THE RACE TO THE STARTING LINE:

Edge-Emitting Diode Lasers vs. VCSELs for the Automotive Lidar Market

LEONARDO

IMPORTANCE OF AUTOMATED DRIVING ASSISTANCE SYSTEMS (ADAS)

In the United States, there are approximately 5.5 million automotive accidents every year, and nearly 30,000 of those accidents are fatal. According to the National Highway Traffic Safety Association (NHTSA), 41% of all automotive accidents result from driver-related recognition errors, most of which were caused by inadequate surveillance. The goal of autonomous driving and autonomous driver assistance systems (ADAS) is to improve a driver's awareness of any surrounding factors that present safety risks. (The term "ADAS" will be used throughout this document with the understanding that ADAS technology is transferrable to fully autonomous vehicles.) According to a new plan from the National Highway Traffic Safety Administration, making automatic emergency braking systems a standard feature on cars could prevent as much as 20 percent of accidents.

REQUIREMENTS AND EXPECTATIONS FOR ADAS

As with all commercial products, three features of ADAS must be optimized: cost, supply, and performance. With ADAS, performance has many facets. Automobiles are a particularly emotional purchase, and a successful ADAS must conform to drivers' expectations. Quantitative values such as range, accuracy, and size all inform ADAS performance, but qualitative issues such as aesthetics and perceived safety are critical to adoption.

LASER-BASED ADAS

Like radar, lidar works on the principle of measuring the time-of-flight of electromagnetic waves from the moment they leave the laser source until the moment they are reflected by an object and detected by the light sensor. In contrast to radar, lidar uses much shorter wavelengths, generally in the near infrared (800–1700 nm). Several technologies have been demonstrated as laser sources for automotive lidar applications; laser diode-based technologies provide the best size, cost, and flexibility metrics. Laser diode-based lidar systems use a single laser source or a few laser sources, with either a beam that is scanned across the scene using a micro-electromagnetic mirror (MEMS mirror) or multiple laser sources that illuminate the scene simultaneously.

	Radar	Laser Scanner
Field of View	Good	**Excellent**
Distance Resolution	Good	**Excellent**
Angular Resolution	Poor	Good
Adverse Weather	**Excellent**	Good
Darkness / Ambient light disturbance	**Excellent**	**Excellent**
Object Classification	Poor	Good

Scanning systems are common today because MEMS are a relatively inexpensive commodity electronic component. However, any moving parts within an ADAS, including MEMS, are undesirable because they reduce ruggedness. It is therefore expected that as the cost of laser diodes falls, multi-laser sources that passively cover the same field of view as scanning systems will become an attractive technology for automotive lidar.

Gated imaging is, in some ways, a merger of lidar and video imaging. Like lidar, gated imaging uses pulses of light and time-of-flight to measure distance to objects. However, gated imaging synchronizes sensor measurements to the light pulses, meaning that only light that has traveled for a specific amount of time, and therefore a specific distance, is detected. By altering the interval between light pulse and sensor activation, a gated imaging system builds a viewable three-dimensional image of the scene. Another feature of gated imaging is that it sees through visual obscurations, such as precipitation and fog. Because gated imaging and lidar systems use similar diode laser sources, it may be assumed that comparisons in this report between laser technologies applies to both lidar and gated imaging ADAS.

THE CURRENT DIODE LASER LANDSCAPE

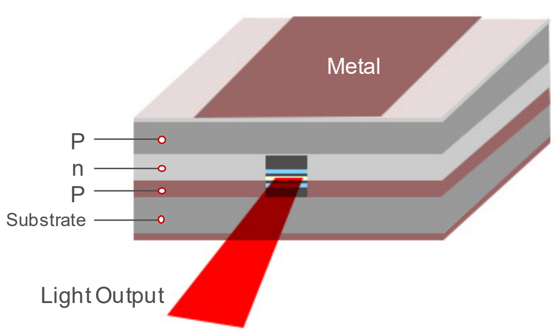
The two primary laser technologies are edge-emitting (or side-emitting) and surface-emitting diodes. The fabrication process and method of operation for these technologies strongly affect the design and operation of automotive lidar systems. Both edge-emitting and surface-emitting lasers comprise multiple layer stacks of semi-conductive materials with varying optical and electrical properties. In edge-emitting lasers, light is confined within a few semi-conductive layers known as the active region and propagates in a direction that is parallel to the stack of semiconductor layers; coherent illumination exits through one edge. In vertical-cavity surface-emitting lasers (VCSELs), light propagates vertically back and forth through the stacks of semiconductor layers in a direction that is perpendicular to the layers before exiting through the top face. Both edge-emitting lasers and VCSELs are fabricated on large wafers and then cleaved or diced to form individual laser chips.

CRITICAL POINTS OF COMPETITION

The winning diode laser technology for ADAS will have the best balance of cost, supply and performance. To forecast a winner, it is important to understand how the two technologies fare against one another in each category.

EEL

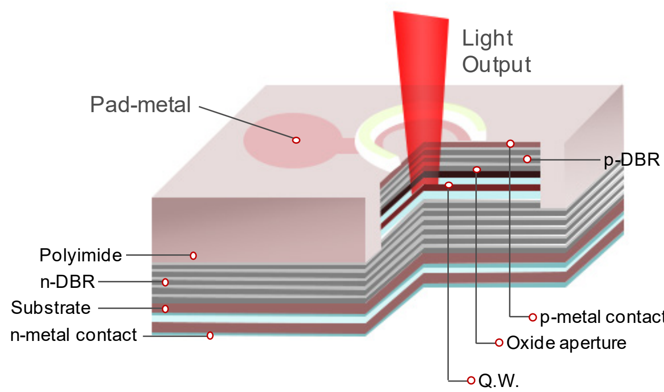
Edge emitting lasers (EEL)



Produce light **parallel** to the substrate

VCSEL

Vertical cavity lasers



Produce light **perpendicular** to the substrate

1. COST

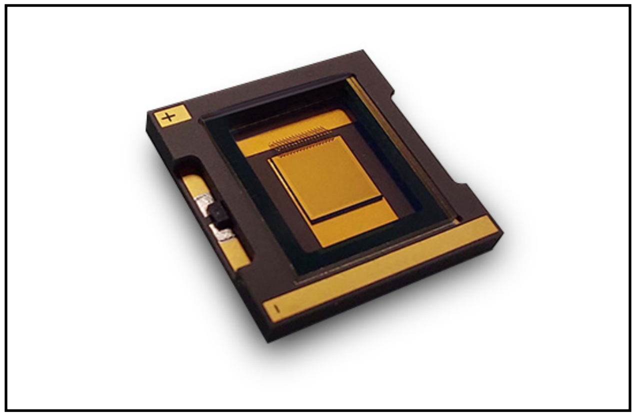
At present, the cost advantage, measured in $/Watt, goes to edge-emitter diode lasers, primarily because the fabrication technology is more mature. Other reasons include:

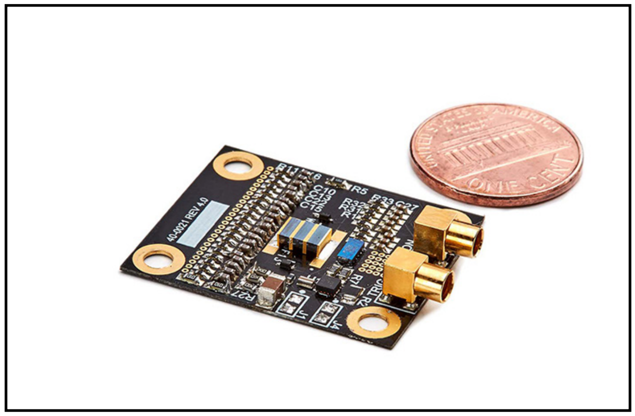
- High power edge-emitting diode lasers are already a mass-market commodity.
- The epitaxial growth process is straightforward.
- Edge-emitting diode lasers emit high power for a small aperture.

The cost advantage of edge-emitting diodes wanes somewhat, however, when factoring in the complexity of physically assembling the individual diodes into the arrays required for an ADAS. Furthermore, the high-power laser emission of the diodes means higher heat emission. Heat retention affects the laser performance in many ways, including wavelength and gain efficiency; for an array of diodes, heat retention becomes a major concern. Addressing this problem requires complex heat-dissipation assemblies, which add to the cost of the overall array cost. The aspheric optics required to condition the elliptical beams emitted by edge-emitting diodes present another issue. The cost of fabricating custom aspheric optics is considerable, and maintaining the performance of the final edge-emitter array requires that each unit be sealed in a composite package.

VCSELs start out at a significant disadvantage. VCSELs require more than 10 times as many epitaxial layers as an edge-emitting diode, and the layer thicknesses must be controlled to sub-micron accuracy. At low production volume, VCSELs cost between 5 and 10 times as much as similar edge-emitting diodes. VCSELs also produce less laser light per unit area, meaning that a VCSEL array must include more diodes than an edge-emitting array of similar power. VCSELs do, however, offer the potential for 5x cost reduction at high volume, because they avoid the assembly issues that increase the cost of edge-emitter diode laser arrays. With VCSELs, the end product is a wafer of fully operational lasers that require no further coating or polishing. Each laser is topped with a molded spherical lens, the design of which is identical layout of VCSEL emitters on the wafer. VCSEL arrays are created by electrically linking neighboring lasers and cleaving them as a unit.

Although edge-emitting lasers are currently the clear winners on cost, their lead is shrinking as automation techniques are developed for high volume fabrication of VCSEL arrays. Leonardo is developing VCSEL technology that would be compatible with fabrication processes that have been established in the silicon semiconductor industry.





Critical Points of Competition

- **Cost**
- **Supply**
- **Performance**

2. SUPPLY

High power edge-emitting diode lasers also have the advantage of available supply. The fabrication time for an unassembled individual edge-emitting laser is similar to fabricating VCSELs arrays. The subtlety appears when one considers the cumulative rate of fabricating fully packaged diode laser arrays. When comparing the entire fabrication process from wafer substrate through final product, a VCSEL array requires fewer steps. VCSEL production rates may increase to the point where VCSEL arrays could compete in volume with edge-emitting diode laser arrays, though higher levels of automation are also increasing efficiencies in edge-emitting diode production.

3. PERFORMANCE

The competition between the two diode laser technologies is most fierce in performance. Performance is defined by six major factors:

Range

Range is the most important requirement that any ADAS system must meet. For forward-looking lidar, any product that cannot reach the minimum range requirement of 150 meters is simply not worth developing. From a performance standpoint, edge-emitting arrays have the clear lead. Edge-emitting diode arrays have a range of 200-500 m, whereas VCSEL arrays are only 100–300 m. It is important to remember, though, that it is not necessary to have the longest range. The winning technology just has to be *good enough*.

Safety

Eye safety is critical to lidar adoption. ADAS illumination is particularly dangerous because the infrared wavelength is damaging to the retina yet invisible to the human eye. Automotive manufacturers are approaching eye safety conservatively, assuring that the eye is safe when directly viewing the light source. Federal regulations are still in development to establish eye safety requirements for vehicle ADAS; any illumination that cannot perform within those requirements will be unmarketable.

Edge-emitting diodes have an advantage in this area because there are already edge-emitting diodes that produce high powers in IR wavelengths outside the damage range for the human eye, eliminating the concern of eye safety altogether. The challenge for VCSELs is that the features that allow VCSEL arrays to produce high-quality illumination also make the illumination a higher risk for eye damage. There are a variety of methods in development to maintain illumination quality while also meeting eye safety standards, but it is an engineering task that edge-emitting diode arrays do not face.

Illumination quality

The quality of the illumination the array produces is the second most important factor after range. Quality factors include beam shape, flash rate and wavelength stability. In these areas, VCSELs have an advantage.

Beam shape: Although edge-emitting lasers produce more light, not all of that light is useful. The beam from an edge-emitting laser diverges much faster than the beam from a VCSEL, and not all of that light can be captured when reshaping the edge-emitting diode's elliptical beam into the profile required for an ADAS. By comparison, a VCSEL emits a tighter beam that is easier to reshape.

Wavelength stability: VCSELs have the advantage in wavelength stability. Since the emission wavelength of the edge-emitting lasers is determined only by the temperature of the layers in the active region, the rate of change of wavelength is a factor of 4x higher than that of VCSELs. Although the variation in wavelength can be addressed by a variety of thermal diffusion methods, those additional components add to the complexity, size and cost of the diode array.

Power efficiency

Edge-emitting diode lasers are more efficient in terms of optical power per amp due to their larger gain region. Edge-emitters are also brighter than VCSELs, producing more light per unit area. Power efficiency becomes an issue only when the heat generated is significant. For most lidar applications this is not a significant factor since the duty cycles tend to be fairly low. For higher duty cycle systems a complexity arises, though, when comparing VCSEL arrays to edge-emitting diode lasers. Although VCSELs are less efficient than edge-emitting diodes, the heat removal process tends to be quite straightforward and so the power efficiency metrics translate more into a cost issue than a performance issue. Presently, for low duty cycle systems, like lidar, edge-emitter arrays have a cost advantage.

Resolution

Lidar resolution is the degree of detail the system can detect within its range of vision. Specifically, resolution determines how well an ADAS can ascertain the size and position of obstacles; both of these metrics are key factors that an ADAS must consider when choosing a course of action. For a scanning lidar system, the resolution is determined by three parameters:

- Time interval between flashes
- Diameter of beam's cross-section
- Distance that the beam moves between pulses

The distance is called the pitch. The flash interval is optimized when the pitch is very close to the diameter of the beam. Pitch depends little on the choice of laser diode, so beam diameter and flash interval are the areas of competition. Resolution is therefore determined by the illumination quality. VCSELs have a modest advantage in beam shaping and in pulse frequency, so it can be inferred that VCSELs currently have a resolution advantage.

Compactness

The size of an ADAS is important from an aesthetic perspective; with automobiles, appearance matters as much (or even more) than performance. In this sense, an ADAS illumination source must be small enough that it does not add visible bulk or unwanted weight to the vehicle. Scanning technologies in use today will not meet the aesthetic demands of the marketplace. Ideally, the winning technology would fit in the existing system rather than require changes; headlight casings, for instance, add heat and durability concerns in addition to size limitations.

PICKING THE WINNER

The competition to be the dominant diode laser source for automotive lidar is not a race to the top, but a race to the starting line. The industry goal is to implement lidar ADAS in consumer vehicles by 2020. At the least, there must be one year of certification and testing prior to going to market. That sets the starting line at 2019. Any lidar ADAS that hopes to compete for the consumer market must be out of R&D and into prototyping by that point.

The winning diode laser technology will have the best balance of cost, supply and performance. Although it is difficult to say what the best balance will be, it is possible to determine minimal performance requirements. Failing to meet one of the critical requirements concedes victory to the competition.

The winning lidar diode technology will:

- Cost no more than $100/unit
- Be available at a rate of at least 100K units/year
- Have a range of >150 meters
- Have a resolution of 50 cm

Currently, both diode technologies fall behind in one or more of these critical requirements. Based on present performance, edge-emitter diode lasers seem to be the closest to putting forth a prototype ADAS that meets the minimum operational requirements. System integrators in automotive must consider risk tolerance and anticipate performance and volume demands when designing lidar systems.

Leonardo engineers collaborate with system integrators to develop and manufacture right-fit laser diode systems. Contact sales@leoardo.us to discuss your project.