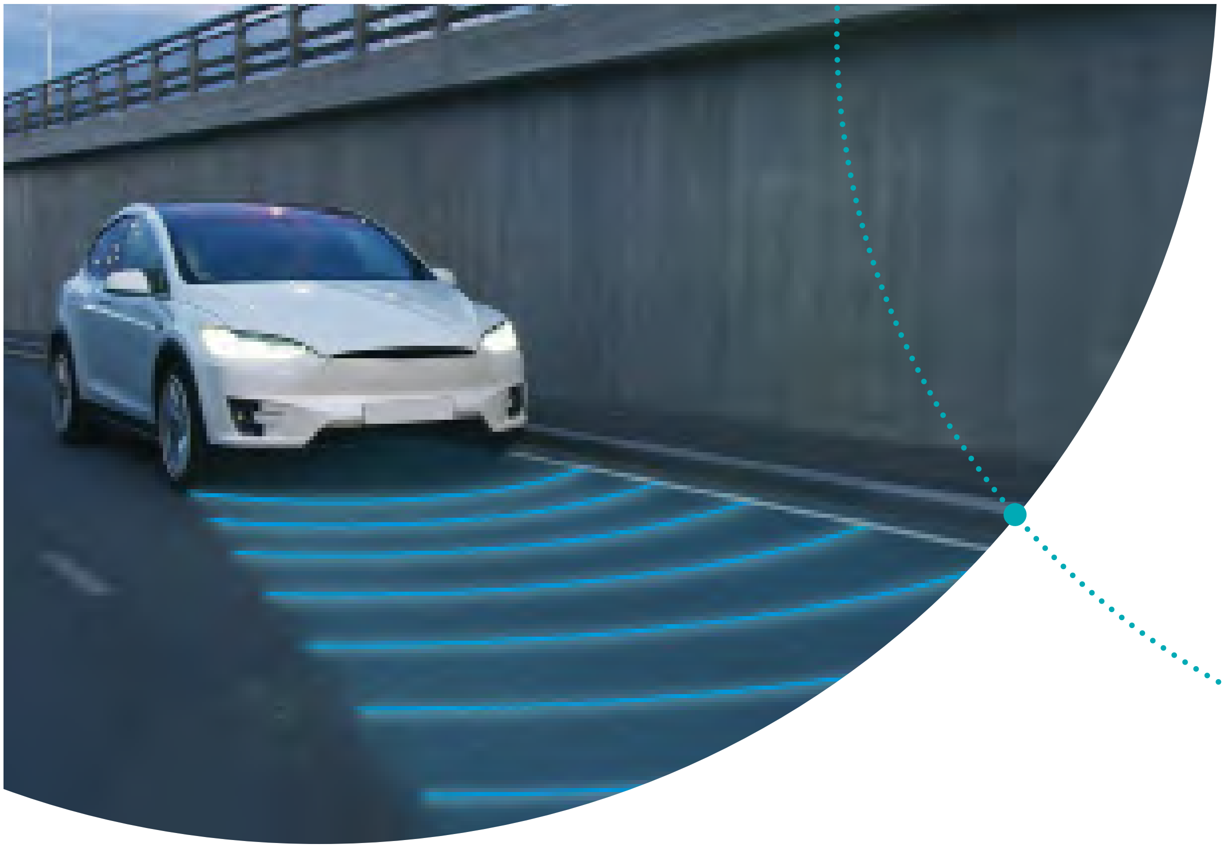

Dymax Active Alignment Adhesives and Their Use in LiDAR and Optical Assemblies

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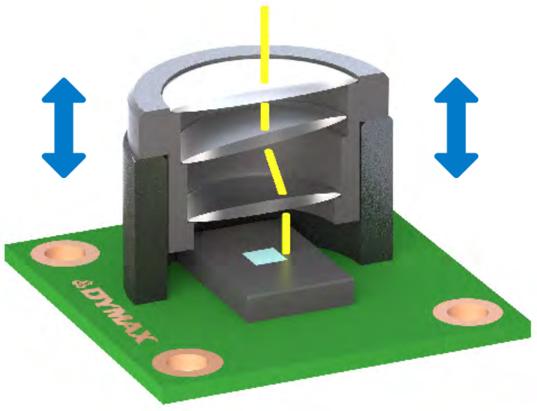
Automotive manufacturers are equipping modern cars and automated vehicles with an array of sensors, cameras, and LiDAR (Light Detection and Ranging). Light Detection and Ranging utilizes high-definition 3D imaging optoelectronic sensors, high accuracy lasers, and mirror positioning to ensure precise environmental surveying. Light Detection and Ranging systems send thousands of laser pulses every second which collide with surrounding objects and reflect back. These light pulses are continuously analyzed and generate detailed three-dimensional information about the surrounding environment and monitor the distance between nearby vehicles and objects. This real-time information is used to stop or slow down the vehicle should LiDAR detect an object in the vehicle's path; conversely it will speed up the vehicle should the road ahead be clear. Advanced Driver Assistance Systems (ADAS) like night vision, blind spot-/-driver monitoring, lane-departure-/-assistance, and collision warning all rely heavily on LiDAR technology to function. Robust and resilient LiDAR-based assemblies will be paramount in self-driving vehicles as these systems, alongside other camera arrays and sensors, will work together to deliver a completely automated vehicle.

In addition to the automotive industry, other industries and fields are using this versatile technology. Advancements in topography, land surveying, mapping, environmental monitoring, and image recognition are a result of LiDAR technology. Augmented reality and virtual reality systems also benefit from LiDAR and other accurate optical components to deliver a more realistic and immersive experience. Drones are often equipped with cameras and depend on LiDAR for navigation, data collection, obstacle detection, and collision avoidance. Smartphones and tablets are utilizing LiDAR technology to deliver advanced augmented reality applications, improved low-light focusing technology, and other depth-sensing innovations.

Light Detection and Ranging assemblies are expected to send and receive the most accurate and reliable information, so their manufacturing must be as precise as possible. Minute laser-/-sensor misalignment could result in significant errors in object detection and mapping leading to safety and quality issues. This strict alignment requirement for LiDAR is also needed for other high-quality optical applications such as camera lenses. Security camera technology is becoming more accurate with improved facial recognition and biometric scanning. Cellphone manufacturers are pressured into continually improving camera image quality with every new release and precise lens-/-sensor alignment is the key alongside advancements in components, computing power, and assembly technology.

As with LiDAR, slight tilts and offsets in camera module alignment can result in image degradation or poor resolution scans by causing the lens and/or laser axis not to be completely perpendicular to the image sensor. One method used to align these components is 'passive alignment,' which is susceptible to greater component orientation errors but benefits in higher production output. Here the accuracy of the alignment relies on narrow component tolerances and high surface quality. The adjustments are mostly restricted to the Z-axis, the use of shims, or physically bending parts of the component housing. It is also challenging for passive alignment methods to compensate for the minute manufacturing flaws of the lens elements, barrels, mirrors, etc., which result in the sensor not being truly perpendicular to the lens to achieve optimal alignment. (Figure 1).

Figure 1. Diagram of Optical Path Offset in Passive Alignment

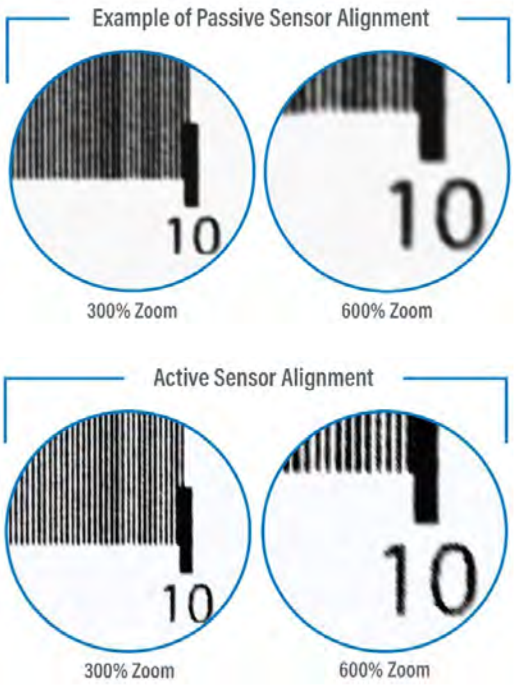


Limited component mobility allows for misalignment through tolerance stack-up

A more accurate type of component placement is termed 'active alignment,' which is a method that takes advantage of being able to fine-tune adjustments along multiple degrees of freedom. With active alignment the manufacturer can align the components more accurately on not only the z-axis, but both the x and y-axis as well as three rotational axes. As opposed to passive alignment, active alignment is a dynamic process using real-time measurements and adjustments to achieve optimal component alignment. Figure 2 compares the two alignment processes and highlights how a 30-micron displacement of the image sensor can have a dramatic effect on image quality.

Active alignment offers more than just highly accurate system alignment, it also provides for higher assembly throughput of precision assemblies and a reduction in manufacturing costs. Passive alignment can use shims, o-rings, and/or other hardware to aid in the positioning of the components which can add additional costs to the overall process. The use of these additional parts, combined with the ever-increasing need for precision optics and the efforts needed to align these systems efficiently, rapidly, and passively within manufactures' specifications can be challenging. Active alignment can use components with a less stringent manufacturing tolerance which can add to cost savings. The freedom for manufacturers to actively align their systems in real-time with fully automated multi-axis motion systems offers them the ability to produce precise optical systems more quickly and reliably.

Figure 2. Comparison of Passive and Active Alignment

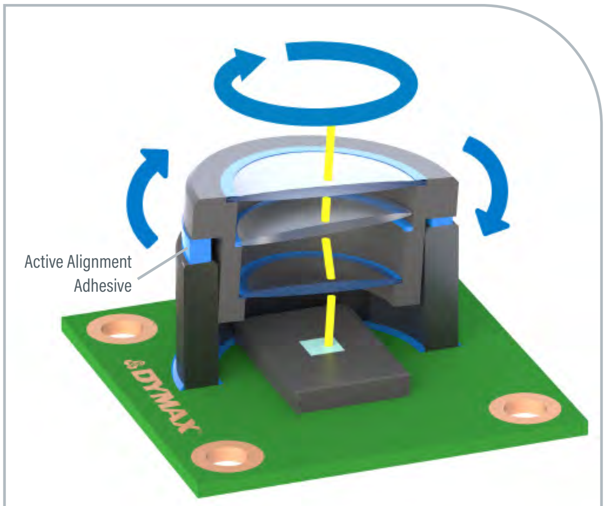


Ref: Lucid Vision Labs

The ability to lock-in the positioning of the LiDAR assembly, lens housing, or other optical components once precise active alignment has been achieved is by utilizing broad-spectrum and/or LED UV/Visible light-curable adhesives. These adhesives cure immediately upon exposure to UV-light and set the components in place. Using a camera assembly as an example, the adhesive is dispensed onto the lens housing and then the components are assembled, and laser aligned by computer. (Figure 3)

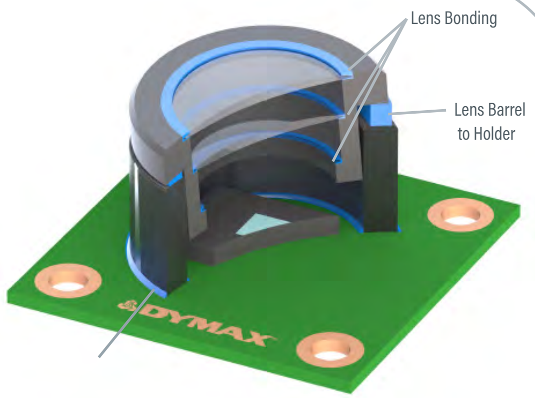
Once the optical components are aligned, the lens package is set in place by curing the adhesive with a suitable light source. Oftentimes, the housings have complex geometries with 'shadow areas,' that may not allow the adhesive to be in direct line of sight of the light source used for curing, resulting in uncured adhesive. Active alignment adhesives are often designed to cure via a secondary mechanism either through heat or ambient moisture to thoroughly cure the adhesive in these non-exposed shadow areas. Figure 4 highlights where active alignment adhesives can be utilized in LiDAR and camera module assemblies.

Figure 3. Diagram of Optical Path Optimization in Active Alignment



More degrees of freedom allow for precise component alignment

Figure 4. Active Alignment Adhesive Locations in Camera



A suitable active alignment adhesive needs to be designed with the following attributes:

- Rapid cure with optional secondary dual cure
- Low and predictable shrinkage to prevent optical alignment shifting upon cure
- Low moisture absorption to prevent swelling and causing component shift
- Low outgassing to prevent lens contamination / fogging
- High glass transition temperature to prevent movement during any thermal cycling
- Superior adhesion to glass, Kapton, flex circuit, FR-4, acrylics, and metal substrates

To address the above required attributes, Dymax has designed a series of cationic LED/UV-curing epoxy-based adhesives for use in bonding LiDAR assemblies, camera modules, and other active alignment applications. Photoinitiated cationic polymerization shares many of the same advantages of free-radical polymerization such as rapid curing at ambient temperatures, solvent-free formulations, and lower energy consumption[1]. However, one of the major advantages of cationic cure systems is the absence of oxygen inhibition which allows for tack-free cure under ambient conditions[2]. The ring-opening polymerization offers low volumetric shrinkage and the generation of hydroxyl groups upon polymerization also contributes towards the improved adhesion of these systems[2]. The adhesives have also been designed to achieve an exceptional depth of cure. Finally, epoxy-based adhesives are characterized by excellent moisture, solvent, and chemical resistance.

These adhesives are designed with a low temperature (80 – 85°C) thermal-cure function to address shadow areas or to use as a primary means of cure. The cured physical and mechanical properties will be similar whether curing with UV/LED only or heat only. High humidity (>70%) and basic environments / substrates have the ability to decrease the rate of cationic polymerization due to the presence of chain transfer agents[3,4]. For applications that do not require a dedicated secondary heat-cure stage Dymax is developing a thermal initiator-free, LED/UV-curable only epoxy-based active alignment adhesives. This will allow the adhesive to have a longer pot life at ambient temperature while maintaining its fast curing/low shrink properties and providing additional curing solutions. Cold temperature storage between 1 - 5°C is required for Dymax active alignment adhesives versus other comparable commercial products that need < 0° / deep freeze storage and dry ice packaging for shipping. Table 1 compares the mechanical and physical properties of Dymax active alignment adhesives and compares them to other recognized 1K active alignment epoxy systems

Table 1. Comparison of Physical and Mechanical Properties of Dymax Active Alignment Adhesives

Product	9801	9802	9803	Market Product #1	Market Product #2
Chemical Class	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy
Component	One Component	One Component	One Component	One Component	One Component
Physical Properties					
Hardness	D90	D90	D95	D84	D92
Glass Transition Temperature (°C)	153	144	184	145	135
CTE (µm/m/°C)	Alpha 1: 17	Alpha 1: 20	Alpha 1: 31	Alpha 1: 28	Alpha 1: 30
	Alpha 2: 80	Alpha 2: 78	Alpha 2: 77	Alpha 2: 83	Alpha 2: 77
Water Absorption, 2 hr Boiling	0.9%	0.2%	0.5%	0.6%	0.5%
Volumetric Shrinkage	1.5%	2.2%	1.1%	1.2%	1.7%
Depth of Cure (mm), (365 nm, 400 mW/cm^2, 15 sec)	1.7	1.4	2.0	1.03	0.46

on the market. The materials were cured using various Dymax LED/UV light-curing systems (BlueWave® MX-150, BlueWave® 200, and 5000-EC units).

The substrates that make up the components, housings, and fixtures in active alignment applications can vary. Thermally and electrically conductive materials and high-performance plastics such as liquid-crystal polymer (LCP) films, glass-reinforced epoxy laminate (FR4), polyamide (PA9T), and polyphenylene sulfide (PPS) are often used. Table 2 measures a suitable adhesion property of Dymax active alignment adhesives on a variety of substrates and compared against the previously mentioned commercial 1K epoxy systems.

Dymax active alignment adhesives are designed to meet and exceed the stringent requirements of LiDAR and other opto-electronic applications. The adhesives are moisture- and thermal-cycle resistant to address the low shrinkage requirements necessary for these assemblies and cure in seconds, providing superior adhesion to substrates found in LiDAR and other precision optical applications. The low temperature cure capability of these materials is also beneficial when used with temperature-sensitive components. Optical device, LiDAR, and ADAS technology is constantly progressing to deliver higher resolution mapping-/-images, improved environmental monitoring, and smaller assemblies. Dymax continues to pioneer advancements in active alignment adhesives to address the continual technological innovations of these devices.

Table 2. Adhesion Comparison (AF = Adhesive Failure, SF = Substrate Failure)

Product	9801	9802	9803	Market Product #1	Market Product #2
Chemical Class	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy
Component	One Component	One Component	One Component	One Component	One Component
Adhesion Properties (UV Cured) - Compression Shear Strength					
Glass/Glass (lbF)	1350 (SF)	1695 (SF)	1019 (SF)	1054 (SF)	1614 (SF)
Glass/Al (lbF)	159 (AF)	209 (AF)	176 (AF)	157 (AF)	142 (AF)
Glass/FR4 (lbF)	419 (AF)	687 (SF)	155 (AF)	110 (AF)	277 (AF)
Glass/LCP (lbF)	276 (AF)	147 (AF)	138 (AF)	78 (AF)	76 (AF)
Glass/PA9T (lbF)	17 (AF)	160 (AF)	141 (AF)	77 (AF)	28 (AF)
Glass/PPS (lbF)	336 (AF)	244 (AF)	242 (AF)	148 (AF)	165 (AF)
Al/Al* (lbF)	225 (AF)	391 (AF)	315 (AF)	144 (AF)	246 (AF)
FR4/FR4* (lbF)	225 (SF)	313 (SF)	164 (SF)	228 (SF)	235 (SF)

*Heat cured at 130°C for 15 min

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