Light is OSRAM

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White Paper
Double Junction General Lecture 2011

1 Introduction

Vertical Cavity Surface Emitting Laser (VCSEL) arrays have emerged as an important technology for applications within the consumer, industrial, automotive, and medical industries. Vixar has developed a family of high-power arrays targeting these applications. This paper introduces the application requirements for this technology, the relevant benefits of VCSEL technology, and up-to-date performance that has been demonstrated with VCSEL arrays.

VCSELs have recently made significant inroads in the consumer market. They have found application as proximity and ranging sensors, face identification, and 3D cameras in cell phones. 3D cameras can also enable gesture recognition in gaming systems and situational awareness for augmented and virtual reality systems. Potential future consumer applications can include home automation involving biometric identification for security or gesture recognition for controlling appliances and electronics.

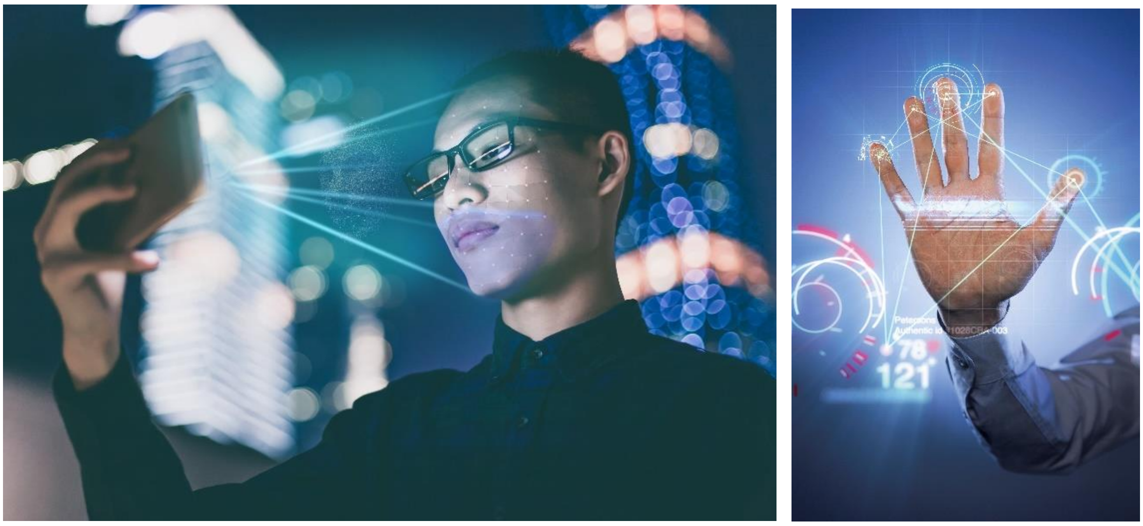


Figure 1. Consumer applications of VCSELs include 3D imaging for facial ID and gesture recognition.

In the industrial market, VCSEL arrays play an important role in providing 3D vision for safety sensors, motion control, and robotic applications for factory and warehouse automation. Industrial applications also consist of IR illumination for night vision in security systems. Drones for surveillance or delivery applications benefit from 3D imaging and sensing, and 3D imaging can help build CAD models beneficial for large-scale design and construction.

The benefits of 3D imaging and sensing are also recognized within the automotive market. The initial application of VCSELs in this market will be in the automobile interior, such as gesture recognition and driver monitoring. Exterior applications include 3D monitoring over shorter distance to avoid side collisions with other automobiles and detect the presence of pedestrians or bicyclists.

Figure 2. Industrial applications for VCSELs include 3D imaging for robots managing material flow in warehouses and nighttime illumination for security cameras.

Figure 3. Automotive applications for VCSEL arrays include driver monitoring and collision avoidance.

To improve the performance of VCSEL applications, many key components of the VCSEL need to be addressed and designed. This paper emphasizes work done in our Double Junction general lecture published on this date of 20th in November (DJunGLe 2011) that illustrates what OSRAM and VIXAR have overcome to meet these market demands.

2 Standard VCSEL Technology Overview

There are 3 main types of semiconductor based light sources. They all require the growth of single crystal layers on a semiconductor substrate. Individual devices are created by photolithographically patterning the wafer. Light Emitting Diodes (LEDs) emit light from the top surface of the wafer and can be tested at the wafer level. Lasers require an active material that emits light and a cavity to provide feedback to achieve stimulated emission. The cavity for edge-emitting lasers (EELs) is formed by cleaving the wafer. Due to this design, light is emitted from the cleaved edge of the chip, and the laser cannot be tested before packaging. In contrast, the cavity for a VCSEL is built by growing mirrors formed by alternating layers of two different refractive indices, creating a Bragg reflector. With the light generating layers between two Bragg reflectors, a cavity is formed to produce stimulated emission that radiates from the surface of the wafer. Therefore, VCSELs can also be tested on the wafer. This reduces production costs by sorting nonfunctional die before device packaging. Furthermore, the vertical emission of the VCSEL allows the use of any kind of package available to LEDs.

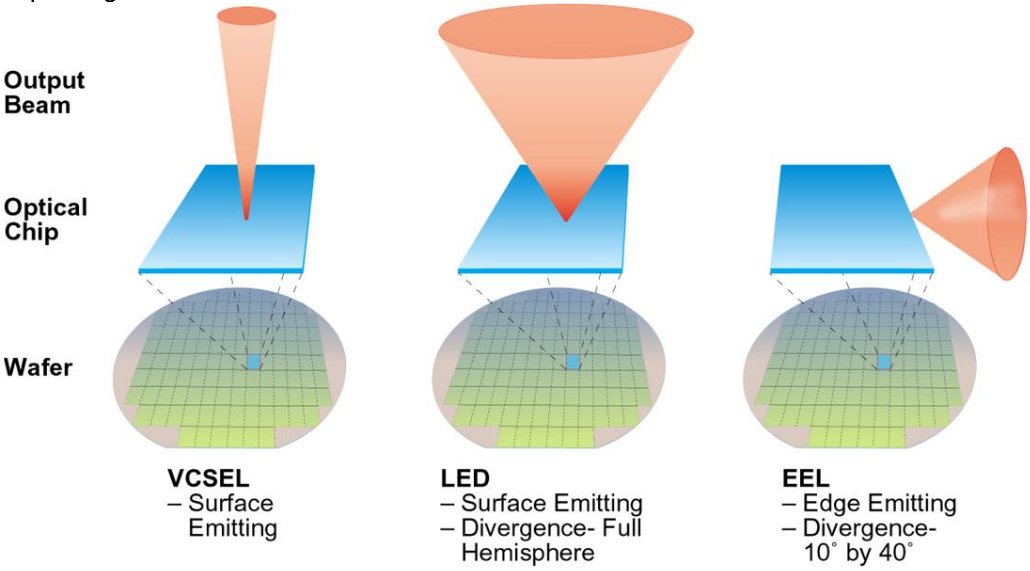


Figure 5. Comparison of the light emission direction and beam profiles of a Vertical Cavity Surface Emitting Laser (VCSEL), Light Emitting Diode (LED) and conventional laser or Edge-Emitting Laser (EEL).

The optical output of each optoelectronic device is different from one another due to these design characteristics. The spontaneous emission from the LED is Lambertian, filling a wide hemisphere with light. The stimulated emission from the VCSEL beam is circular with a much narrower emission angle. The beam angle from the edge emitting laser is elliptical due to the asymmetric nature of the optical cavity, where the angle of emission is wider in the direction normal to the die surface. While LEDs have 30-50nm spectral widths, VCSELs and EELs emit light with narrower spectral widths (1-2nm). VCSELs and EELs can also be modulated at higher speeds, typically >100X faster than LEDs. Therefore, VCSELs combine the manufacturing advantages of LEDs with the performance advantages of lasers.

The VCSEL geometry limits the amount of optical power a single VCSEL can provide. The mirrors grown on either side of the active region create a laser cavity for optical confinement in the vertical direction. However, efficient operation of the device also requires current confinement in the lateral direction. This is achieved with an electrically insulating oxidation layer to force current flow through the center of the VCSEL. A metal contact on the top surface of the VCSEL provides current injection into the VCSEL. For top emitting VCSELs, the metal must have a transparent aperture to allow the light to leave the device.

There is a limit to how efficiently the current can be spread across this aperture. Thus, the maximum power that can be emitted from a single aperture is limited. For applications requiring more power, multiple VCSELs are created on a single die and operate together in parallel. An important advantage of this solution is that the array of mutually incoherent lasers provides a low speckle illumination source that also has a narrow linewidth.

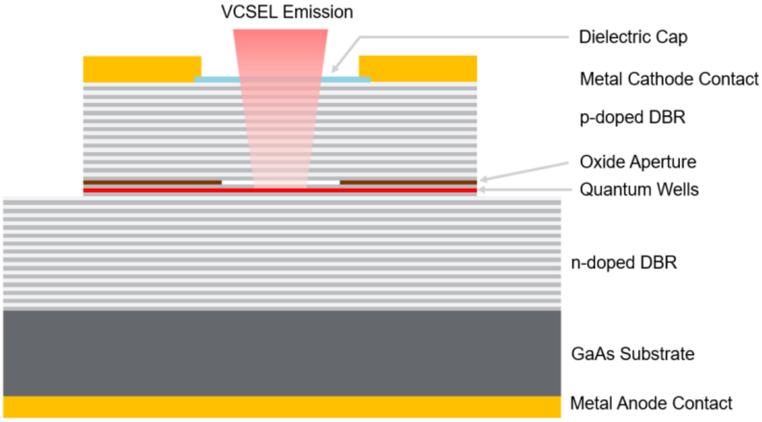
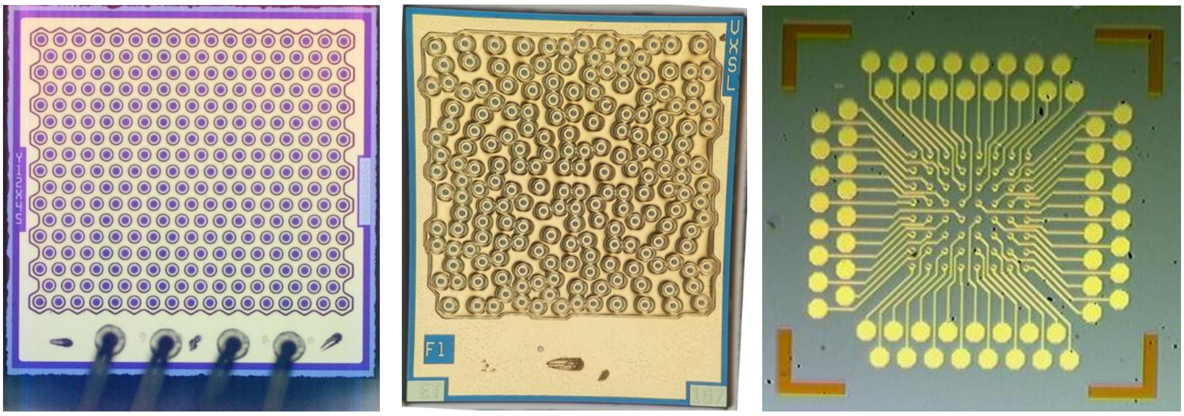


Figure 6. Illustration of the structure of a VCSEL.



(a) (b) (c)

Figure 7. Photos of VCSEL arrays. (a) A 281 element VCSEL array with both common anode and common cathode. Wire bonds to a package are visible on the bottom side of the chip. (b) A pseudo-random array used for structured lighting. (c) An 8x8 VCSEL array where each VCSEL can be modulated independently.

3 Advances in VCSEL Die Performance

The two main steps required in the fabrication of a VCSEL involve (1) growing epi on a substrate wafer and (2) fabricationg die out fo the processed wafer. Both processes can be optimized to peak the performance of VCSEL power arrays.

3.1 Advances in VCSEL Epi Designs

The Epi growth is the ultimate recipe that results in the key performance parameters that separate the boys from the men in the VCSEL world. The recipes involve the strict design and control of hundreds of epitaxially grown layers that determine the VCSEL's operating wavelength and quantum efficiency. Vixar has a proven track record of improved VCSEL performance over the years in terms of output power and efficiency through strict epi growth and analysis. Current production parts have been shown experimentally to achieve efficiency levels > 50% with many of Vixar's power array design soon to incorporate these performance enhancements.

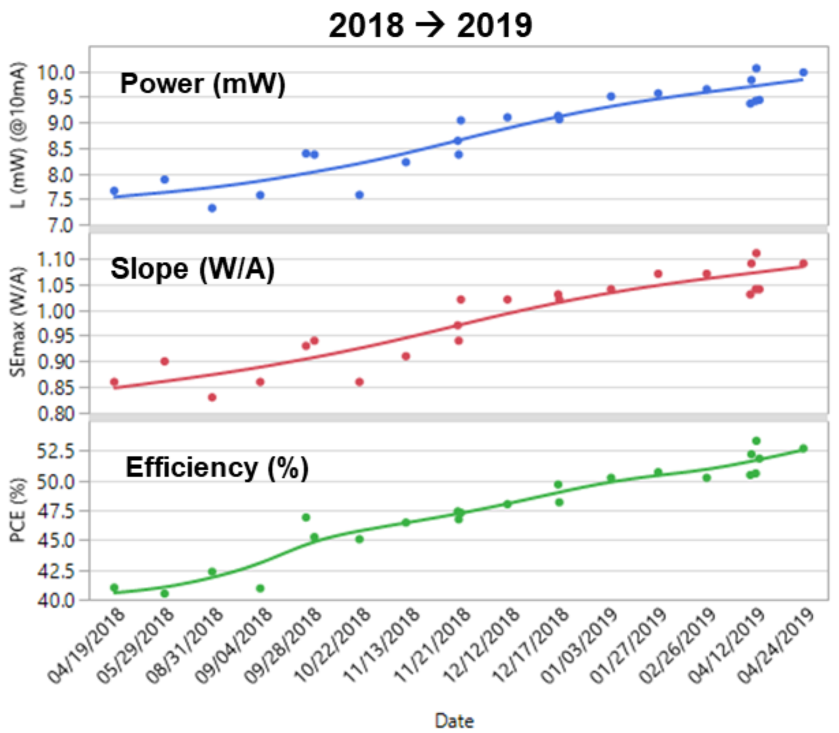


Figure 8. Single aperture performance history at 25C from production run data.

3.2 Multiple Junction VCSELs

One of the main limitations in VCSEL performance is the limited gain medium length that the cavity power observes between the DBRs. A traditional VCSEL only has a single active region of 1-3 quantum wells. By adjusting the epi design to allow for multiple active regions inside the cavity region with assistance of tunnel junctions, the optical gain length inside the cavity is increased. An illustration of a dual-junction VCSEL diode is shown below.

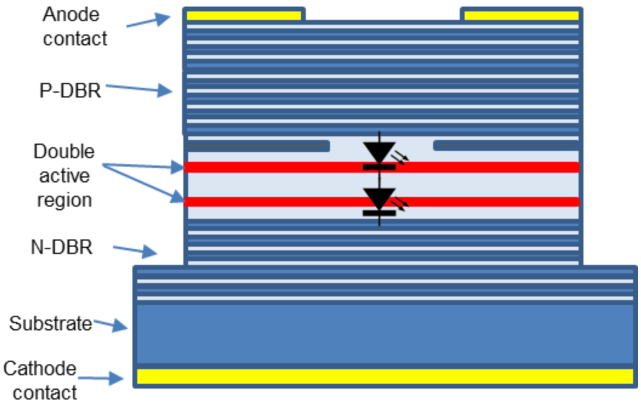


Figure 11. Illustration of a dual-junction VCSEL.

Dual-junction VCSELs from Vixar have been tested with experimental results shown below. Observing the data, one notices that the forward voltage required to drive a specified amount of current through the VCSEL is double compared to a single junction VCSEL. This also correlates to a doubling in the optical output power of the die. Due to the confinement of optical energy and improved gain medium inside the VCSEL cavity, improvements in the maximum wall plug efficiency (WPE) was observed. The dual-junction VCSEL resulted in a peak WPE of 59%, significantly higher than the single-junction equivalent's performance of 52% peak WPE.

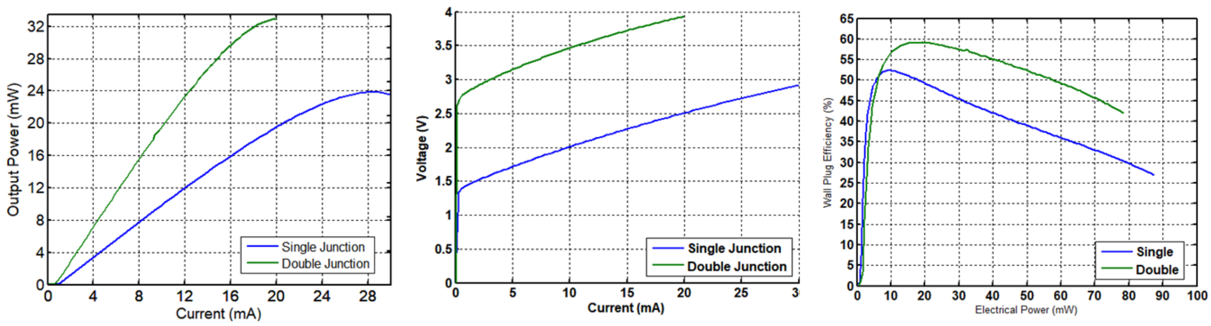


Figure 12. Measured performance of a dual-junction VCSEL die.

3.3 Advances in VCSEL Die Designs

While most of the performance characteristics are determined from epi growth, die fabrication can be optimized for advanced end-user applications. For instance, many time of flight applications require a fast rise time. Most VCSELs minimize the area for wire bonding to maximize wafer area reserved for VCSEL active areas. However, designing ToF VCSELs with opposing wire bond pads allows for improved current delivery and uniform current density. Such parameters, when integrated approriately, will improve opti cal power rise time. In addition, opposite wire bond connections create reversed magnetic fields that cancel each other out, reducing circuit inductance and electrical parasistics. Vixar has determined these feastures as a priority and plans to make dual junctions VCSELs with dual wire bonds for mobile applications available in Q2 2019.

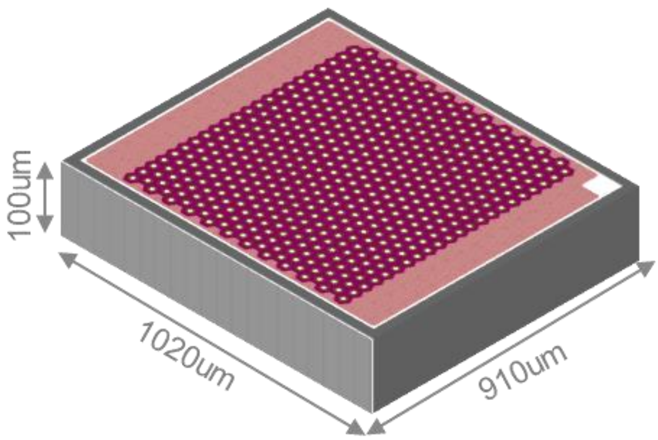


Figure 9. Illustration of a 3W VCSEL with dual bond pads for fast rise times.

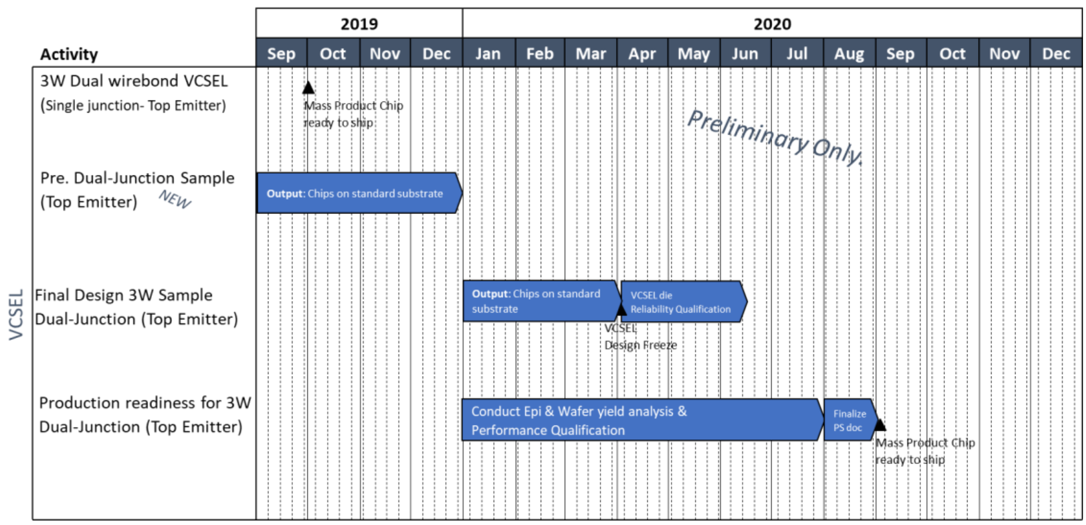


Figure 10. VCSEL Project Timeline for 3W 940nm chip

4 VCSEL Packaging and Integration

The vertically emitting nature of the VCSEL can take advantage of surface mount packaging that has been developed for many advanced LED component assembly. For the previously stated use cases for VCSELs, the end application requires high rise times with peak power efficiency from both the laser and electronics. Such a design requires the tight integration between the VCSEL and the laser driver and required passive components. Component separation needs to be minimized to decrease parasitic inductance. Capacitors need to be placed near the VCSEL to improve charge carrier delivery to the laser. Additional safety and monitoring features can also be integrated into a package.

Vixar and OSRAM have worked together to design and deliver an embedded driver IC for higher integration and reduced capacitance. The design has the VCSEL, FET, and driver all in close proximity in a reduced footprint. Monitor photodiodes and ITO-patterned diffusers are incorporated for diffuser performance monitoring and heightened laser safety. The final design is encased in a solder-reflowable SMD package.

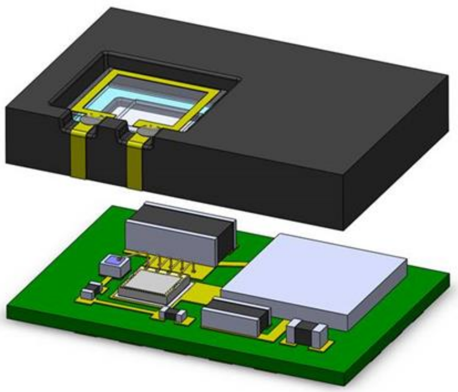


Figure 13. Illustration of a VCSEL and driver integrated into a single SMT module.

VCSEL Performance	Units	Current Performance	Remarks
Optical Power	[W]	2.3	Typical value @ 60C Low driving current
Voltage	[V]	2.0	
Current	[A]	2.7	
PCE	[%]	43%	
Optical Power	[W]	3.44	Typical value @ 60C High driving current
Voltage	[V]	2.25	
Current	[A]	4.0	
PCE	[%]	38.2%	
Wavelength	[nm]	940	Typical value @ 60C
Rise/Fall Time	[nS]	0.3-0.8	Optical Pulse, 10-90%

Figure 14. Values obtained from a laser module integrated with a dual pad VCSEL.

5 Conclusion

Vixar and OSRAM both recognize the economic requirements of VCSELs as important key components for consumer, industrial, and automotive applications. Vixar has developed a family of VCSEL power arrays targeting these applications, and they strive to push the boundaries of key performance parameters desired by these industries. Key parameter improvements include strategic achievements in VCSEL epi design, die construction, and module packaging.

For more information about Vixar and OSRAM's current and upcoming performance achievements, please reach out to Vixar at sales@vixarinc.com and reference this white paper and any specific parameters of interest.

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