Commercialization of VCSELs

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***Abstract*:** Nearly 50 years after practical conception, VCSELs are now ubiquitous. Massive investment has been made to scale production, but has it been overbuilt? What are the most viable next commercial influences in the VCSEL market? This paper examines several of the market forces in both supply and demand of VCSELs.

1. Introduction

Vertical Cavity Surface Emitting Lasers (VCSELs) first became commercially available in 1996 and were targeted for data communications. Datacom VCSELs dominated the shipping volume for more than a decade until other high-volume applications such as optical mice and proximity sensors emerged. In 2015, high power 2D arrays of VCSELs began to be used in several applications, and most notably in the Apple iPhone and has since dominated the production VCSEL volume manufacturing. The consumer market demand is nearly 4x in quantity, but with multiple chip content and larger die size (~16x), the wafer volume demand is more than 20x all other markets combined. This has led to widespread capacity expansion in both vertically integrated and outsource manufacturing operations. The next major market anticipation is in Automotive LiDAR in the coming years. In this paper the different markets and technologies are reviewed and cast in terms of global supply relative to other GaAs based devices.

2. Data Communications

Several hundred million VCSELs are now operating in the global data infrastructure. Since the VCSEL introduction, the individual line rate has grown from 1Gbps to more than 25Gbps today. While impressive, this has not kept pace with demand and has led to the adoption of multiplexed solutions, namely array interconnects. The global market for data communications chips has grown at a steady 15 to 20% CAGR over the last decade. To extend the speed of the VCSEL links, standards have adopted PAM-4 signalling to achieve 50Gbps. Recent advances in VCSELs are now making PAM-2 operation at 50Gbps possible, and even 100Gbps using PAM-4. Figure 1 shows an optical eye diagram at 50Gbps using a novel supermode dynamic modulation technique [1]. Extending operation to 100Gbps PAM-2 requires even higher modulation bandwidth and equalization techniques that are currently under development by several companies with at least one company announcing product availability. While the move to single mode fiber in data center cabling has been growing, VCSEL based multimode optical fiber still represents the lowest cost connection from point to point within a rack or row. The demand for data will continue to grow as more of the world becomes connected and applications like video on demand become more globally available.

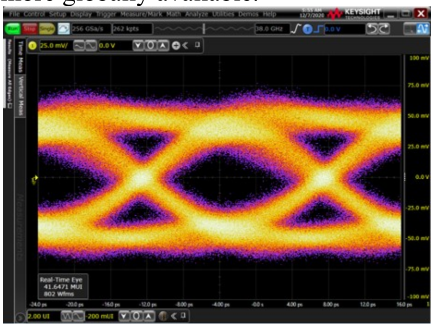

Fig. 1. Optical eye diagram at 50Gbps PAM-2 modulation [1].

3. Consumer Electronics and 3D Sensing

The largest user of VCSEL wafers is now consumer electronics, and primarily the Apple iPhone. Each phone has three large area VCSEL die, the so-called dot projector and the flood illuminator on the front side of the phone, and the LiDAR chip on the back side of the phone. In total it is approximately 3mm^2 of VCSEL material. The widespread availability of the components for 3D sensing will create demand into other markets. However, at the moment, there is not a major application that is driving the interest of consumers. Augmented and virtual reality gaming and other applications are expected to emerge, and further adoption into the Android ecosystem is anticipated. Other application areas like driver awareness and industrial sensing are beginning to take hold. The widely anticipated growth in demand has driven a dramatic expansion in the availability of capacity in both vertically integrated manufacturers and contract manufacturers. Most mobile phones today have VCSEL based proximity sensors that perform a variety of functions, namely turning the screen off while holding the phone to ear. Some high-end gaming mice continue to use a VCSEL illuminator for improved contrast and resolution. Both of these markets use very small VCSEL die and consume a limited number of wafers annually.

4. Automotive LiDAR

The anticipated adoption of VCSEL based LiDAR systems to enable autonomous driving is also fueling the potential demand for VCSELs. It is unlikely that a single LiDAR solution will dominate the automotive market, and is more likely that a fusion of long, medium and short distance systems will be needed to enable level 5 autonomous driving. Among the most desired operating characteristics is no moving parts for scanning. Several companies are now demonstrating VCSEL based LiDAR systems with more than 90-degree field of view and operating to more than 50m range. This is considered the medium range sensing and where VCSEL based solutions are most likely to be successful. Because of the extremely high power (driven by the distance requirements) and the large field of view, very large chip sizes (or multiple chips and systems), a total of 10mm^2 of VCSEL material may be needed. One innovation driving the automotive LiDAR market is the advent of tunnel junction VCSELs to achieve wall plug efficiencies in excess of 60% with slope efficiency near 3W/A [2]. The trade off in voltage for current makes the devices easier to operate. These devices are more interesting for automotive than consumer applications because of the availability of higher voltages in the operating environment. With such large die footprints, and large potential markets, the expansion of global capacity seems warranted. Further, the large chips make the move to even larger substrates like 200mm or even 300mm Ge more attractive [3].

5. Global Capacity

The demand for VCSEL material has grown dramatically over the last several years with the advent of 3D sensors. Figure 2 shows the historical global volume of VCSEL die in the major application areas [4].

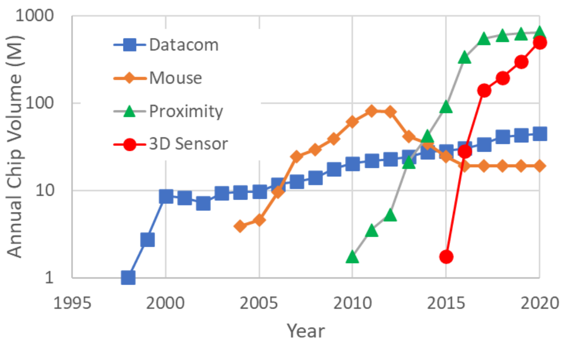

Fig. 2. Historical shipping volumes for VCSELs in several major application areas.

It is clear that the dominate chip volume is driven by proximity sensors and 3D sensing applications, but they drive very different wafer demands. Table 1 summarizes the several application areas by die size, annual volume (2020) and annual wafer volumes. The automotive market is shown for information, with the volume taken as the number of automobiles sold in the US annually and a 10mm^2 total die size. To calculate the wafers needed per year, 80% of the wafer area was considered usable, and 100% yield was assumed. It is useful to understand the scale of the VCSEL market with respect to other GaAs based devices. One example is RFICs used in mobile phone manufacturing, where annual volumes approach 1M wafers per year, and the VCSEL wafer volume is about 5% by comparison. Another example is the LED industry, which drives even larger wafer volumes and VCSELs represent a few percent of that output.

Table 1 Summary of VCSEL die size, annual volume (2020), die per 150mm wafer, and annual wafer volumes.

Application	Die Size (mm^2)	Volume (M)	Chips per Wafer (k)	150mm Wafers (k)
Proximity	0.025	640	601	1.06
Mouse	0.025	20	601	0.03
Datacom	0.0625	45	240	0.19
3D	1	500	15	33.33
LiDAR	10	17	2	8.50

6. Conclusion

VCSELs have moved from a pure focus on data communications markets and other more niche applications to more mainstream consumer products. The change has also driven a marked increase in the number of VCSEL wafers produced each year driven by both an increase in volume and chip size. The 3D sensing industry is primarily driven by one major consumer and as other makers add the technology to products the global demand for VCSELs will continue to grow. The industry could also get another step up in volume with the addition of a strong presence in automotive LiDAR solutions that use VCSELs. In response, vertical manufacturers such as II-VI and AMS have made large investments in infrastructure. This has also been happening in China where the drive for more products to be made in domestically has driven large investments in green field photonic wafer fabrication facilities. Contract manufacturers for wafers such as IQE, and wafer fabrication facilities such as WIN Semiconductor and AWSC have also invested in tools specific for making VCSEL wafers.

References

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