

VCSELS - MARKET AND TECHNOLOGY TRENDS 2020

Market & Technology Report - October 2020

VCSEL market growth is triggered now but still under evolution. Changes are happening at design, manufacturing, supply chain and application levels.

WHAT'S NEW

- Development status of GaN-based VCSELs
- Development status of long wavelength VCSELs
- Insights on critical steps in VCSEL manufacturing
- Focus on automotive opportunities for VCSELs
- Focus on industrial opportunities for VCSELs

KEY FEATURES

- VCSEL market volume and revenue 2017 – 2025
- Analysis of visible and NIR VCSEL industry
- VCSEL ecosystem analysis
- Positioning of new entrants
- Critical steps in the manufacturing process
- Analysis of VCSEL technology for mobile and consumer

REPORT OBJECTIVES

Provide market data on different VCSEL applications

- Volume and revenue by application and by market segment
- Average selling price (ASP) and expected evolution
- Ranking of top-5 VCSEL manufacturers

Deliver an in-depth understanding of the VCSEL business value chain, players and trends:

- Global list of VCSEL manufacturers
- Supply chain information for mobile applications: who supplies to whom
- Supply chain analysis
- Comparison of VCSELs used in mobile applications

Give insights on manufacturing and associated challenges

- What is a VCSEL?
- Analysis of visible and NIR VCSEL industry
- Insights on critical steps in VCSEL manufacturing

MOBILE 3D SENSING WILL REPRESENT ~75% OF OVERALL VCSEL REVENUES IN 2020

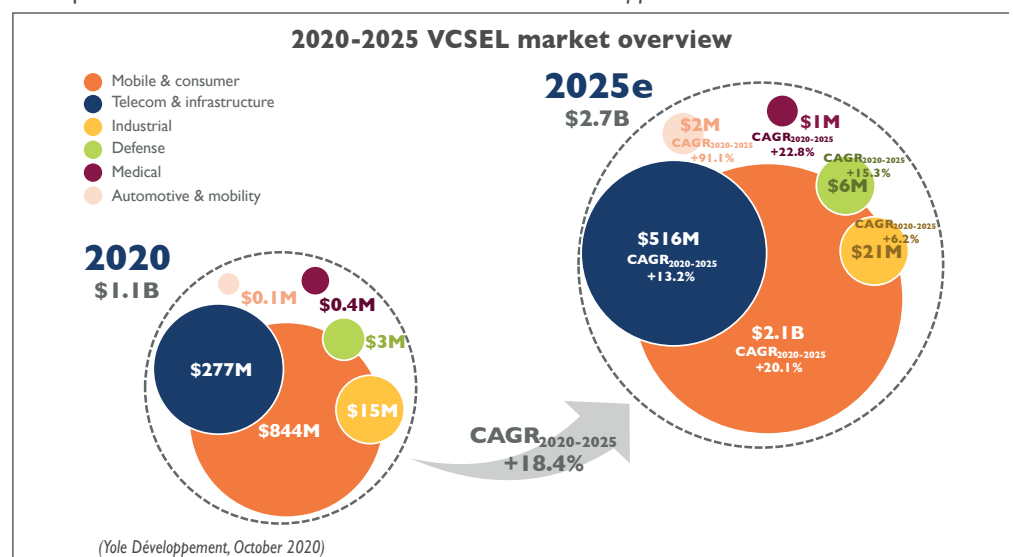
Until 2017, the VCSEL market was driven by datacom applications that emerged in 1996. In between, several other applications have used VCSELs but they remained niche applications. Since then, the datacom application that was driving the market has been replaced by 3D sensing application, especially since the implementation of the Face ID module in iPhones.

Following the release of the iPhone X, several smartphone manufacturers followed the same path and implemented 3D sensing module in the front side of smartphone for face recognition. Since this, it was expected that other Chinese smartphone manufacturers would also implement such module on the front side. This was the case the following year, but it rapidly declined, and 3D sensing modules moved from the front side to the world facing side, mainly for photography application. This can be explained by several factors: the cost of 3D sensing modules, the intellectual property around structured light solution, and the competition of under display fingerprint solutions that were more accessible to mid-end smartphones.

This transition from the front side to the world facing side has an important consequence on the VCSEL market. It was expected that front 3D modules would use structured light solution with two VCSELs contrary to world facing 3D modules using Time-of-Flight (ToF) solution with only one VCSEL. In this context, mobile and consumer applications are expected to generate revenue of \$843.6M in 2020 and this should reach \$2.1B in 2025 at a CAGR of 20.1%.

Globally, the VCSEL market is expected to generate revenue of \$1.1B in 2020 and should reach \$2.7B in 2025 at a CAGR of 18.3%. In this VCSEL market, telecom and infrastructure application, mainly datacom, are expected to generate revenue of \$277M in 2020 and should reach \$516M in 2025 at a CAGR of 13.2%. Other applications are not significant yet but could emerge at mid to long term such as automotive applications like LiDAR or driver monitoring systems.

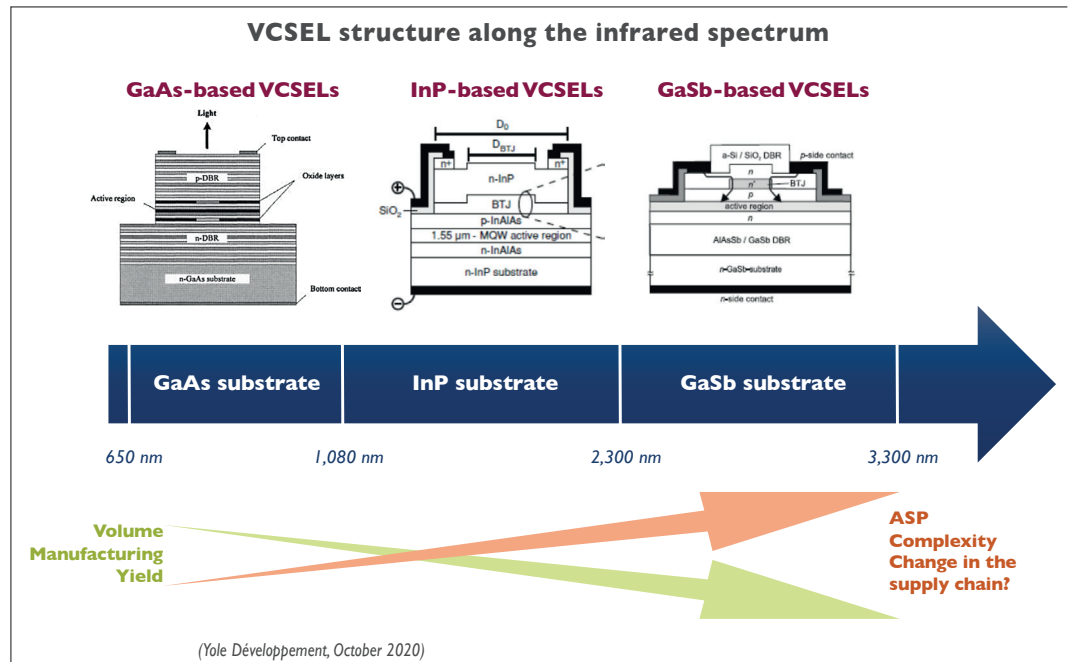
This report presents a comprehensive overview of the main VCSEL applications, including an in-depth analysis of 3D sensing in the consumer and automotive landscapes as well as datacom and industrial applications.



TECHNOLOGY IS NOT YET MATURE AND COULD FURTHER MUTATE IN THE FUTURE

On the technology side, VCSELs are still evolving. This is clearly the case for VCSELs on the rear side of smartphones. At first, it was expected that these VCSELs would be larger

than on the front side to achieve a longer detection range. But this is not really the case and Apple, once again, showed that VCSELs can still be improved.



On the word facing side of the last iPad, Apple implemented a LiDAR module. In this module, the VCSEL used inside is quite different from other VCSELs found in indirect ToF modules. This module, with a VCSEL and a SPAD array, is using 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 all in 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. And there is not only a specific metallization but also a ceramic substrate for a better heat spreading.

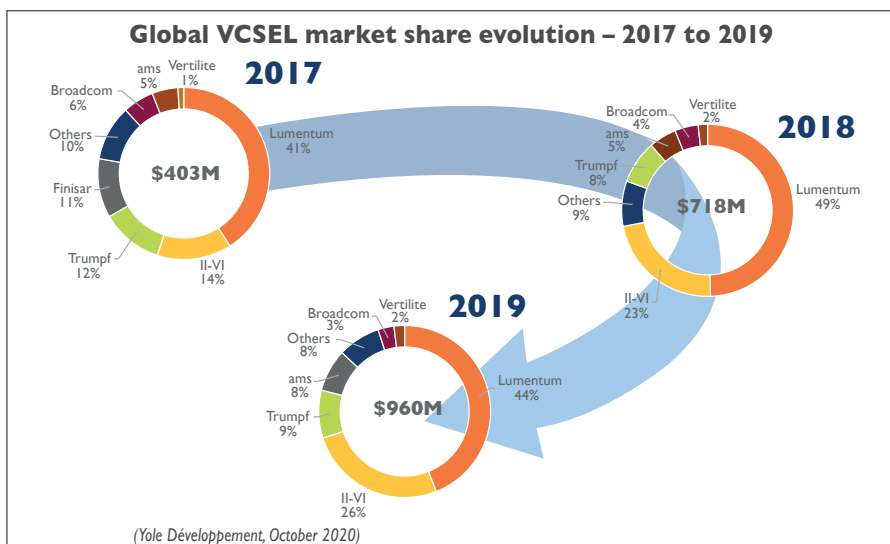
Technology evolution is not limited to the world facing side and on the front side, several companies are working on integrating the 3D module under the OLED display. This integration is directly linked with the trend to maximize

the display size in smartphone. So, the notch has already been reduced and is now about to disappear under the display. This integration could impact the VCSEL as the OLED material is expected to absorb some of the light emitted by the VCSEL. Depending on the absorption, the wavelength of the VCSEL could move from 940nm to more than 1,080nm.

If the wavelength must be changed beyond 1,080nm, there could be a change in the material used to manufacture VCSELs. Indeed, Indium Phosphide (InP) could be used instead of Gallium Arsenide (GaAs). This change will take some time but could considerably change the VCSEL industry with the emergence of new players, low manufacturing yields, and higher cost of VCSELs.

This report gives insights on manufacturing yields of VCSELs with details on each manufacturing step. It presents the challenges linked to VCSELs with a long wavelength.

LUMENTUM IS DOMINATING THE MARKET BUT NEW PLAYERS ARE EMERGING



Since 2017 and the integration of 3D sensing modules in smartphones, Apple is consuming the majority of VCSELs produced by Lumentum. In 2017, 41 million units were implemented in iPhones and in 2020, more than 325 million of VCSEL are expected to be used in iPhones. This number represents more than 2/3 of the total VCSEL consumption for mobile 3D sensing.

Lumentum, as the main supplier of Apple's VCSELs, is clearly leading the mobile and consumer market with 58% of the market in 2020. Behind Lumentum, II-VI and ams are completing the podium with market shares of 17% and 10% respectively.

The supply chain is also evolving following political decision and the trade war between US and China. In May 2019, the US ban Huawei. Lumentum stops

supplying Huawei and Huawei must find a new provider of VCSELs. This ban severely damaged Huawei's supply chain. Huawei had no choice but to build its own supply chain. This is the rise of Vertilite. Other Chinese VCSEL suppliers are expected to emerge as other smartphone manufacturers like Oppo, Xiaomi, or Vivo could

follow this trend and develop a local ecosystem to secure their supply chain.

The report estimates the global market share of VCSEL manufacturers with a focus on mobile and consumer. The report gives insights on the emergence of new players that could compete with traditional ones.

COMPANIES CITED IN THE REPORT (non exhaustive list)

Accelink, Aixtron, Alight, ams, Anadigics, Apple, Avago, AWSC, Beam Express, Bosch, Broadcom, Canon, Changelight, Device Innovation, Egismos Technology Corporation, Emcore, Epistar, EpiWorks, Finetech, Finisar, FLIR, Foxconn, Fuji Xerox, Fujitsu, Global Communication Semiconductor, Google, Hamamatsu, Heptagon, Himax, HLJ, Honeywell, Honor, Huawei, Ibeo, II-VI, Infineon, Intel, IntelliEPI, IQE, JDSU, Landmark Opto, Lasermate, Lasertel, Laytec, LeddarTech, Lenovo, LG, Lumentum, LuxNet, Mantis Vision, Masimo, Namuga, Oclaro, OmniVision, Oppo, Optowell, Orbbec, Osram, Oxford Instruments, Picolight, POET Technologies, Primesense, QSI, RayCan, Realsense, Riber, Ricoh, Samsung, Sanan, Santec Corporation, SCAT, Seiko Epson, Seminex, SensL, Shiraz University, Sick, SinoSemic, SoftKinetic, Sony Corporation, Stanley, STMicroelectronics, Sumitomo Chemicals, Sunny Optical Technology, Thorlabs, TriLumina, TrueLight Corporation, Trumpf, Tyson Technology, Ulm Photonics, Ultra Communication, US Lasers Inc., Ushio, Veeco, Vertically Integrated Systems, Vertilas, Vertilite, Vixar, VPEC, Win Semiconductor, Xiaomi, and more.



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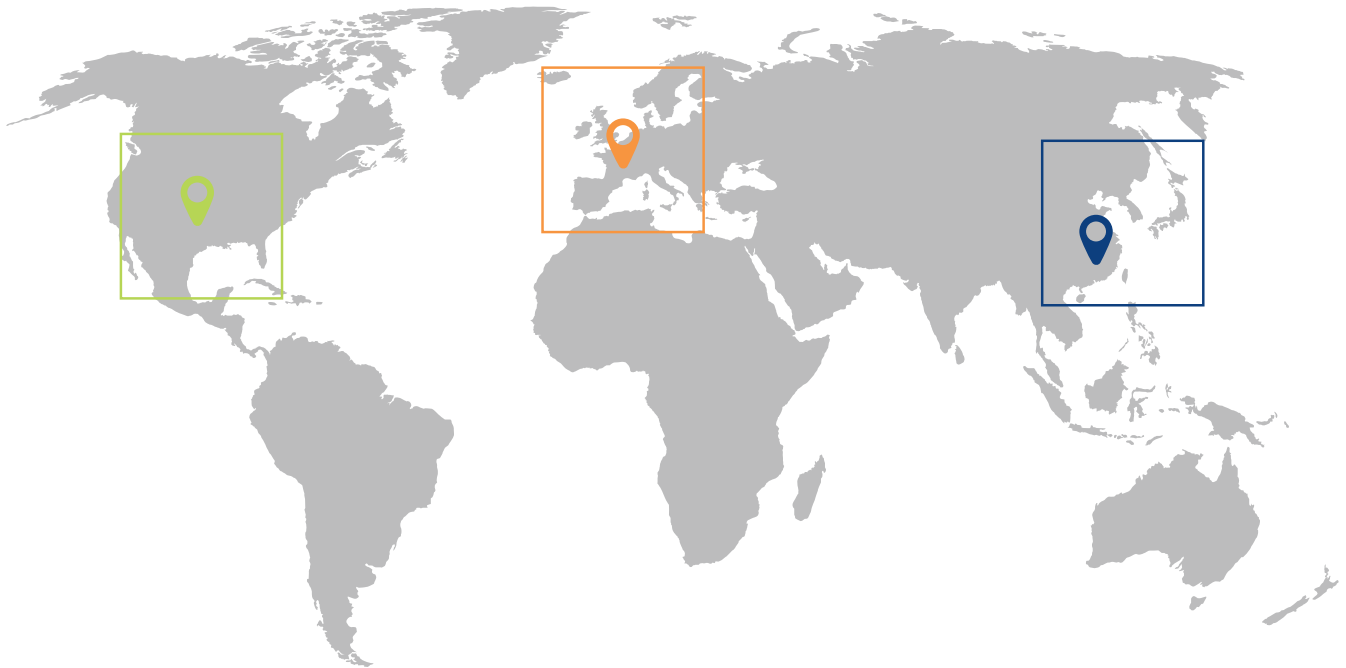
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- 3D Imaging & Sensing 2020
- GaAs Wafer and Epiwafer Market: RF, Photonics, LED, Display and PV Applications 2020
- InP Wafer and Epiwafer Market – Photonic and RF Applications
- Apple iPad Pro LiDAR Module
- VCSEL in Smartphone – Comparison 2019

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ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

CONSULTING AND ANALYSIS

- Market data & research, marketing analysis
- Technology analysis
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- Design and characterization of innovative optical systems
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More information on www.yole.fr

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“Buyer”: Any business user (i.e. any person acting in the course of its business activities for its business needs) placing an order pursuant to these General Terms and Conditions of Sale, with the exclusion of any individual consumer acting for his/her sole personal interest.

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 - Within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.
- 2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.
- 2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in Article 3 above.

2.4. The mailing is operated through electronic means either by email via the sales department or automatically online via an email/password. The Buyer is responsible for ensuring that the Buyers platform has the required capacities and authorisations to receive the Product(s) emailed by the Seller. If the Product’s electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that the Seller is informed of the defective formatting within 90 days from the date of the original download or receipt of the Product.

2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the Products and their conformity with the order. Any claim for apparent defects or for non-conformity shall be sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No return of Products shall be accepted without prior written notification from the Buyer to the Seller, even in case of delayed delivery. Any Product returned to the Seller without the Buyer providing prior notification to the Seller as required under Article 2.5 above shall remain at the Buyer’s risk. In no event shall the Seller incur any liability for Products erroneously ordered by the Buyer, or for any request from the Buyer to replace a Product previously ordered by a different Product.

3. PRICE, INVOICING AND PAYMENT

3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are deemed to be inclusive of all taxes applicable in the country where the Seller is based (except for France where VAT will be added). The prices are re-evaluated from time to time by the Seller. The effective price is deemed to be the one applicable at the time of the order.

3.2 Payments due by the Buyer shall be sent by cheque payable to Yole Développement, or made by credit card or by electronic transfer to the following account:
HSBC, 1 place de la Bourse 69002 Lyon France
Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587

To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except as otherwise specifically agreed in writing by the Buyer and the Seller. If the Buyer fails to pay at the due date and fails to request and obtain from the Seller a payment extension, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the “BCE” + 7 points, in accordance with article L.441-6 of the French Commercial Code.

3.4 The Seller publications (reports, monitors, tracks...) are due for delivery only after receipt by the Seller of any payment due by the Buyer prior to delivery.

3.5 In the event of termination of the contract by the Seller attributable to Buyer misconduct during the contract, the Seller will have the right to invoice all work performed at the time of termination, and to take legal action for damages.

4. LIABILITIES

4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for the choice of the Products purchased as well as for the use and interpretations the Buyer makes of the documents it purchases, of the results the Buyer obtains, and of the advice and acts the Buyer bases thereon .

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8. MISCELLANEOUS

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