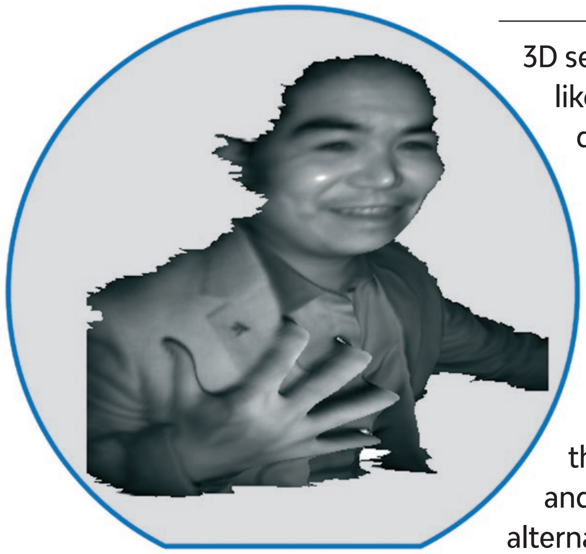
A NEW APPROACH IN VCSEL



3D sensing technology is already well established for applications like face recognition in our mobile phones, but the technical demands for other 3D sensing in emerging applications like Autonomous Driving call for different 3D sensing technical solutions based on time of flight (TOF) with NIR VCSEL technology. Meanwhile, other types of VCSELs like shortwave VCSEL and blue VCSEL have also drawn attention due to promising market potential in applications like datacoms, 3D printing, chip sized atomic clocks, HB light sources and so on. Evatec Product Marketing Manager **Dr. Chongqi Yu** reviews the benefits of VCSEL technology for these growing markets and how Evatec's process solutions can help VCSEL makers find alternatives when traditional techniques don't make the grade.

Typical Time Of Flight image ouput featuring Dr. Chongqi Yu.

Choosing the right 3D technology

It's all about achieving accurate optical distance measurement. The relative merits of today's typical optical distance measurement techniques available – Interferometry, Triangulation and TOF are illustrated in table 1. Interference methods are limited to measurements in the micron range. A triangulation (structured light or stereo) using geometry approach is an ideal solution for many of the "Front Side" cameras in many of today's mobile phones as the measurement range is still low up to the metre range and offers low power consumption, but for emerging "rear side" applications including photography and augmented reality where the ranges are larger and lighting conditions much more challenging industry analysts like Yole are expecting Time of Flight technology to dominate going forward. LiDAR (Light Detection and Ranging) enabling Autonomous Driving will also call for sensing technologies like TOF effective over much longer distances and in a range of challenging ambient light situations.

Light Sources – LED or VCSEL?

TOF technology relies on extremely fast, accurate and precise measurement of the time taken for light from a source to reach an object and then for reflected light from that object to return to the detector. Effective filtering, reading and analysing of the return signal at the detector is a key step in achieving overall system performance and the choice of light source (typically LED or VCSEL) plays a key role. We can define a number of ideal characteristics of the light source to optimize overall detection efficiency and accuracy.

- **High peak power and narrow pulse width: providing a high signal to noise ratio**
  A light source with high peak power and narrow pulse width is extremely critical to achieve a high signal-to-noise ratio for the outdoor long distance measurement in applications like LiDAR, since the reflected signal of the source from the target is so weak and the sunlight generated background noise is so strong.

	Interferometry	Triangulation	Time Of Flight
Range	µm	µm to m	cm to km
Frame rate	high	very high	high
Strong ambient light	bad	good	very good
Weak ambient light	good	good	very good
Power consumption	low	low	high
Cost	high	low	medium
Economic potential	low	low	high
Miniaturation potential	low	medium	high

Table 1: Comparison of optical distance measurement techniques (Courtesy of ESPROS Photonics).

	LED		VCSEL	
	850 nm	940 nm	850 nm	940 nm
Rise time	12 ns	9 ns	< 1 ns	< 1 ns
Fall time	17 ns	13 ns	< 1 ns	< 1 ns
Max. operation requency	< 40 MHz	< 40 MHz	> 40 MHz	> 40 MHz
Spectral width (FWHM)	35 nm	50 nm	0.8 nm	0.8 nm
Temperature coefficient	0.26 nm/°C	0.29 nm/°C	0.07 nm/°C	0.07 nm/°C
Wall plug efficiency	38%	44%	30%	29%
Eye safety	Intrinsically safe		Additional safety meaures needed	
Mx pyrometer reading	168	169	192	90
Measured bow (mm)	≤4	≤4	≤4	≤4

Table 2: Extract from typical performance of LED vs. VCSEL in the NIR range. Courtesy of Lumileds Holding B.V.

- **Low spectral shift by temperature: enabling a narrower optical band pass filter**
  The sun is TOF's biggest enemy since it introduces so much background noise to the detector. Therefore, a bandpass filter is required to filter out the photons with unwanted wavelengths. However, if the light source has a large spectral shift by temperature (e.g. during the change of seasons), a relative wide spectral width of the filter needs to be implemented for the compensation of the spectral shift, leading to more background noise coming in, i.e. less effectiveness in filtering.
- **Fast modulation and short rise / fall time: achieving better precision and resolution**
  A light source with fast modulation and short rise / fall time is very important for short distance measurement applications like face recognition. For example, the face recognition is usually applied with a distance below two meters, which typically requires a modulation frequency higher than 75MHz and rise / fall time less than 3ns.
- **Large output intensity: supporting long range operation**
  Distance has a power of two impact on the intensity of reflected light from an object. Therefore, a light source with large output intensity is essential for long range distance measurement. For example, LiDAR (~ 200 meters) requires x10,000 stronger illumination power than face recognition (~2 meters).

Table 2 shows a typical performance of LED vs. VCSEL in the NIR range. We can clearly see that VCSEL technology offers significant advantages of higher operation frequency, faster rise / fall times, narrower spectral width and higher temperature stability essential for future applications like LiDAR. Fortunately, critical issues like "eye safety" which need to be addressed for VCSEL technology can be solved relatively easily via integration of a so called "diffuser layer" within the source package.

VCSEL – A growing market

Analysts like Yole report that the NIR applications like 3D sensing currently dominating the market will continue to grow rapidly with the expected emergence of LiDAR. However, they also anticipate that other applications including medical, data communication and printing will enable growth opportunities for other VCSEL technologies in other wavelength ranges such as visible, short wave infrared (SWIR) or blue over the next years providing the manufacturing challenges can be solved.

Evatec manufacturing solutions for VCSEL

Just like in LED technology Evatec can offer know-how across a number of processes in the manufacturing chain for VCSEL technology (Figure 1).

Evatec already has more than 15 years know-how in delivering manufacturing solutions for DBRs, TCOs, metals and passivation layers in LED applications. That know-how can be leveraged to develop tailored thin film processes for VCSEL too together with customers.

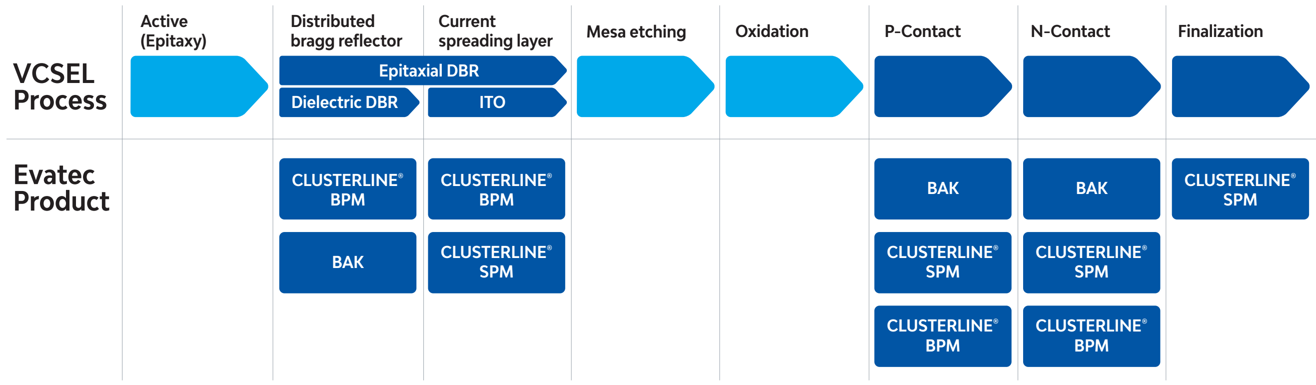


Figure 1: Evatec offers production solutions across many typical VCSEL processes.

A view from Yole

Until 2017, the VCSEL market was driven by the datacom applications that emerged in 1996. At the same time, several other applications have used VCSELs, but they have remained niche applications. Since then, the datacom application that was driving the market has been replaced by the 3D sensing application, especially since the implementation of the Face ID module in iPhones.

Globally, the VCSEL market is expected to generate revenue of $1,139.5 million in 2020 and should reach $2,651.5 million in 2025 at a CAGR of 18.3%. In this VCSEL market, telecom and infrastructure applications, mainly datacom, are expected to generate revenue of $277 million in 2020 and should reach $516 million in 2025 at a CAGR of 13.2%. Mobile and consumer applications are expected to generate revenue of $843.6 million in 2020 and this should reach $2,105 million in 2025 at a CAGR of 20.1%. Other applications are not significant yet but could emerge in the mid- to long-term, such as automotive applications like LiDAR or driver monitoring systems.

Recently, Apple implemented a LiDAR module. In this module, the VCSEL used is quite different from VCSELs found in indirect ToF modules. This module, with a VCSEL and a SPAD array, is using the direct time of flight principle. The VCSEL is slightly different with more wire bonds and more metallization. Contrary to other VCSEL arrays used in smartphones where all the cavities are driven at the same time, this VCSEL array has multiple connections so that each line can be driven separately. The particular metallization visible on this VCSEL array is used also to dissipate the heat produced by the VCSEL array.

The above case is for the NIR VCSELs used in the two main markets. But other niche applications can use other wavelengths. This is the case for optical gas sensing where wavelengths from 1,280nm to 2,300nm can be used, especially in the Oil and Gas industry to monitor toxic and/or explosive gases in real-time. On the opposite side of the spectrum, GaN-based VCSELs are being developed by a few players, including universities. Most of them are focusing on blue VCSELs but some are also focusing on green. The targeted application for such VCSELs would be AR & VR displays due to their low power consumption and better color purity and brightness compared to LEDs.

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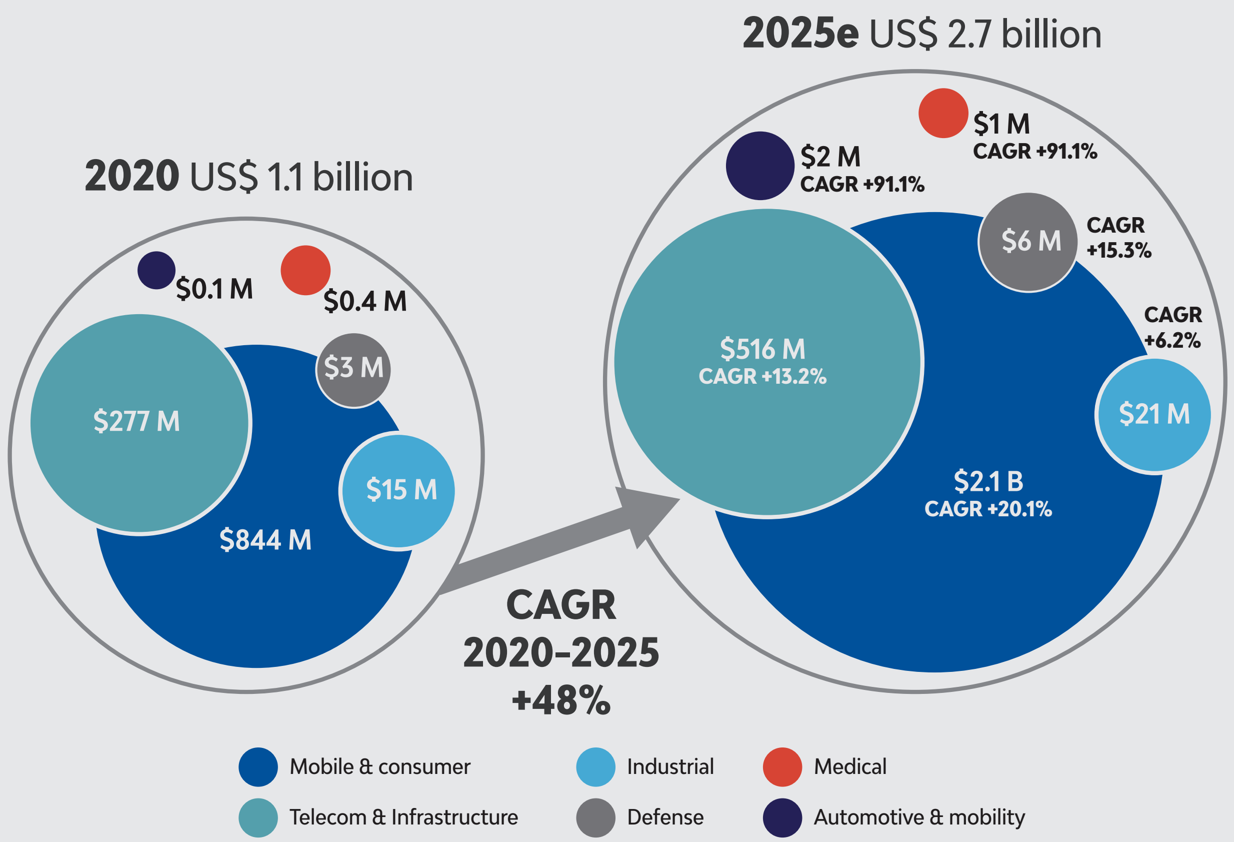
2020-2025 VCSEL market overview

(Source: VCSELs - Market and Technology trends 2020 report. Yole Développement, 2020)



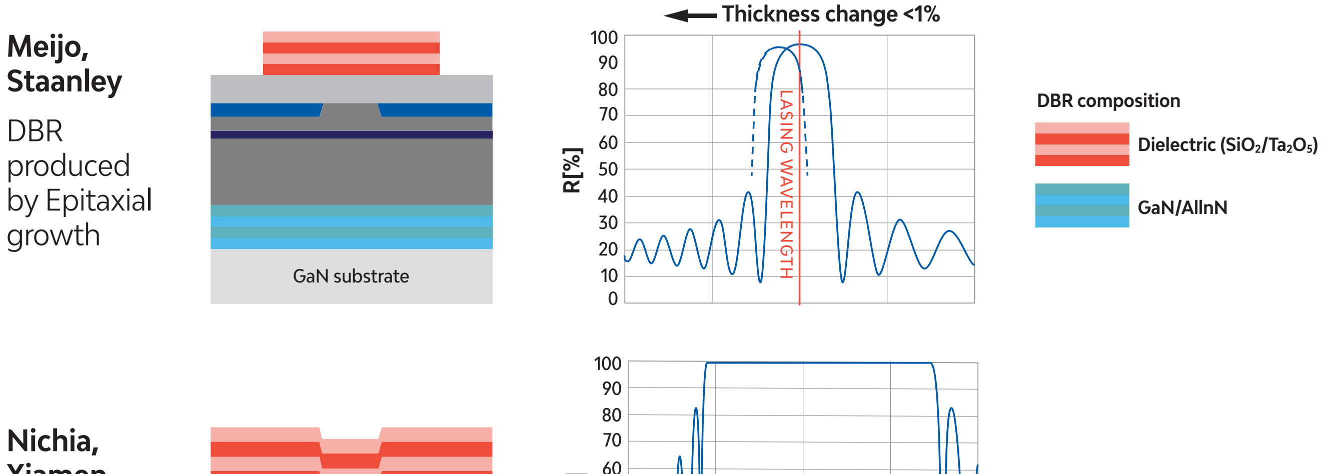


Figure 2: Comparison of optical performance for DBRs produced by epitaxy and sputter.

Source: SONY 2019. EPIC Meeting on VCSELs Technology and Applications.

Process know-how for better performance

Unlike LEDS, where photons may undergo only single reflection within the active region, photons may be reflected many times within the VCSEL cavity so DBR performance with very high reflectivities on both front and back sides is critical to avoid unacceptable losses in light output.

Sputtered DBR layers (Figure 2) can potentially deliver significant device performance advantages over traditional epitaxial layers, especially in the blue domain, through:

- Higher peak reflectance for improved light output
- Wider stop band for larger wavelength range
- Lower spectral shift for improved yield
- Thinner stack structure for less surface stress
- Lower total resistance for increased efficiency

Just as importantly however, the superior thickness uniformities, repeatibilities and particle performance on high throughput cassette to cassette sputter systems offer key advantages essential for achieving consistently high yields in series production. Table 3 shows the excellent WiW (wafer in wafer), WtW (wafer to wafer) and RTR (run to run) uniformities achieved for single layers of typical dielectric materials which can be achieved on an optimized sputter platform.

The performance of Epitaxial DBR stacks grown by traditional MOCVD processes would fall far short of the performance for sputtered stacks.

Proven Production Platforms

Evatec's CLUSTERLINE® 200 BPM is already a well proven production platform for DBRs, TCOs and metals in established LED and emerging Mini and Micro LED technologies. The typical cassette to cassette layout for batch processing of all substrates up to 8 inch is optimized for high throughput processing of GaAs or GaN based products. Key process control technologies of In situ plasma emission monitoring (PEM) combined with optical monitoring (GSM) ensure deposition of fully stoichiometric films at the highest throughput and in stacks of optimized spectral performance.

Looking ahead

The well established epitaxial DBR processes used for current NIR VCSEL technology look here to stay, but for other wavelengths such as blue VCSEL based on GaN, for which device performance and manufacturability by epitaxial techniques is limited due to the low refractive index contrast of the epitaxial materials available. Alternative sputter solutions can now step in to make VCSEL manufacturing viable for other wavelength ranges and help new emerging applications reach their full market potential.

Material	Layer thickness	Thickness Uniformity			Refractive Index (@ 550 nm)
		WIW	WTW	RTR	
SiO_2	300 nm	< ± 0.5%	< ± 0.5%	< ± 0.5%	1.48
Nb_2O_5	300 nm	< ± 0.5%	< ± 0.5%	< ± 0.5%	2.36
TiO_2	300 nm	< ± 0.5%	< ± 0.5%	< ± 0.5%	2.48

Table 3: WiW, WtW and RTR uniformities.