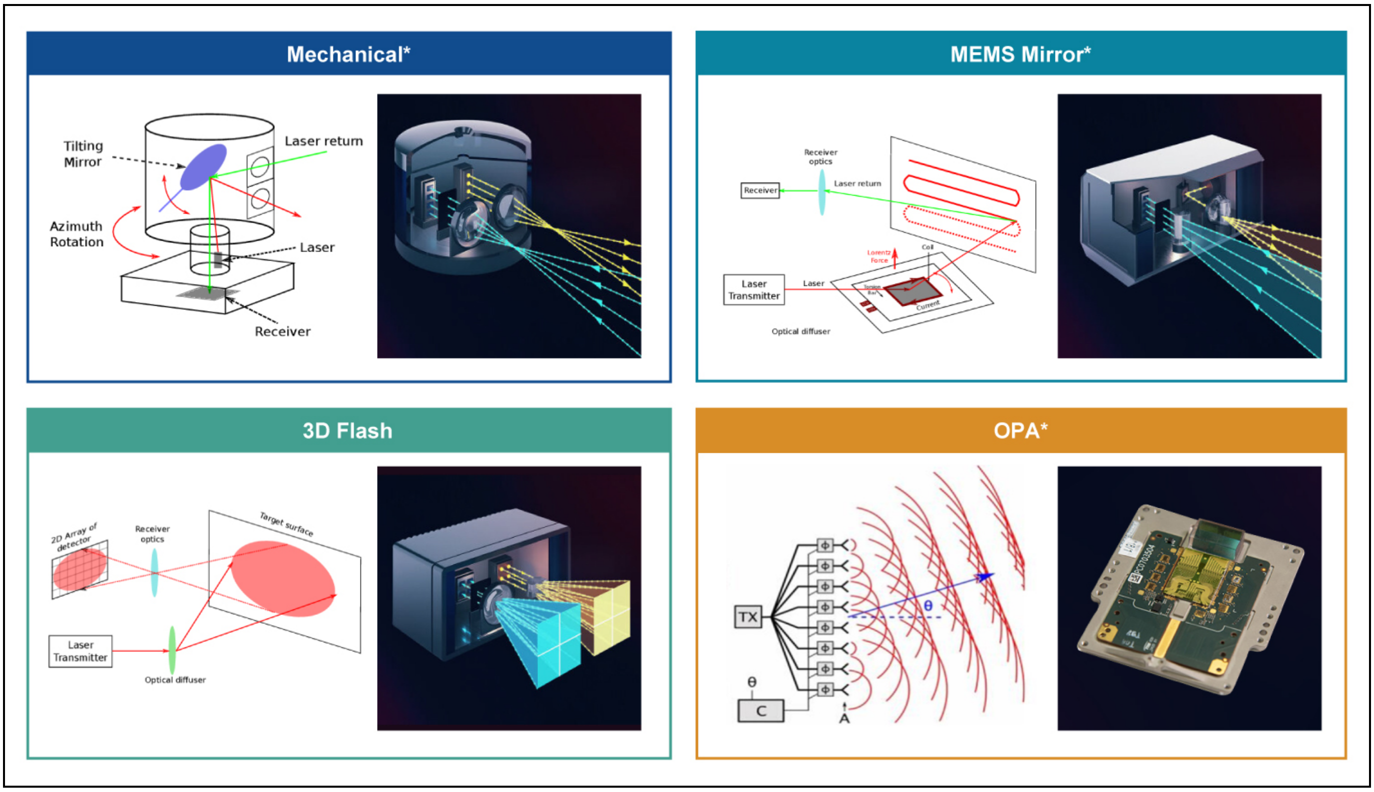


Figure 3: Relative comparison of radar, camera and LIDAR. SOURCES: Quanergy, Velodyne

Qualitatively, cameras require significantly more computing power due to the image processing for the acquired images. On the other hand, LIDAR sensors rely on analog detection or statistical methods to generate point cloud images. So, fewer number of compute cycles are required with LIDAR. While LIDAR sensors have better range, resolution and accuracy than cameras, LIDAR cannot replace cameras because of a camera's ability to recognize road traffic signs and different colors. Alternatively, both LIDAR and camera sensing benefit from using radar as an antecedent technology for ADAS systems. For example, operation of camera sensors can be impaired by snow, while weather conditions can change the refractive index of the propagation medium and reduce the possible range of LIDAR.


Mechanical*

MEMS Mirror*

3D Flash

OPA*

Figure 4: LIDAR beam-steering technologies [3]. (* Indicates scanning mechanism.)

LIDAR sensor landscape

To understand the underlying driving forces, the current landscape of the LIDAR sensor market can be broadly divided into four segments: measurement technique, emitter source, detector, and beam steering. From a measurement perspective, two dominant approaches are being pursued: time of flight (ToF) and frequency modulation continuous wave (FMCW). In ToF, range is measured by determining the difference in time of transmission and time of arrival of the pulse. The pulses used in such systems tend to be of very high power, but with narrow pulse width. Detectable range is directly proportional to the peak power of the pulse. In this measurement technique, range of the object is measurable, but not velocity.

With ToF, signal-to-noise ratio (SNR) issues are higher, especially in bright conditions. Because of achievable receiver sensitivities of current ToF systems, range is often limited to 100-200m. On the other hand, FMCW is relatively immune to SNR problems because this technique relies on the number of transmitted photons, not on the peak laser power. Additionally, because of the coherent detection nature, only the relevant wavelengths are amplified for signal processing. FMCW enables detection of both range and velocity of objects at a relatively lower power.

In terms of emitter technology, most designers prefer laser diodes over fiber lasers or other types because they offer better cost, performance and system-level integration. Among the oft-used laser diode designs, edge-emitting lasers (EELs) and vertical-cavity surface emitting lasers (VCSELs) are being discussed extensively. Because light is emitted from the side in EELs, they are better suited as discrete elements rather than arrays. However, for a wider field of view (FoV) and longer range, arrays are preferred over discrete diodes and emitters operating at high peak powers. This often results in higher costs for cooling systems. VCSELs, on the other hand, can be manufactured as arrays because of their top emission. Though VCSEL technology is an emerging area, its cost/watt is expected to improve with its adoption in automotive applications. Range is believed to be up to 500m from EEL sources, however, illumination is a disadvantage given the elliptical nature of the beam. Alternatively, the usable range of VCSEL sources can be up to 300m with a beam shape that is tighter compared to EELs. Finally, the wavelength of emission is another key factor to consider in emitter sources. In the context of maximum permissible exposure, most of the emitters used today are around 905nm near-infrared (NIR), which are relatively unsafe for the human eye at elevated powers. Because of this concern, emitters around 1550nm short-wave infrared (SWIR) wavelengths are garnering a lot of attention because of better eye-safe levels.

On the receiving side, FoV is essential to ensure that returning light is captured effectively and processed via analog detection or statistical detection. The active area of the photo detector, focal length of the lens, and placement of the optical bandpass filter determine the FoV. In principle, a wider FoV is preferred, but it is achieved at the cost of larger photo detector die, resulting in higher terminal capacitance and higher noise. There are different types of detectors that are used in LIDARs today, such as photodiodes (PDs), avalanche photodiodes (APDs), silicon photomultipliers (SiPMs), and single-photon avalanche diodes (SPADs). Detectors paired with NIR emitters are silicon based and, as a result, cost is not a concern. However, SWIR detectors are not based on silicon and relatively expensive, resulting in higher system cost at around 1550nm wavelengths. While sensitivity and infrared detection performance is acceptable among all of these detector types, gain is much higher in SiPMs and SPADs. For effective detection, the receiving signal power cannot be increased without increasing the aperture of the collecting lens or using a detector with high photosensitivity. Another challenge is the design of bandpass filters that need to work at wavelengths of sun during the day, and streetlights and headlights during the night. Consequently, analog detection still has a lot of challenges. Some designers have opted for statistical detection using SPADs because SPADs work on the principle of received pulses and histogram development.

Finally, the key beam-steering technologies that are being implemented and researched today (as shown in **Figure 4**) include: mechanical, microelectromechanical systems (MEMS), Flash, and optical phased arrays (OPAs) and discussed more in depth in reference [3]. Mechanical LIDARs are primarily used in robotic cars today. These are multi-channel devices with multiple lasers and detectors that rotate 360°. The mechanical designs are bulky, costly and present aesthetic problems for the average customer, limiting its implementation in light passenger vehicles. MEMS LIDAR uses a microscanning mirror integrated with actuators on silicon that steer the laser beam during illumination. These designs are relatively cheaper, compared to mechanical LIDARs, but reliability concerns persist under all terrain conditions. In Flash LIDARs, instead of scanning over an entire area, the laser beam is illuminated all at once. There are no moving parts in such LIDARs, offering better reliability for automotive use cases. Obviously, an array of detectors is needed to form an image. A slight variation of the Flash concept is sequential Flash where illumination of an entire scene is not done at once, but rather, column by column. Lastly, OPA steers the illumination by controlling the phase of an array of lasers. Similar to Flash LIDARs, there are no moving parts and therefore, OPA offers good reliability as well.

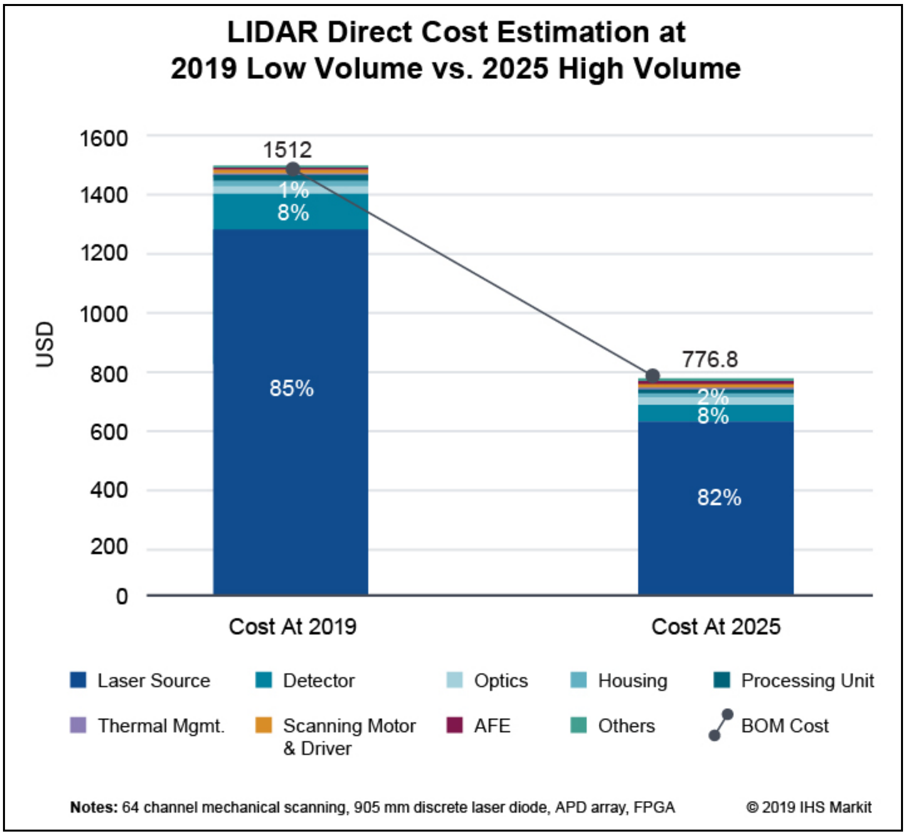


Figure 5: LIDAR cost breakdown and trends. SOURCE: IHS Markit

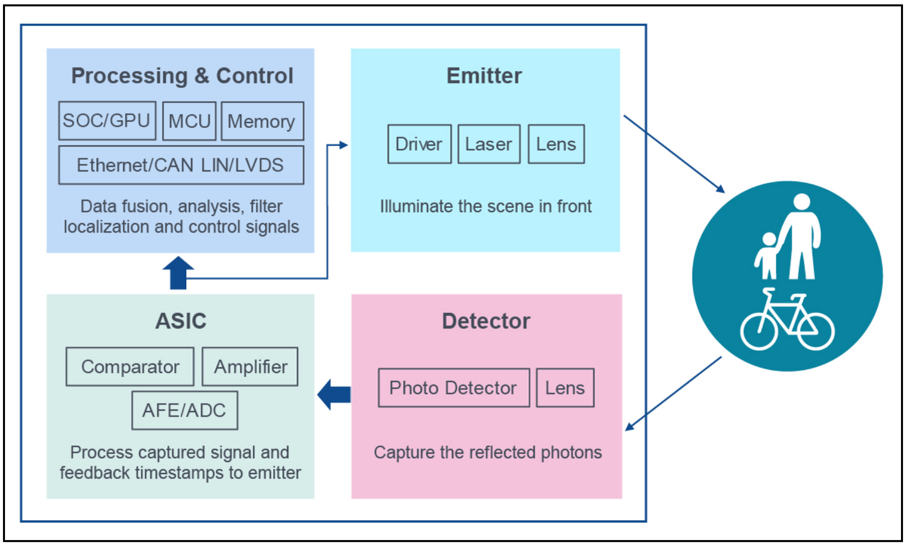


Figure 6: LIDAR building blocks. SOURCE: IHS Markit

Packaging solutions

Lacking government mandates for LIDAR, vehicle OEMs have chosen the path of redundancy to ensure safety in autonomous driving. Cameras, radar and LIDAR not only complement each other, but also compete in some applications as shown in **Figure 3**. We are able to provide package solutions for the emerging LIDAR sensors of the ADAS market. Because of the varying requirements of LIDAR customers, the market consists of highly fragmented solutions. Today, however, the cost of LIDAR systems is higher because of the lack of economies of scale and inherently expensive incumbent technologies for mass markets such as

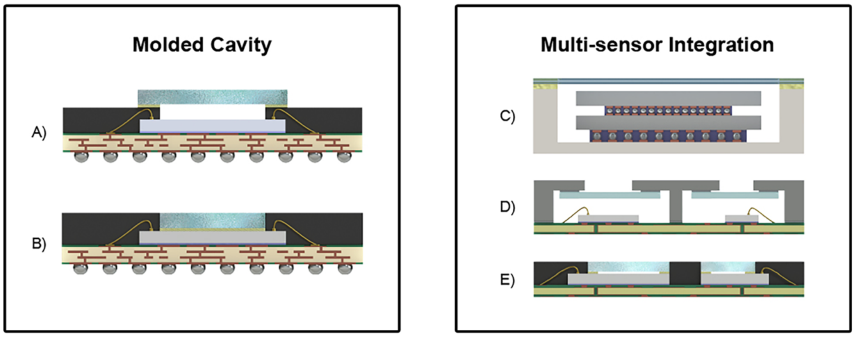


Figure 7: Amkor's packaging solutions.

automotive. One example of the cost breakdown of a mechanical LIDAR is shown in **Figure 5**. According to IHS Markit, the cost of a mechanical LIDAR system with 64-channel scanning could reach a price point below $800 by 2025. If achieved, such a price point for a LIDAR module might be affordable for OEMs focusing on mobility as a service (MaaS) with ADAS capabilities higher than Level 4. For personal use vehicles, cheaper LIDAR solutions may be preferred.

Being an outsourced semiconductor assembly and test (OSAT) supplier, we bring knowledge and economies of scale to offer cost-effective solutions. For example, successful cost reduction has been demonstrated by using a standardized process flow through our MEMS sensors platform. Cavity ball grid array (BGA)/land grid array (LGA) and molded cavity BGA/LGA standardized packages can target many market categories such as biometric authentication, automotive, human interface, environmental and healthcare/fitness. Standardization also offers faster time to market. Though most of the current laser diode and detector packaging uses high-cost ceramic substrates, leveraging suppliers' continued development of laminates, lid and mold compounds can ensure quality and performance for low-cost solutions. To further understand the levers to reduce cost and improve functionality, one needs to understand the building blocks for a LIDAR system (**Figure 6**). The current building blocks for a LIDAR system contain an emitter that illuminates the scene, a detector to capture the reflected light, an application-specific integrated circuit (ASIC) to process the signal, and a processing unit to analyze the data. While most of the solutions today are in discrete form, integration of multiple chips in a single package or multiple packaged parts on a single substrate could be possible future trends.

With system-in-package (SiP) modules being so successful in other automotive applications, as well as applications such as infotainment, it begs the question of how integrated a LIDAR package solution can be and the possibility of integration trends. For example, an integrated APD and a trans-impedance amplifier (TIA) or an integrated SPAD with an ASIC can be packaged either in a side-by-side or as a chip-on-wafer (CoW) solution. Further, a digital signal processing (DSP) die can be co-integrated through a possible hybrid solution on a printed circuit board (PCB) or monolithic system on chip (SoC) detector solution. Both have their own advantages and disadvantages. For example, monolithic solutions offer low NIR sensitivity and better speed of detection, while hybrid solutions offer higher NIR sensitivity and have a better aperture ratio.

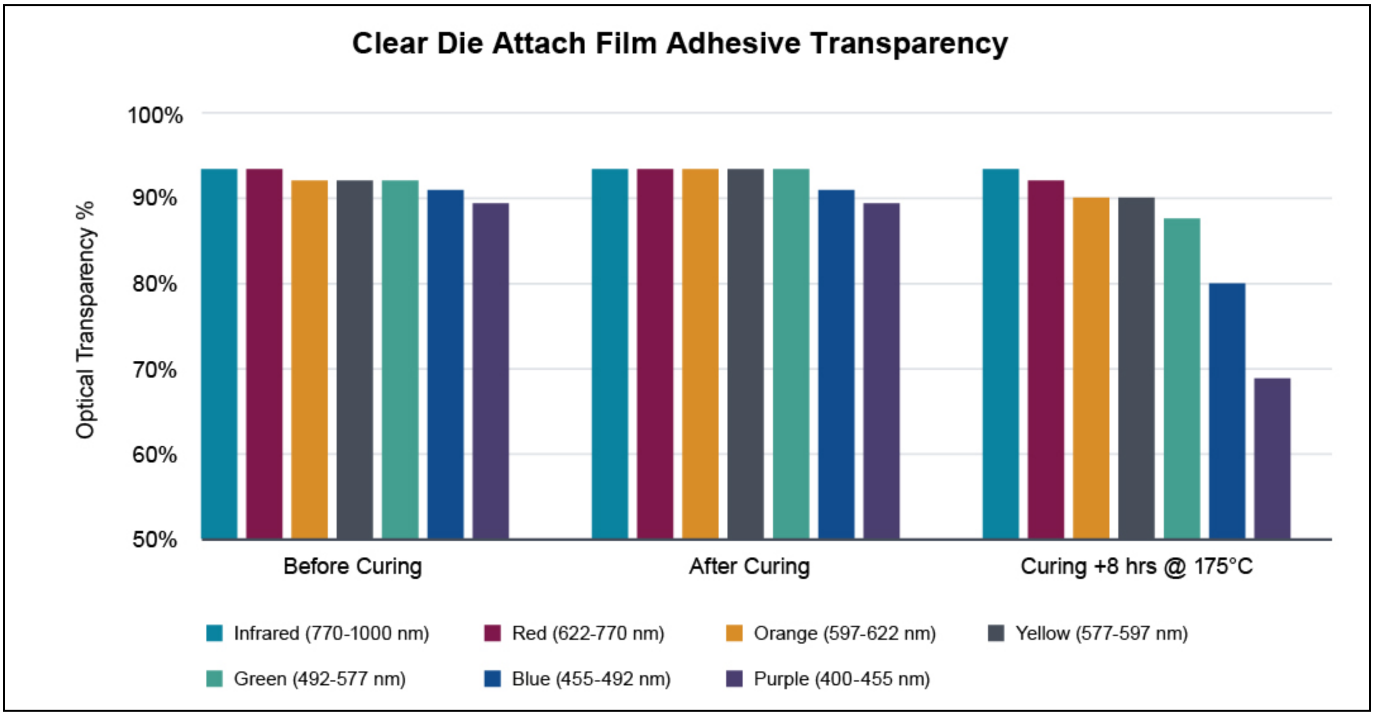


Figure 8: Clear die attach film transparency spectrum. (SOURCES: Loctite, Henkel Adhesives

With low inductance being a priority, especially for ToF applications in the detectable range, high-power short-pulse is a requirement and a transition from long-lead, through-hole laser packages (with high inductance) to surface mount packages with an array of laser diodes will be key. Beam quality is another requirement that will depend heavily on reducing package electrical losses. To find the right path forward, the successful technology achievements in optical fingerprint sensors and MEMS sensors can be leveraged to offer improved packaging solutions for LIDAR customers.

In addition, molded-cavity fingerprint sensor packaging (**Figure 7**, structures A and B) has been successfully qualified for automotive applications under the Automotive Electronics Council's AEC-Q100 Grade 2 specifications. While automotive grade packages need to undergo more stringent requirements than consumer fingerprint sensors, we have been able to use a standardized process and qualify them specifically for automotive complementary metal-oxide-semiconductor (CMOS) image sensors, ToF and LIDAR applications. The current molded-cavity structures can be modified to meet customers' needs including, flip-chip/copper pillar bonds instead of wire bond, LGA instead of BGA and varying glass attach epoxies for different applications.

As an example of the discussion above, consider that a ToF sensor within the cabin of a vehicle for a gesture control application might not need an extremely clear and precise image, so by eliminating the need for an air gap and attaching the glass using a clear die attach film (DAF), pressure buildup within the package might be reduced. **Figure 8** shows the transparency at different wavelengths for a clear DAF solution adhesive that offers over 93% transparency in the infrared spectrum (770-1000nm wavelength). Structure B (**Figure 7**) utilizes a clear DAF to attach the glass while structure A uses an ultraviolet (UV) curable epoxy to attach the glass to create an air gap. A UV-curable epoxy aids in mitigating pressure buildup within the cavity that would be increased with a thermal cure epoxy. By utilizing similar technologies, multiple sensors can be integrated into one package and continue to evolve into the future. As shown in **Figure 7**, structures C, D and E show three different solutions for combo-sensors including a ceramic substrate with a stacked die solution on top (structure C). Because of the high average power of approximately 12-25W for long range LIDAR, a ceramic substrate such as the top solution might be required. The top solution is also optimal for many ToF applications where a large amount of heat is produced because it poses the best thermal performance and least warpage. Structures D and E both utilize wire-bond interconnects with a laminate substrate. The difference is one utilizes a molded solution (E), while the other a liquid crystal polymer (LCP) lid (D). Both solutions are optimal for lower power applications. An example of this might be short-range LIDARs where the typical power output may be <6W. These packages can be used to bring a lower cost, high-quality LIDAR solution to the market through strategic partnerships with the supply chain and customers.

Summary

Driven by environmental, economic and social factors, demand for sophisticated automotive safety solutions will increase. Affordable safety being a priority, LIDAR is being developed as a major component for ADAS. We are positioned to provide package solutions for each segment of ADAS, including cameras, radar and LIDAR. Utilizing geographically dispersed factories, services are strategically implemented to customers worldwide in automotive, industrial and consumer applications. While focused on delivering products from the existing portfolio of packages in the photo detector portion of the LIDAR block, innovative solutions in the form of system-in-package (emitter and receiver) that further spearhead integration in a single package/module will be developed as LIDAR continues to evolve towards cost-effective solutions. Going forward, we will rely on our strong technology know-how and customer partnerships to deliver advanced solutions to these challenges.

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Biographies

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