LUMENTUM

Making Vehicles Smarter and Safer with Diode Laser-Based 3D Sensing

There is tremendous development underway to improve vehicle safety through technologies like driver assistance and autonomous driving. Part of the challenge in making vehicles smarter is that they need to be able to handle all of the complex and unexpected situations that can arise on the road.

Evolving 3D sensing technology will play an increasingly critical role in improving the safety of smart and autonomous cars. By providing real-time data about the physical environment, the vehicle, and the driver, 3D sensors make it possible to create a comprehensive map of all objects surrounding the car, both near and far, and in 360 degrees. Backed by analytics, vehicles will be able to identify objects, track their relative velocity, and accurately predict their future position. The more extensive and accurate a mapping the vehicle has to work with, the better—and safer—decisions it can make.

3D Sensing in Vehicles

Building a comprehensive 3D map of the environment and the objects within it involves capturing a wide variety of data (see Figure 1), from what is happening hundreds of meters down the road to how alert the driver is:

- Long-range radar: Supporting the furthest scanning range, long-range radar assists with adaptive cruise control when the vehicle is moving at high speeds. It also identifies future potential hazards.
- Long-range LiDAR: With a range up to 200 m, long-range LiDAR uses a narrow cone of light to detect objects ahead of the vehicle. It provides data used for pedestrian detection, collision avoidance, and emergency braking.
- Cameras: Visual sensing is used to identify hazards as well as collect local environmental context, such as traffic signals and signs. Cameras are also used to trigger lane departure warnings, enable parking assist, and provide a surround view of the vehicle to the driver.
- Short-range LiDAR: Short-range LiDAR is used to scan the area around the bumpers. It is used not to just detect objects but to also identify what they are. For example, it can help the vehicle identify the difference between a stationary garbage can or a child standing by the curb.
- In-cabin sensing: By collecting driver and occupant data, in-cabin sensing enables monitoring of the state of the driver; i.e., whether the driver is actively paying attention to the road or is distracted or drowsy. In-cabin sensing also makes it possible to support gesture recognition for in-car navigation, communications, and infotainment systems.

Creating an accurate map requires many different types of sensors, each with specific capabilities that allow it to capture and integrate its measurements with other sensors. Because safety is such an important element of autonomous vehicles, sensors must be extremely reliable and robust as well.

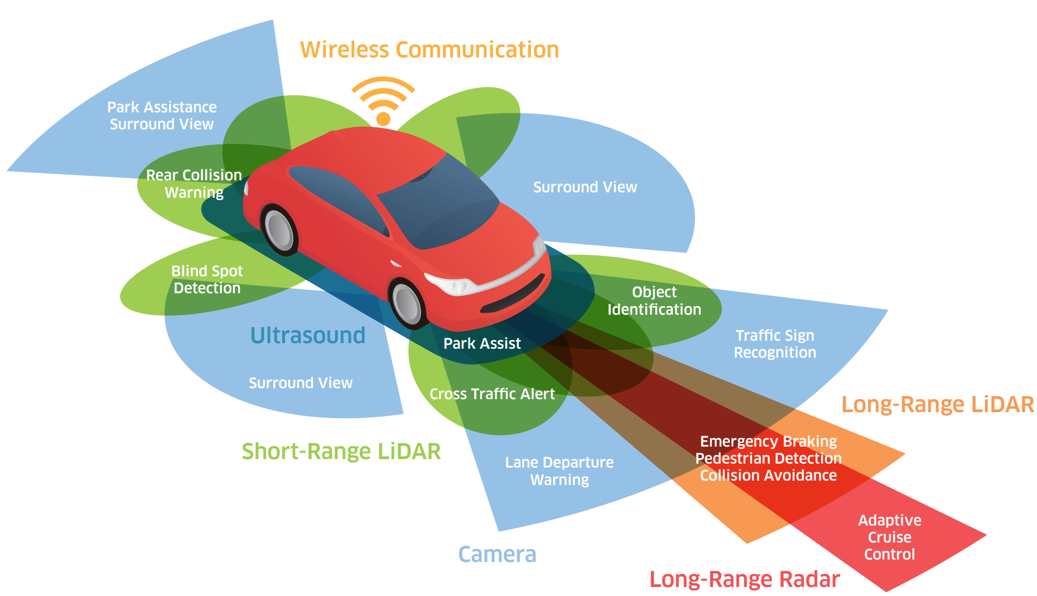


Figure 1 Automotive 3D sensing captures a great deal of vehicle, environmental, and driver data, from what is happening hundreds of meters down the road to how alert the driver is.

The Limitations of Radar and Image Sensors

Radar has proven to be an effective technology in long-range sensing applications because of its ability to detect the presence of objects at far distances. Given its maturity, radar is relatively inexpensive and has already been deployed in all smart vehicles. However, radar has its shortcomings. Because of its limited spatial resolution, radar often cannot provide enough information to enable identification of what an object is or what it might be doing.

Image sensors are currently being used to visually collect environmental context, especially in close proximity to the vehicle. They can also be used to augment the capabilities of radar to enable better identification of objects at a distance.

However, today's image sensing technology falls short of where it needs to be to assure sufficient levels of safety. Because image sensors rely on environmental light, they perform poorly at night or when light is shined directly at the camera, such as the headlights of an oncoming car the vehicle needs to track accurately. Image sensors can also mistakenly identify objects that are actually painted images on the sides of trucks or on storefronts.

The primary safety concern is that autonomous vehicles must be able to resolve "corner cases" and exceptions in a robust manner. The unexpected is where these systems need to excel. For this reason, both radar and image sensors still have many blind spots, so to speak, to be reliable enough.

Diode Laser-Based 3D Sensing

Diode laser-based 3D sensing fundamentally captures more detailed information and provides greater accuracy compared to traditional scanning-based sensing technologies like radar and camera-based imaging. In particular, diode lasers offer a cost-effective way to implement long- and short-range LiDAR, as well as close-range, in-cabin sensing.

Diode lasers have a long history of reliability. For several decades, diode lasers have played a fundamental role in high-speed communications telecom and datacom equipment. These applications require extremely high reliability to maintain "five nines" operation.

Ongoing innovation in diode laser technology has driven the pace of networking advances by accommodating faster speeds and achieving a higher signal-to-noise ratio (SNR) for greater accuracy. Diode laser manufacturers have also had to improve power efficiency, reliability, and density while maintaining cost.

At the same time, innovation has been taking place in parallel to bring diode laser technology to consumer-level products. For example, diode laser-based 3D sensing is already embedded in numerous volume applications, including gaming systems and mobile devices for face recognition.

Similarly, LiDAR is an established diode laser-based technology used in military applications, topology mapping, depth sensing, security, and many others. However, these implementations are not suitable for automotive applications from a cost, size, and power perspective.

Building on their expertise in delivering reliable solutions for communications, consumer, and military applications, industry leaders like Lumentum have expanded upon their existing technology to develop a portfolio of diode laser products that match the quality, range, and reliability requirements of the automotive industry. This diverse range of products gives automotive OEMs the ability to select the best diode laser for their particular application. The widespread use of diode lasers in other applications also means the automotive market will be able to benefit from the maturity and lower cost of these lasers. Furthermore, as the diode laser industry is in a state of tremendous growth, these savings will only increase as diode lasers reach into an even wider range of applications.

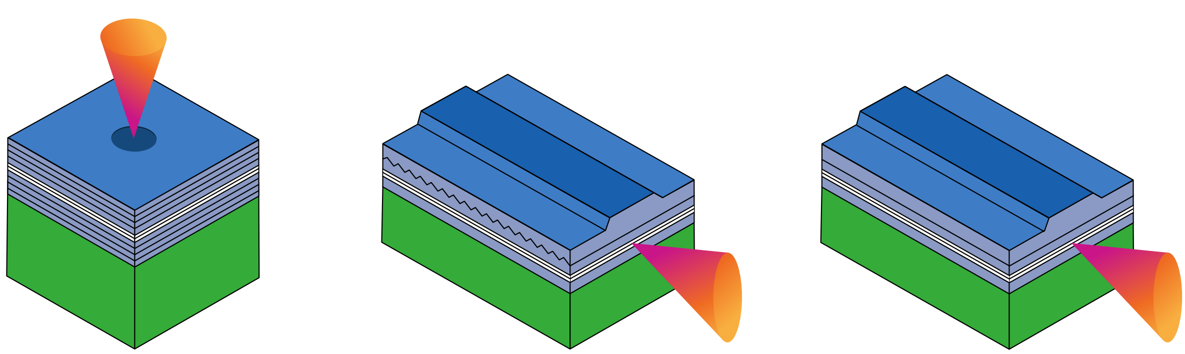
VCSELs and Edge Emitters
Some companies focus their expertise on manufacturing a single type of laser. However, there are several different diode laser technologies that are used in optical-based 3D sensors: vertical cavity surface-emitting lasers (VCSELs), distributed feedback (DFB) or Fabry-Perot edge-emitter lasers (see Figure 2). Each technology offers specific advantages, and the right diode laser to use depends on the application.

VCSELs emit light perpendicular to their substrate. As such, they are simple to mount and can be easily grouped in two-dimensional arrays, with hundreds or thousands of VCSELs on a single chip. This gives developers a great deal of flexibility in optimizing output power, reliability, and accuracy.

Specifically, the flexibility of VCSEL arrays greatly simplifies scaling output power since an array can be made larger to increase overall output power and extend the distance at which a system can sense. Consistency of output is improved as well with so many individual emitters since any variation between VCSELs tends to be averaged out, resulting in uniform illumination and better sensing accuracy. VCSEL arrays also provide greater reliability because they inherently offer redundancy since the loss of a single VCSEL emitter will have little effect on the array's overall output power or consistency. Finally, their uniformity eliminates the need for calibration, lowering manufacturing complexity and cost.

The ability of a VCSEL array to illuminate and capture a scene makes VCSELs ideal for short-range 3D sensing applications such as in-cabin sensing. They offer excellent power efficiency, are more cost effective than other illuminator types, and don't require complex techniques to provide accurate sensing.

Edge-emitter diode lasers are an established technology that has been used in a variety of applications. The laser light is emitted from the edge of the chip and therefore parallel to the board on which it is mounted. For long-range applications, edge-emitter diode lasers tend to be an ideal technology. Edge emitters have much higher individual output power than VCSELs and can sense at longer distances for equivalent chip area. They also provide much higher power in a single spatial mode (i.e., higher brightness), and can be pulsed faster to provide resolution that exceeds that possible with radar and/or image sensors.



VCSELs

- Narrow bandwidth: <1 nm
- Power range: 200 mW – scalable to 10s of watts
- Output beam: circular
- Wavelength locking with temperature

DFB Edge Emitters

- Narrow bandwidth: <1 nm
- Power range: 200 mW – scalable to 10s of watts
- Output beam: elliptical
- Wavelength locking with temperature

Fabry-Perot Edge Emitters

- Wide bandwidth: >1 nm
- Power range: 200 mW – scalable to 10s of watts
- Output beam: elliptical
- The most efficient solution

Figure 2 There are many different diode laser options available on the market, each offering specific advantages depending upon the application.

Of the different types of edge-emitter diode lasers, Fabry-Perot edge emitters are the most efficient for many applications. However, Fabry-Perot edge emitters have a wider bandwidth and lower temperature stability that can negatively impact SNR and accuracy in some 3D sensing applications (see Figure 3). For example, a free running Fabry-Perot edge emitter has a stability of ~0.1 nm/°C. Distributed feedback (DFB) lasers have similar temperature stability to VCSELs since the wavelength is stabilized “locked” resulting in a shift of only ~0.07 nm/°C.

Particularly important for long-range sensing, only edge emitters can be practically designed to operate efficiently at longer wavelengths needed to improve eye safety (i.e., 1550 nm). Thus, many factors come into consideration when selecting the ideal diode laser for an application.

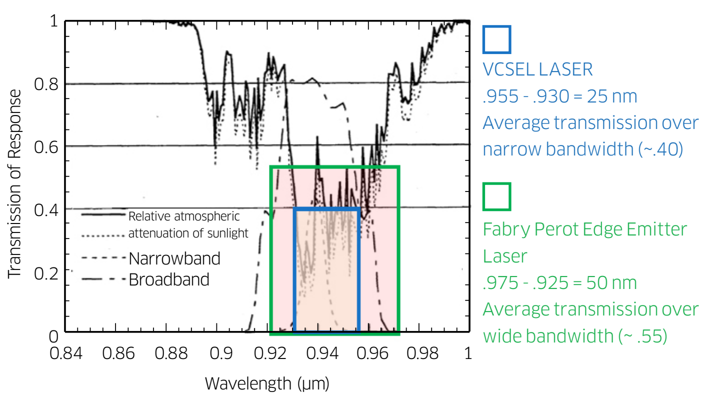


Figure 3 Wavelength stabilization “locking” is critical to maintaining a good signal-to-noise ratio (SNR)—and therefore accuracy—over the wide temperature range in which automotive vehicles need to be able to operate reliably.

In-Cabin Sensing

In-cabin sensing will play an increasingly important role in implementing more advanced smart car features. For example, moderate levels of autonomous driving require that the driver be fully engaged when the vehicle is in motion.

In-cabin sensing uses image processing to confirm that the driver is not falling sleep, checking email, or staring out the side window. The challenge in implementing in-cabin sensing with the use of traditional image sensors has been the difficulty of capturing driver data under diverse lighting conditions. In-cabin sensing needs to provide crisp images in full daylight, at night, and for all lighting conditions between. To achieve this, the system needs to consistently illuminate the driver in a reliable manner without adversely impacting his or her ability to drive (i.e., an LED that blinds or distracts the driver).

VCSELs are able to safely illuminate the driver by operating in a part of the spectrum that the driver cannot see. Additionally, because VCSELs use a specific wavelength, it is possible to combine them with bandpass filters to capture light only in the spectrum of interest. This effectively illuminates the driver while filtering out environmental light such as oncoming headlights or bright sunlight. The end result is clear and consistent images for the processing subsystem to work with.

An alternative to VCSELs for in-cabin 3D sensing is IR LEDs. However, the efficiency of IR LEDs (25-30%) is lower than VCSELs (35-40%). The bandwidth of an IR LED is also wider (30-40 nm) compared to a VCSEL (<10 nm), resulting in the rejection of less ambient light, a lower SNR, and capture of a less stable image for processing.

It is important to note that the recent Euro NCAP (The European New Car Assessment Programme) mandate for driver monitoring systems (DMS) is well on its way to becoming a safety standard in Europe for next-generation vehicles. While it will be some time before this standard is required in vehicles, driver monitoring is still of interest to automotive manufacturers as it enables them to offer a differentiating safety feature for higher-end vehicles. Doing so also enables OEMs to gain experience with these technologies so they will be prepared when such monitoring becomes mandatory.

Advantages of LiDAR

For sensing outside the vehicle, LiDAR is becoming the technology of choice. LiDAR is able to accurately sense object distance and create a comprehensive 3D environmental depth map. The sensor is designed to be robust to the presence of ambient light (sunlight, on-coming headlights, etc.) and under these conditions provides greater accuracy. Note that radar has a longer wavelength and therefore has a fundamental spatial resolution equivalent to that wavelength. LiDAR has a much smaller wavelength and consequently can discern smaller objects with significantly greater detail. This is helpful with object identification and separation (for example, a fire hydrant and a child standing still who might suddenly move).

Typical LiDAR sensors can currently capture images at up to 15 frames per second. With this much data, vehicles can quickly identify hazards (the child has started moving), track their speed and trajectory (the child is moving into the path of the car), and take appropriate action (slow down, start turning, or stop to avoid the child).

It is important to realize that while LiDAR will replace radar in many applications, LiDAR itself is evolving as a technology. Current implementations of LiDAR have been built around commodity diode laser technology (derived from telecom) rather than more advanced diode laser technology. This has resulted in system tradeoffs being made to accommodate these legacy lasers and imposing many unnecessary limitations on LiDAR.

For example, to increase sensing range, higher output power is required. As LiDAR sensing systems must comply with increasingly tighter eye safety regulations, the shorter wavelength of legacy diode lasers restricts power output and, in turn, limits sensing distance.

To advance LiDAR technology, diode lasers must be able to adapt to the needs of the applications in which they will be used. For example, edge-emitter diode lasers designed for long-range sensing use a longer wavelength, enabling them to output 100X the power of shorter-wavelength lasers and still be eye safety compliant.

Quality is also an issue. Legacy lasers rely upon reflection of the laser pulse to make measurements. However, other light—including sunlight and LiDAR from other vehicles on the road—can interfere with reflected laser light and reduce accuracy.

Advanced diode lasers for LiDAR leverage a long history of laser technology that have been used extensively in optical communications. For example, reliability and quality can be improved through the use of a second signal; analyzing the interference patterns in both signals significantly improves SNR.

It is clear that diode lasers are going to need to continue to evolve as new standards emerge. Autonomous driving is a rapidly changing field and, as the technology advances, its growth will be accompanied by new compliance regulations. OEMs who want to develop 3D sensing subsystems that will be able to meet the future requirements of autonomous and smart vehicles will need to rely on diode laser technology that is itself evolving.

It is important to note that this evolution will happen in different ways. For example, some applications will need diode lasers to evolve to offer greater capabilities. At the same time, OEMs will need to reduce complex technology like that used in the military to be able to bring simpler solutions to market that better meet the performance, reliability, and cost requirements of automotive applications.

Diode Lasers Designed for Automotive Applications

In addition to a diode laser's technical capabilities, automotive OEMs must also consider factors such as reliable operation over life and harsh environmental operating conditions, consistent quality at high volume production, and the ecosystem expertise supporting the diode laser.

VCSELs, for example, have been used extensively in optical telecommunications and short-range data communications. They are even being used in undersea applications with 25-year reliability requirements where product failure is extremely expensive to resolve.

A diode laser manufacturer must also be able to maintain reliability and quality during very high volume production. To date, with 150K diode lasers delivered to undersea applications, Lumentum has had zero failures in these installations. Reliability of diode lasers is high, even for consumer goods: with a rated lifetime of five years, Lumentum has delivered 200 million lasers, with less than one part per million failure.

Achieving this level of reliability requires ongoing innovation as well. For example, Lumentum has developed a burn-in process using data-driven analysis to identify devices at risk for early failure so they can be scrapped (see Figure 4). This process is customizable, enabling Lumentum to optimize this and other manufacturing processes to meet specific application requirements while balancing cost and reliability. With such flexibility, automotive OEMs can assure reliability in mission-critical applications while managing cost in less-critical sensing systems.

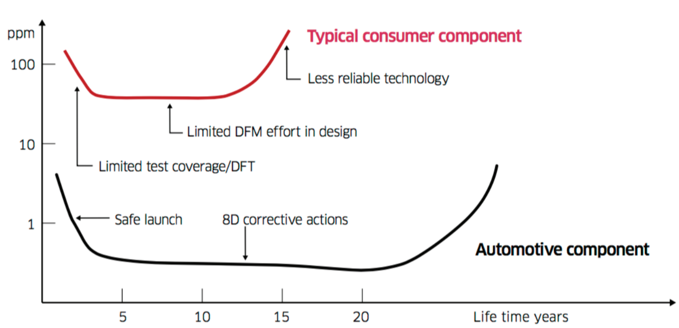


Figure 4 Lumentum has developed a burn-in process using data-driven analysis that identifies devices at risk for early failure to optimize its manufacturing processes to meet specific customer automotive requirements while balancing cost and reliability.

The Right Diode Laser Supplier for Your Application

In the end, however, the selection of the right laser is not always straightforward. The different types of automotive 3D sensing systems have specific requirements and different cost constraints. In addition, the tremendous number of options available can make it challenging for OEMs new to laser technology to determine the optimal diode laser for their product designs.

With the right expertise, an optimal solution can be found for each application. Thus, it helps to have a partner who understands the capabilities and limitations of the different diode laser technologies, as well as the impact of environmental factors on laser operation, reliability, and accuracy. Furthermore, the right partner can support integration of diode lasers into existing systems as well as help navigate compliance regulations to accelerate development, speed time-to-market, and minimize design investment.

Lumentum has a long history of manufacturing diode lasers. With its deep understanding of lasers and strong partnerships throughout the industry, Lumentum has built a reliable supply chain that is resilient to unpredictable geographical, technical, and financial events that could otherwise impact production. The company also continues to leverage its technology platforms to provide the leading-edge products OEMs need to deliver the future today.

Lumentum offers a broad range of VCSELs, DFB edge emitters, and Fabry-Perot edge emitters, as well as alternative technologies like IR LEDs, to meet the 3D sensing needs of automotive applications. In addition, its solutions have been innovated over generations, resulting in diode laser technology that leads the industry.

Formerly a part of JDS Uniphase, Lumentum has a 30-year history of high reliability and high volume backed by nearly 1000 patents. Lumentum is a global leader in optical components with $1.25B in revenue for 2018 and is the largest supplier of laser illuminators used for 3D sensing. With its unparalleled manufacturing and design experience across a wide spectrum of laser technology, Lumentum can help automotive OEMs select the right laser for their 3D sensing applications.

Conclusion

3D sensing using diode lasers will play an increasingly critical role in improving the safety of smart and autonomous cars by providing real-time information about the vehicle, the physical environment, and the driver. Using proven diode laser technology, automotive OEMs can design 3D sensing systems that will enable next-generation capabilities in a cost-effective manner. Many of these capabilities are anticipated to become mainstream features by the end of the decade, making diode lasers an important emerging technology for automotive applications.

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