Bringing LiDAR to the Masses

How silicon photonics can revolutionize the autonomous driving market

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Abstract

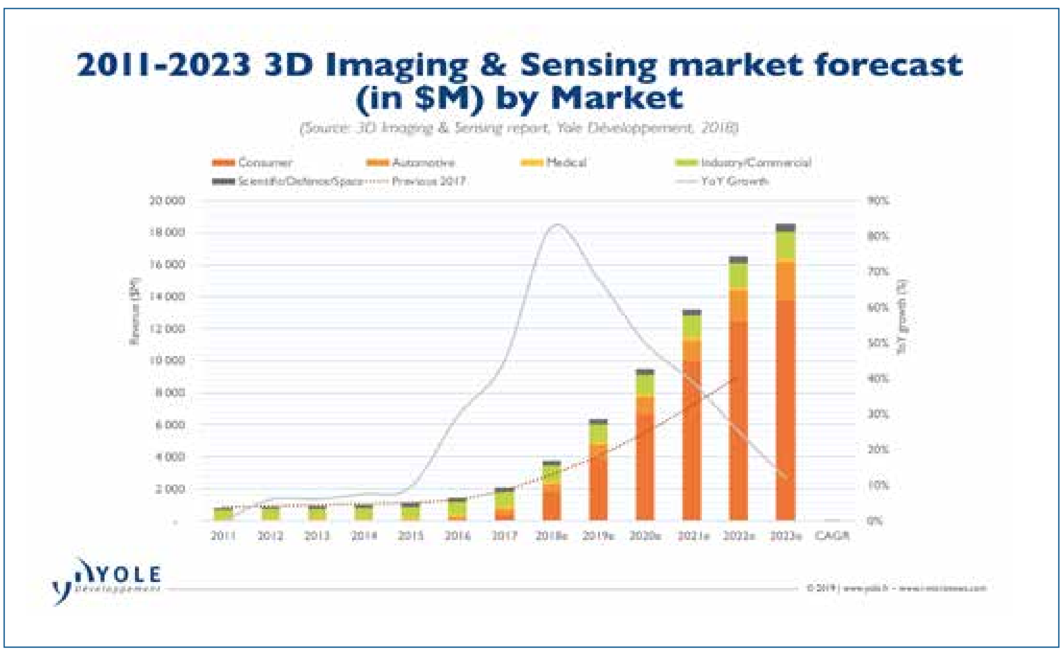
3D imaging and sensing is a growing technology in the consumer, automotive and industry/commercial markets. Specifically, LiDAR, or Light Detection and Ranging, is an emerging sensor technology that most automotive makers rely on in their pursuit for Level 4 (fully automated and driverless) and Level 5 (fully automated and no steering wheel needed) vehicle [1] autonomy. However, the ubiquity of this technology is limited by exceptionally high costs. LiDAR units today cost thousands if not tens of thousands of dollars – far too high to put on standard consumer vehicles. The high cost is due to precision beam steering components, optical components – the lasers, modulators, amplifiers, detectors and lenses – and precise manufacturing tolerances required.

Silicon photonics seeks to disrupt this cost basis through integration on a scalable platform. Much like consumer electronics have benefited from silicon, with products achieving record low prices, the same can happen with LiDAR. The telecommunications industry has driven innovation in this space for decades, the learnings of which can be transferred to the LiDAR space. However, a few challenges must be overcome, such as the need for higher power and narrower linewidth. Rockley's silicon photonics platform uniquely addresses this space with its patented "photon optimized" multi-micron waveguide technology. Through this platform, Rockley is poised to disrupt the LiDAR market and bring autonomy to the masses.

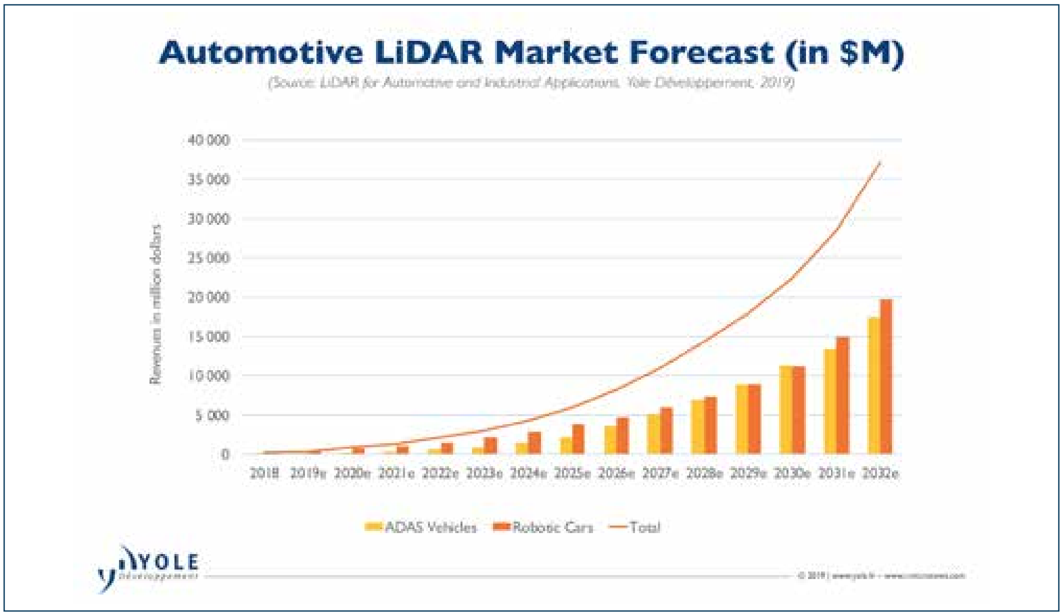
Introduction – LiDAR for Autonomy

To the extent that the electronics revolution brought computers to our laps and cell phones to our hands, the next revolution seeks to make all these things invisible. Devices will chug along in the background without intervention. Factories can churn out products with minimal operators, smart phones detect who you are just by looking at you [2] and cars can actively drive you along the highway, adjusting speed according to the flow of traffic, making decisions and navigating obstacles and situations both expected and unexpected. What do all these things have in common? An exploding new technology called 3D imaging and sensing.

Unsurprisingly, it has been predicted that the expansion of this technology into consumer, automotive, medical, industry/commercial, and science/defense, will lead to market growth at a 44% CAGR from $6B to $18.5B in just 4 years [3]. Looking beyond 4 years, there is a strong expectation for the automotive industry to show even more significant growth. In fact, just in the past year, Yole Développement has increased their projections by 20% going from less than $5B to $6B for the year 2024 [4].



(a) 3D imaging & sensing market forecast showing significant growth in consumer and automotive industries [3]



(b) Automotive LiDAR market forecast [4,5]

Figure 1: Market value projections by Yole Développement

One of the key technologies to enable this growth is LiDAR, or Light Detection And Ranging. LiDAR is similar to SONAR (Sound Navigation And Ranging) and RADAR (Radio Detection And Ranging), but with much higher angular resolution. Despite the higher resolution, most autonomous cars today are equipped with SONAR and RADAR rather than LiDAR as a low-cost solution to achieving feature-rich add-ons like adaptive cruise control and collision avoidance. To move to Level 4 ("eyes off") or 5 ("brain-off") autonomy, it is widely believed in the automotive industry that a suite of sensors will be required. What is included in the suite is debated, but leading autonomy companies, like Waymo, state that redundancy is necessary and that cameras, SONAR, RADAR and LiDAR will all be crucial to full autonomy and meeting reliability requirements [6].

Despite the value in having more sensors and the higher performance resolution obtained with LiDAR, many have not adopted it in consumer solutions due to the prohibitive price point and low volume capability [7]. Most LiDAR solutions today utilize Time of Flight (ToF) technology at ~900nm. While this technology dominates the industry, it is not an ideal solution. Some of the challenges that ToF faces as we drive to the future include:

(1) Eye safety – lower cost ToF systems utilizing 900nm are range limited due to eye safety output optical power limitations. To operate at longer distances with 900nm, more power needs to be pulsed out of the system or the detectors need to become more sensitive. ToF will always have a challenging tradeoff to achieve better range while not exceeding eye safety limitations. 1550nm for ToF is another approach to improve eye safety, but components are much more expensive.

(2) Cost & scalability – ToF typically uses VCSELs, which while being low-cost sources, do not integrate well with other key components needed in the system, such as photodiodes, limiting scalability. Additionally, if any optical manipulation is required (e.g. lenses, isolators, amplifiers, etc.), precision assembly is required, leading to challenging manufacturing requirements and limited ability to scale.

(3) Robustness to background noise – since ToF simply detects the presence of light, it can be susceptible to ambient light and stray ToF systems from nearby cars causing problems with accuracy. Alternatively, solutions exist to improve robustness such as narrow filters, but these increase the number of components and complexity of the system. While measures can be implemented to reduce background noise, these solutions further contribute to cost and power implications.

(4) Velocity measurements: ToF systems are only capable of measuring location with a single data point. However, velocity has to be determined through a series of measurements – at least two measurements are needed. Thus, the overall system is slowed down – a crucial problem at highway speeds.

One solution to the challenges presented by ToF is to use coherent LiDAR at longer wavelengths. Longer wavelengths can output more power without affecting the eye, thus moving to coherent solutions has benefits on eye safety [8]. Since coherent systems are looking for a correlation between signatures on their own local lasers and the returning signals, they are far less susceptible to interference by either ambient or stray LiDAR light [9]. The modulation, e,g "chirp", of a coherent laser allows measurement of velocity directly through a phenomenon known as the Doppler shift [9]. Consequently, coherent technology easily addresses three out of the four challenges mentioned above. Table 1 gives a comparison between these two top LiDAR technologies for autonomy today. To date, adoption of coherent LiDAR has been limited, as current solutions do not meet cost and scalability requirements to get to mass production.

Table 1: Comparison of top LiDAR technology across key market needs

	Time of Flight (905nm)	**Coherent** (1550nm – non-Si photonics)	**Coherent** (1550nm – Si photonics)
Angular resolution	Superior	Superior	Superior
Max range	Average	Superior	Superior
Range resolution	Superior	Superior	Superior
Scanning rate	Average	Average	Average
Robustness to interference	Average	Superior	Superior
Night operation	Superior	Superior	Superior
Adverse weather	Limited	Average	Average
Velocity detection	Limited	Superior	Superior
Eye safety	Average	Superior	Superior
Cost	Average	High	Low
Size	Medium	Medium	Small
Integration	Limited	Average	Superior
Manufacturability	Average	Average	Superior
Scalability	Average	Average	High

Silicon photonics is poised to enable coherent LiDAR with a low-cost, high-performance and highly integrated solution, thus overcoming scalability, manufacturing and system architecture challenges. Since such a solution leverages the silicon industry, it has the capability of scaling to very high volumes while driving cost orders of magnitude lower. In this paper, we will discuss how Rockley's silicon photonics platform is ideally suited to solve the challenges this market creates and opens up the opportunity to achieve low cost and high volume.

A Vertical Unified Platform that Uniquely Enables the LiDAR Market

Much like the silicon industry has created new markets and driven the production of new technologies based on electrons at ever astounding volumes, silicon is poised to do the same thing with photons. Photons have proven to be the most efficient platform for communication and as data rates have increased over time, this platform has penetrated to shorter and shorter distances. Because of this drive for more data, the communication industry has sought solutions that would yield higher volume at lower cost. Silicon photonics is the driving force to enable such a transition in the communication market. Fortunately for LiDAR, the silicon platform can be leveraged as a means to similarly drive volume up and cost down. However, it takes a unique silicon platform to enable such a solution for LiDAR. Rockley Photonics' platform has the key features that can drive the industry forward. In this section, we will describe what silicon photonics is and how Rockley's platform enables the LiDAR market.

Silicon photonics is a technology solution that leverages the mass volume scaling capability of silicon with optical components either through direct fabrication in silicon or integration with other materials, such as III-V or II-IV semiconductors. Typical optical components include: Light sources (e.g. LASERs), modulators, waveguides and other passive components, and detectors. Figure 2 shows main building blocks from Rockley's silicon photonics platform.

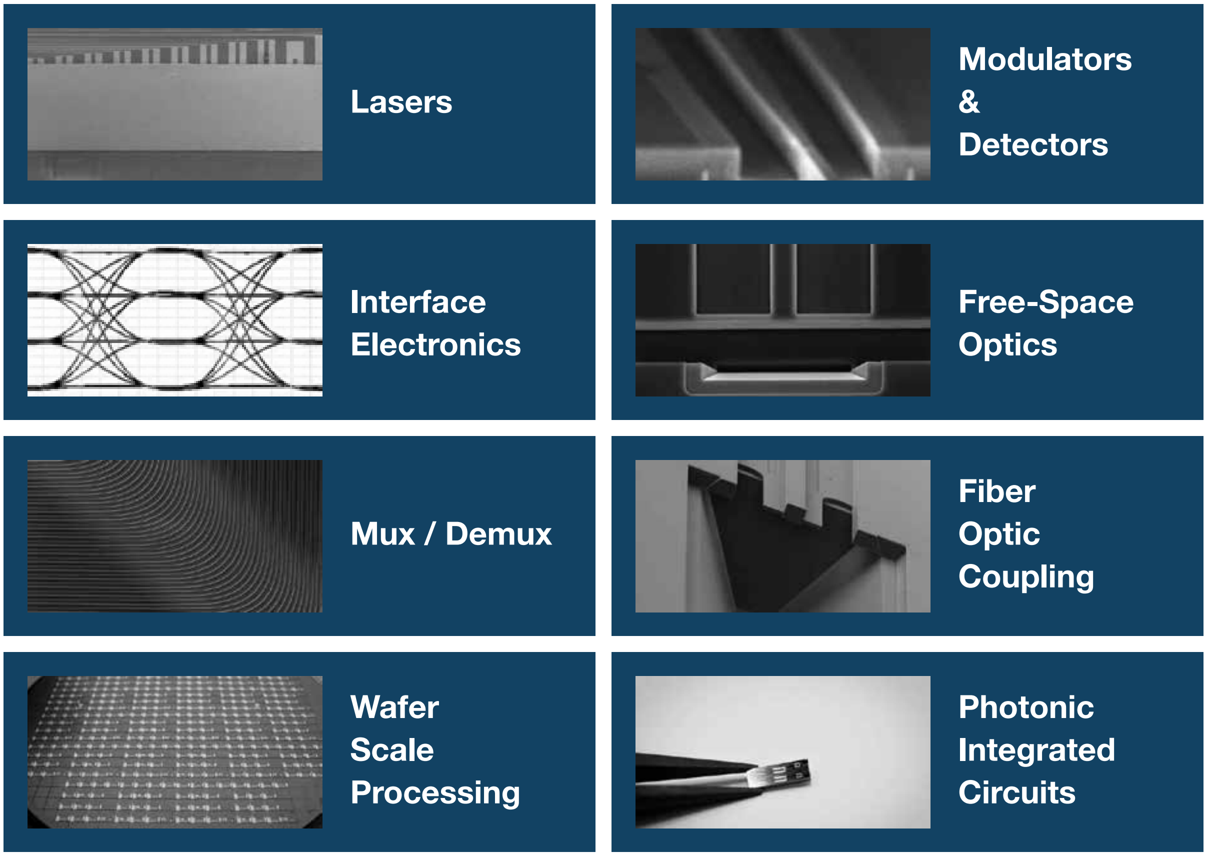


Figure 2: Rockley Photonics' Silicon Photonics Platform

Silicon is an optimal material for low loss passive components, such as waveguides and splitters, as well as detectors depending on the wavelength of operation. However, it does not have ideal physical properties to enable light generation. Most pioneers in silicon photonics have sought to solve this problem through hybrid integration with optimized light generation materials, such as GaAs and InP [10]. Additionally, to optimize detection and modulation at certain wavelengths, germanium is often introduced, leading to further material complexity. Despite these challenges to optimize active optical components on silicon, many companies are beginning to succeed. For example, Intel has demonstrated 100G transceivers using their silicon photonics platform, gaining significant traction in the data center market [11]. Foundries, such as Global Foundries, are also providing their own PDKs (Process Development Kits) to design silicon photonics on chip [12]. Rockley Photonics has also demonstrated commercial success in the communication space through both showcasing the world first commercial optoASIC – Topanga [13] – and a partnership with Hengtong, one of the largest optical fiber vendors, for high speed optical transceivers manufacturing [14].

While the challenges of producing incredibly high-speed components has led development and progress in silicon photonics for communications, the LiDAR space has unique challenges that not all silicon platforms currently address. The two biggest requirements are (a) creating and handling optical powers much higher than those typically needed in communications applications and (b) having a sufficiently narrow linewidth for detection at long ranges.

The two biggest LiDAR requirements for implementing in silicon photonics are:

(a) creating and handling optical powers much higher than those typically needed in communications applications, and

(b) having a sufficiently narrow linewidth for detection at long ranges.

Rockley has an ideal laser source for LiDAR with the ability to achieve power and linewidths to operate at hundreds of meters, a distance beyond the range typical of ToF systems today. Additionally, because it is coherent technology, it can simultaneously measure velocity. However, having the optical source is not the only requirement to truly enable volume scaling and lowered cost. Integration of this source is key while also being able to handle the high optical power. Rockley's laser is fully integrated in a silicon platform with multi-micron waveguides – a unique solution in the silicon photonics industry – and it can handle higher optical power with very low loss [15–18]. Through process techniques similar to those we use for lasers, we can also integrate onto the same platform the other necessary optical components for a coherent LiDAR system: modulators (either through directly modulating the laser or through phase modulation at the laser output), splitters, waveguides, semiconductor optical amplifiers (SOAs) and balanced detectors. Figure 3 shows a block diagram of the necessary components to build a LiDAR solution, all of which Rockley's technology can enable.

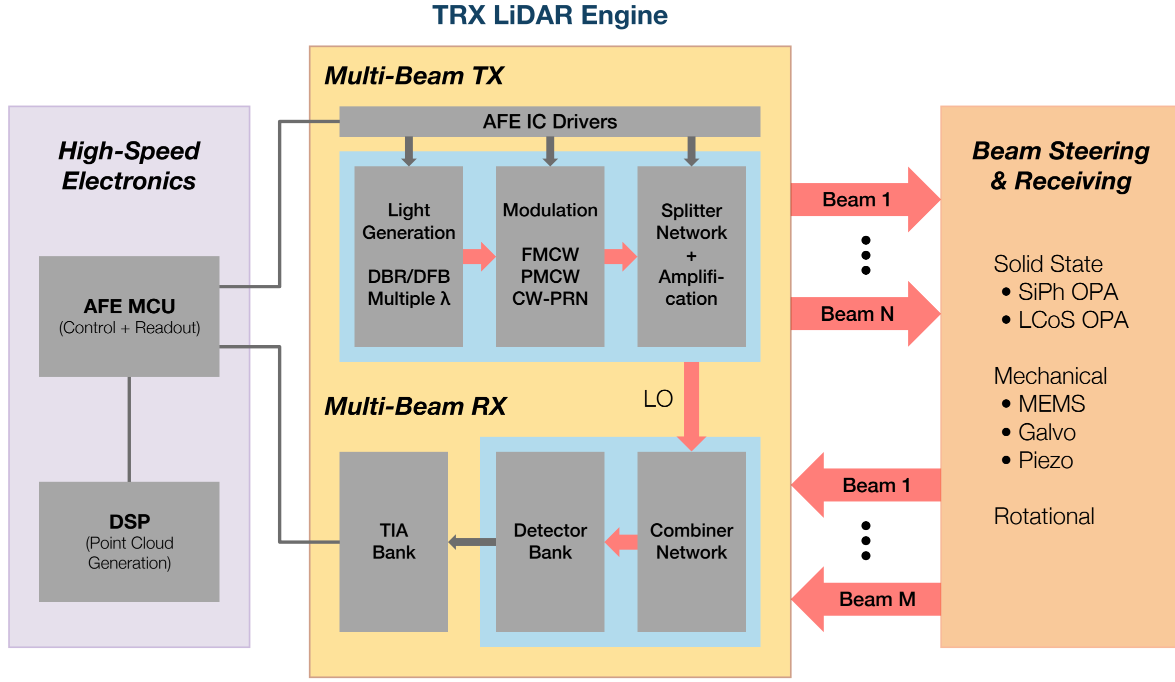


Figure 3: Block diagram of components needed, both optical and IC, to build a LiDAR engine.

Thus far, we have only discussed the components within the "TRX LiDAR Engine" shown in Figure 3. However, the silicon platform also has the potential of integrating solid state beam steering and receiving solutions, such as an optical phase array [19]. By using silicon photonics as a platform, combining key elements for the entire LiDAR solution is possible. The Rockley platform has ideal features that are key to enable this technology. The silicon waveguide size in the Rockley platform can handle very large powers needed for long range applications. The high-speed silicon phase shifters provide efficient scanning and large frame rates enabling the system to spend most of its time measuring and not steering. Scanning can also be achieved through using multiple wavelengths. The hybrid silicon platform allows Rockley to incorporate many wavelengths on a single chip, thus enabling novel beam steering solutions.

By integration of all optical components on a wafer-scale platform from the TRX engine to an OPA, the path toward simple manufacturing, scalability, high volume and low cost may be realized. Using longer wavelength infrared coherent LiDAR (e.g. 1550nm vs. ~900nm ToF) further improves the platform performance in eye safety, velocity measurements, resolution and range, getting the best of everything as we move to full autonomy. Lastly, integration also provides added reliability with fewer moving parts on the vehicle, something which is critical in this industry. Development of this platform can additionally enable solutions across a wide range of industries and markets, such as medical and consumer, that have needs in 3D sensing and imaging, and where it is desirable to further drive down cost.

Conclusion

3D sensing and imaging is a fast-growing market. LiDAR is one technology in this market poised to enable Level 4 and 5 autonomy. However, today's LiDAR solution is costly in both components and manufacturing requirements, limiting full adoption in the consumer market. Coherent LiDAR will likely disrupt the market, but only through improving both performance as well as cost and scalability. Silicon photonics is an ideal platform to cause such a disruption, much as silicon did in the electronics industry. Rockley's patented multi-micron waveguide technology is uniquely suited to the LiDAR market with its enhanced laser performance in power output and linewidth as well as its ability to fully integrate components onto a single platform.

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About Rockley Photonics

Rockley Photonics was formed in 2013 by an experienced management team, previously successful with two silicon photonics companies. Rockley Photonics has developed a highly versatile, third-generation silicon photonics platform specifically designed for the optical I/O challenges facing next-generation sensor systems and communications networks.

Rockley's photonic technology platform was developed with a total focus on high volume manufacture of highly integrated optical/electronic devices for high performance applications. The technology platform, exploiting optimized waveguide dimensions, offers significant benefits over conventional solutions. These benefits include the production of higher density optical circuits, the ability to create more complex integration, better manufacturing tolerances, superior power handling, lower loss and higher efficiency photonic IC interfaces. In summary, Rockley Photonics' technology can be adapted to be application specific, whilst simplifying manufacturing, assembly, test and validation, and optimizing power, size and cost of complex optical systems.

Rockley's founder, Andrew Rickman, is recognized across the industry for his technical and commercial success in silicon photonics. Andrew founded the first company to commercialize silicon photonics, Bookham Technology. Bookham had a successful IPO in 2000, became Oclaro in 2009 and is now a part of Lumentum. He later became the chairman of Kotura, which was successfully sold to Mellanox in 2013.