BluGlass Ltd.

Seizing the opportunity in laser diodes

Share Price: A$0.03

ASX: BLG
Sector: Technology
27 September 2022

BluGlass (ASX:BLG) is an Australian-headquartered laser diode manufacturer. Laser diodes are semiconductor devices that have a wide variety of applications, including in advanced manufacturing, cars, bio-medical devices, AR/VR displays and in scientific research. In the last 16 years, BluGlass has built up a tremendous body of expertise that can be leveraged to manufacture high-performance Gallium Nitride (GaN) laser diodes. It pivoted its business model to become a laser diode manufacturer to capture the significant opportunity in the GaN laser diode market.

This market is expected to grow by more than 23% annually to US$2.5bn by 2025, but is currently constrained by limited suppliers and lack of flexibility in terms of new product development and laser diode form factors. So, there is a large unmet need for GaN laser diodes.

Two game changers for the company

In the last 12 months, BLG has had two pivotal changes that will place it in good stead for commercialisation. The first was the purchase of a laser diode manufacturing facility in Fremont, California (USA), including key staff. This will enable the company to capitalise on the lack of design and manufacturing flexibility on the part of the incumbents. Having its own fab will give BLG full control over the wafer manufacturing process and should facilitate substantially higher gross margins and faster time to market once fully ramped up.

The second was the appointment of Jim Haden as company President. Mr Haden brings three decades of industry experience, leadership and an extensive customer network to the company. He has a proven track record of transitioning early-stage laser companies into industry leaders.

Proprietary technology is icing on the cake

While BLG will initially be manufacturing laser diodes using the current industry standard Metal Organic Chemical Vapour Deposition (MOCVD) manufacturing process, it aims to also use its proprietary Remote Plasma CVD (RPCVD) process to manufacture high-value green laser diodes in due course. RPCVD promises higher performing laser diodes while using less energy. We believe the combined strengths of the two can add substantial value to the company over time.

All the building blocks are now in place

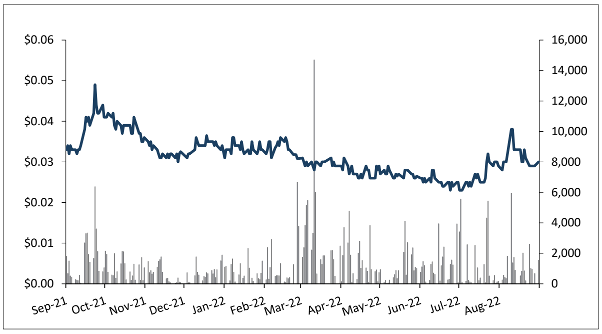
We believe all the building blocks that should enable the company to make a successful entry into the laser diode market are now in place.

We will endeavour to publish a full financial model and valuation in upcoming reports. Please see page 32 for a full risk analysis.

Market cap. (A$ m)	38.3
# shares outstanding (m)	1,275.8
# shares fully diluted (m)	1,456.1
Market cap ful. dil. (A$ m)	43.7
Free float	100.0%
12-months high/low (A$)	0.052 / 0.023
Avg. 12M daily volume ('1000)	1,279.4
Website	www.bluglass.com.au

Source: Company, Pitt Street Research

Share price (A$) and avg. daily volume (k, r.h.s.)



Source: Refinitiv Eikon, Pitt Street Research

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The BluGlass investment case

Through its Research & Development (R&D) work over the years in Light Emitting Diodes (LEDs) and microLEDs as well as its foundry work with EpiBlu, BluGlass (ASX:BLG) has built up a tremendous body of expertise that can be leveraged to manufacture high performance Gallium Nitride (GaN) laser diodes.

Getting its US production facility ready

To complement the company's existing wafer fab in Sydney, BluGlass is currently vertically integrating to bring downstream laser diode processing and packaging in-house across its two US-based locations, in the Boston area, New Hampshire and Fremont, California – where it will turn laser diode wafers into customer-ready products.

We believe vertically integrating enables BluGlass to capture a lucrative segment of the laser diode market. The Fremont fab was acquired in April 2022 at very attractive terms and we believe it will be a game changer for BLG when it comes to accelerating learning cycles when it reaches scalable manufacturing capacity. Once the Fremont fab is fully converted for GaN production, BLG should have US$160m in revenue capacity available.

Unlike LEDs, the laser diode market is not commoditised

Laser diode market is not commoditised, unlike LEDs

Laser diodes require highly specialised manufacturing processes, which enable manufacturers to distinguish themselves from their peers. As a consequence, this market is anything but commoditised, unlike the LED market. In other words, we believe BLG should be able to carve out a lucrative niche in the laser diode market.

Laser diode market growing >23% CAGR

Additionally, given the strong growth rate in the laser diodes market, i.e. >23% compounded annual growth rate though 2025, there is large unmet demand, even for mainstream laser diode products in a range of verticals, including Life Sciences, Industrial, Display, Defence and Research/Scientific. We also observe that laser diodes sell at a significant premium to LEDs – Fully processed LED wafers (normalised to 2" wafer size) yield ~US$60-$100 in revenue whereas laser diode wafers of the same size yield ~US$10,000-$20,000 in revenue.

Compared to incumbents, BLG has 3 main advantages

Although the industry incumbents include two large, established players, BLG should be able to compete in this market because of three distinct advantages:

Agile and flexible development and manufacturing

- **First,** the company is much more agile and flexible when it comes to new laser diode designs. Due to size of equipment and competing LED priorities, incumbents prefer to manufacture at large scale and have little to no room to address specific customer requirements when it comes to developing and testing new designs. This is a particularly important requirement for the Life Sciences and Research verticals that BLG is addressing.
- **Second**, over time BLG will position itself as a provider of the industry's 'easiest to use light', by offering laser diodes in a range of form factors, including multi-chip modules, and address unmet product/wavelength needs. Incumbents typically offer few wavelengths and limited form factors, called TO Cans, which can be costly and bulky for customers to integrate into their product specifications.
- **Third**, while BLG's initial product lines are grown using the industry standard Metal Organic Chemical Vapour Deposition (MOCVD) manufacturing process, its advanced roadmaps leverage its proprietary

Remote Plasma CVD (RPCVD) process to manufacture higher-value, higher-brightness laser diodes, including longer-wavelength products, such as green laser diodes in due course. The unique advantages of RPCVD manufacturing promise higher performing laser diodes (higher light output) while using less energy.

Ready for take off

BLG is currently putting the building blocks in place to be able to accommodate much of its future production requirements. With the potential to generate US$160m in revenues at its own Fremont fab, we believe BLG will have several years of ramp up runway as it commercialises.

We also believe the strengthened leadership team with the appointment of industry veterans Jim Haden as President, and Jean-Michel Pelaprat as Non-executive Director, is a game-changer for BluGlass, bringing rich industry experience, leadership and customer networks to the business.

Mr Haden has a demonstrated track record transforming advanced technology businesses from R&D and early-stage product development to profitable high-growth commercial entities.

Strengthened leadership team

In his most recent role at Soraa Laser Diode (now Kyocera-SLD), he was responsible for guiding operations and development teams, assisting in building rapid revenue growth, and ultimately the company's acquisition by Kyocera in January 2021. Prior to this, Mr Haden was Chief Operating Officer at nLIGHT helping transform the business form early-stage revenue generation to a market-leading position. During his time, he more than doubled revenue, delivered a four-fold increase in R&D return on investment, streamlined production management and improved manufacturing yields and cost margins, ultimately assisting the business to attract expansion capital of US$25m.

Mr Pelaprat brings deep photonics industry expertise, with over 30 years' experience establishing, commercialising, and scaling laser and semiconductor businesses. As co-founder and Director of NUBURU - a US-based company recognised as a pioneer in blue GaN lasers for industrial, medical, display, and 3D printing applications - Mr Pelaprat helped steer the business over the past six years from start-up to a recognised industry leader.

Before founding NUBURU, Mr Pelaprat held numerous leadership positions in high-growth photonics businesses, including President and CEO of Vytran, a fiber optics capital equipment company supplying optical communications, fiber lasers, medical devices, sensing and aerospace applications. He led the business to growth and profitability during the 2009-2010 recession and served on the Board of Vytran's parent company, NKT Photonics.

While BLG still needs to prove itself as a product company, we believe it is very well-positioned to make a successful entry into the high-growth GaN laser diode market.

We will endeavour to publish a full financial model and valuation in upcoming reports.

Who is BluGlass

BluGlass (ASX:BLG) is an Australia-owned semiconductor company servicing the global Gallium Nitride (GaN) photonics industry. With substantial experience in Light Emitting Diode (LED) manufacturing technology, the company has pivoted to the laser diode space. BLG has 93 internationally-granted patents in key semiconductor manufacturing jurisdictions.

The company aims to ensure that the next generation of photonics are smarter, cleaner and more efficient, driven by its proprietary semiconductor material growth technology, Remote Plasma Chemical Vapour Deposition (RPCVD).

A brief history

BLG was spun off from the Physics department of Macquarie University in 2005 and was listed on the ASX in 2006. It began its journey focussed on depositing GaN onto glass substrates to produce low-cost blue, green and white LEDs for general lighting applications. The plasma deposition process developed by BLG replaces ammonia gas as the source of active nitrogen with a nitrogen plasma, reducing one of the key costs and performance inhibitors for LED manufacturers.

Launch of the direct-to-market laser diode business unit to pivot from equipment and licensing model

In 2008, BLG opened its state-of-the-art semiconductor deposition and demonstration plant at Silverwater in Sydney. Its first commercial-scale semiconductor reactor was fitted with home-grown RPCVD technology at the Silverwater pilot LED demonstration plant. The company aimed to use the plant to achieve large cost benefits for LED device manufacturers.

By April 2018, BLG was commercialising its proprietary RPCVD equipment for the GaN-based LED, microLED and power electronics industries. The company has developed many unique technological advantages, including cascade LEDs, tunnel junctions, long-wavelength LED demonstrations and others. It has also made deep technological progress and created world-class epitaxy capabilities.

Pivoting to laser diodes

BLG's proprietary RPCVD technology is likely to help the company meet its milestones to produce cutting-edge laser diodes

At the end of 2019, BLG commenced its transition from an equipment and licensing model in the LED and microLED space to a product and device manufacturer. BLG implemented this pivot through the launch of its direct-to-market GaN laser diode business unit with the aim to capture 6-10% of the serviceable market in due course.

In 2020, BLG opened a laser diode testing facility in New Hampshire (USA) and commissioned the largest commercial-scale RPCVD manufacturing platform, the BLG-500. This modern generation platform was completed in collaboration with global semiconductor equipment leader AIXTRON. This was a key RPCVD scaling milestone and contributed significantly to BLG's commercial-scale activities.

BLG is taking rapid steps to create a commercially viable business in the laser diode industry

In the pivot to laser diodes, BLG aims to offer a full suite of plug-and-play and custom GaN laser solutions to several market segments, including the industrial, defence, display and scientific industries. The company will be providing bespoke solutions to customers through its end-to-end laser diode design, fabrication and packaging capabilities. It will offer a broad spectrum of wavelengths ranging from 405-450nm and beyond in both single and multi-mode options. Products will be available in a range of form-factors, e.g. individual chips, bars, chip on sub-mounts and multi-chip modules. BluGlass will offer customers small-batch development through to volume manufacturing.

Initial production using today's mainstream technology

BLG will combine MOCVD and RPCVD manufacturing processes

Initially, BLG will be offering laser diode products that are manufactured using today's mainstream manufacturing process, Metal Organic Chemical Vapour Deposition (MOCVD). BLG aims to start using its proprietary Remote Plasma CVD (RPCVD) process to manufacture the next generation of advanced GaN laser diodes.

To be clear, if BLG never introduced RPCVD production and stuck with MOCVD, it would still have a very compelling business model, with highly differentiated product offerings and high performing laser diodes. Laser diodes are highly intricate, complicated, and important devices, that are essential underpinning technologies enabling millions of devices today. BLG aims to manufacture laser diodes that are superior to today's GaN-based laser diodes.

BluGlass is vertically integrating its supply chain

The company opened its laser diode test facility in New Hampshire (USA) in June 2020. This facility supports BLG in managing its third-party fabrication (contract manufacturers) and supply chain processes, and completes device packaging and reliability testing prior to shipping. The manufacturing of the semiconductor materials (called epitaxy growth) for devices takes place at the Sydney facility. However, the company is currently using contract manufacturers for most of its downstream laser diode manufacturing steps.

The new Fremont facility is a game-changer for BLG

To bring the entire laser diode manufacturing process in-house, BLG acquired a 19,000 square ft (~1,765 square m) purpose-built commercial laser diode production facility in Fremont, California (USA) for US$2.5m in April 2022, a fraction of the +$US40M it would cost to build today. We believe that the addition of this fab will significantly expand BLG's capabilities and will fast-track the development timelines for laser diodes at different wavelengths.

BLG shipped its first fully packaged 405nm and 420nm single-mode and multi-mode laser prototypes for customer evaluation in June 2022. The products are in the alpha development phase and are being integrated and tested by customers.

With BLG's focus on laser diodes going forward, we expect the importance of the company's original activities, i.e. LEDs, microLEDs and EpiBlu, will gradually diminish over time. However, BLG's expertise in laser diodes is a direct result of the extensive R&D work that has been done in these areas for over a decade.

BLG's original LED and microLED portfolio

Importance of "legacy" activities to diminish over time

BLG has combined traditional manufacturing techniques with its unique low temperature, low resistivity nitride growth process to produce novel, LED and microLED devices (Figure 1) for high performance applications. RPCVD's lower temperature manufacturing process facilitates novel device architectures designed to address performance losses and improve performance of longer wavelength applications.

BLG's RPCVD tunnel junction technology provides further significant performance potential in several key applications by providing a path to higher efficiency laser diodes across the board.

Figure 1: BluGlass' customer microLED display

Source: Company

EpiBlu foundry services is another service offering

EpiBlu is BLG's services arm that offers specialised custom epitaxy, foundry and characterisation services. BLG works in close collaboration with its customers to provide a complete epitaxial solution from initial concept development to product prototyping, optimisation, intellectual property development and technology transfer. This paid development work has provided BluGlass with deep industry connections and honed its world-class epitaxy capabilities across numerous applications.

Seizing the opportunity in laser diodes

BLG has been in existence since 2005 and historically focussed on licensing revenue and providing semiconductor hardware (deposition reactors) to LED manufacturers. However, in the past two years, the company has pivoted to a product-oriented business in the laser diode market.

Leveraging its expertise in laser diode manufacturing

The rationale behind the pivot to laser diodes is to capitalise on the significant untapped opportunity in the high-value, high-margin and underserved laser diode market segment. The pivot also allows BLG to leverage its deep capability and expertise to address a very fast-growing market. Additionally, the laser diode market provides an easier path to commercialisation in terms of scale and capex requirements compared to the LED market.

BLG is well-placed to address unmet market needs

Laser diode incumbents are inflexible

Laser diode manufacturing is complex, providing significant barriers to entry for new players. As a result, there are very few end-to-end GaN laser diode manufacturers globally and requirements of many customers remain unaddressed. Often customers are looking for greater flexibility, faster development, enhanced performance, and lower cost solutions. The existing large players do not provide sufficient form factor flexibility[1] and supply in several wavelengths are constrained. Consequently, end-customers need to undertake significant customisation and post-purchase packaging. BLG is looking to address these needs and is developing product offerings together with its customers in several of its target segments. The aim is to provide enhanced plug-and-play offerings along with customised solutions to the market.

Figure 2: BluGlass' initial target markets

Source: Company

[1] Form factors refer to the shape, size, interface and other physical components of the laser. It also includes how the laser electrically and physically connects to a system, and whether the light is delivered through a fiber, or straight from the emitter itself.

Currently, BLG is addressing unmet customer needs across violet and blue (405-450nm) laser diodes with several form factor offerings. It is targeting in-demand and under-served wavelengths for use in industrial, display, defence and scientific application sectors. In the long run, it plans to offer an expanded range of wavelengths, form factors and package integration options, which will in part be facilitated by its proprietary RPCVD process.

BLG aims to create a diversified product portfolio

The company will be primarily targeting the industrial, scientific, and biotech verticals, which focus on applications such as industrial cutting and welding for high tech applications (such as chip manufacturing, EV and renewable energy battery storage etc), 3D printing, quantum computing and medical diagnostics. These three verticals are expected to grow to US$735m in size by 2025 (Figure 2).

Carving out its place in the laser diode market

Before we delve into BLG's product lines, it is vital to understand the different types of laser diodes.

Laser diodes can be classified into infrared, red, green, blue, violet and ultra-violet by wavelength, measured in nanometres (nm). A laser diode's wavelength is determined by the semiconductor material used and determines the colour and visibility of the light beam. Wavelengths of laser diodes fall into the following categories:

Green laser diodes offer significant advantages in terms of efficiency, size and direct modulation

- **Infrared (Gallium Arsenide GaAs) laser diodes.** These are electronic components converting electric current into electromagnetic radiation, which emits a wavelength between visible light and microwave radiation. Infrared is the portion of the electromagnetic band, which is shorter wavelength than radio waves, but longer wavelength than rainbow red in the visible spectrum. Infrared laser diodes provide light used for solid state laser pumping in optical fibre networks, scientific spectral analysis and materials processing.
- **Red laser diodes.** These are available in different power output levels, ranging from a few milliwatts (such as single emitters) to 100 watts from diode bars.
- **Green laser diodes. Gallium Nitride** semiconductors with quantum wells containing high percentages of indium, a rare post-transition metal, are used for green laser diodes. The light produced has a wavelength between 520nm and 540nm. Green laser diodes are small in size and can be directly modulated.
- **Blue laser diodes.** GaN blue laser diodes are high-value and high-margin products. They emit light in a wavelength range of 420nm to 499nm. They are usually fabricated from aluminium gallium nitride or aluminium indium gallium nitride. Blue laser gallium nitride diodes are powerful and efficient, creating new opportunities for applications ranging from medical and stage lighting, to manufacturing and automotive. A key advantage of blue laser diodes over infrared laser diodes is that the latter requires almost 10-15 times the output power of blue lasers for processing of copper, required for welding of lithium-ion batteries. The higher absorption of blue light enables manufacturers to use lower power resulting in a more controlled process ensuring a smooth welding seam.
- **Violet laser diodes.** These are monochromatic in nature and emit light in a wavelength range of 395nm to 415nm, depending on the specifications of the individual diode. In comparison with other laser diodes, violet laser diodes are relatively economical, compact and efficient. Violet laser diodes are used in optical storage applications. They are also useful as replacement laser sources for krypton-ion lasers on stream-in-air cytometers[2].
- **Ultra-violet laser diodes.** Short wavelength laser diodes are being developed for UV disinfection and water treatment applications, with increased significance following the COVID outbreak. Ultraviolet (UV) radiation is highly effective in disinfecting surfaces, water, and air. UV light is used to disinfect water and in wastewater treatment. Because UV disinfection is a physical process and does not require adding any chemicals to the water to clean it, it can be a very safe and effective

[2] Cytometry is the measure of the number and characteristics of cells. Variables that can be measured by cytometric methods include cell size, cell count, cell morphology, cell cycle phase, DNA content and the existence or absence of specific proteins on the cell surface or in the cytoplasm.

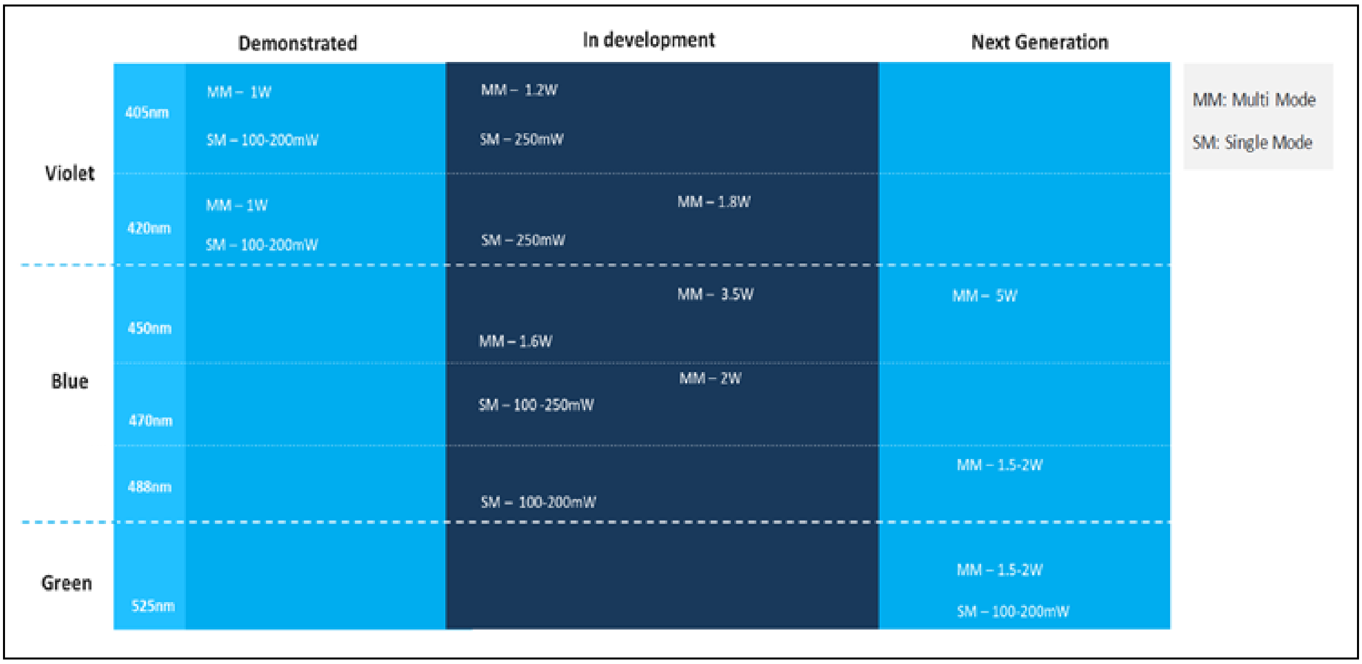
option. UV light can reduce the incidence of parasites, viruses and spore pathogens; such as cryptosporidia or giardia, which can be resistant even to chemical disinfection, viruses and spore pathogens. One facility in New York uses UV light to treat more than 2 billion gallons of water a day for use in New York City.

UV light is also widely used in disinfecting surfaces and equipment in healthcare, food and beverage and other production facilities. UV light can destroy active viruses and other pathogens on a surface in just a matter of seconds. In this case, UV devices in healthcare facilities are much more efficient and effective than other cleaning and disinfecting options.

BLG intends to offer a range of laser diode products, including the standard MOCVD-manufactured laser diodes and differentiated RPCVD laser diodes across a broad spectrum of wavelengths, ranging from 405nm to 450nm in both single and multi-mode (Figure 3).

Products will range from individual chips, bars, chips-on-sub-mounts, multi-chip modules and can be provided from small-batch development to volume production.

Figure 3: BLG's product development pipeline



Source: Company

Although BLG will initially focus on offering violet and blue laser diodes of 405-450nm wavelengths using MOCVD manufacturing, its long-term ambition is to expand into green laser diodes using its proprietary RPCVD process.

The company is also looking to develop novel laser architectures, leveraging its proprietary RPCVD and tunnel junction technology, to achieve brighter, higher efficiency and higher power laser light, in particular for longer wavelength devices (green).

BLG has launched alpha products and is working with several customers testing the prototypes

First prototype products shipped

In June 2022, BLG shipped its first fully packaged laser diode prototypes for customer evaluation. The company's 405nm and 420nm alpha products can now be integrated and tested by customers within their product designs and development cycles.

An alpha product is an advanced prototype that is still in the design phase. It is primarily used to collect customer feedback in real-world applications. BLG would incorporate such feedback before locking in product design for beta production and subsequent mass production. Once designs are locked in it becomes significantly more expensive to implement design changes, hence the importance of customer feedback during the alpha stage.

The company is also working with several customers who want to trial its alpha products in fields such as medical devices, sensing, quantum computing and automotive. The fact that customers are eager to receive BLG's alpha products ahead of its full product launch is indicative of the significant unmet demand within the 405nm and 420nm wavelengths.

The new Fremont facility is a game changer

BLG acquired a full suite laser diode front and back end fab

In April 2022, BLG acquired a 19,000 square ft (~1,765 square m) commercial laser diode production facility along with manufacturing equipment in Silicon Valley for US$2.5m - a fraction of the cost it would take to build today. We strongly believe that the Fremont fab is going be a game changer for BLG for a number of reasons.

1. The Fremont fab will fast track BLG's long-term strategy

The Fremont fab acquisition is in line with the company's long-term strategy of bringing key fabrication processes in-house. This should enable BLG to improve end-product quality and maintain consistency in its GaN laser diodes.

The addition of the fab facility is expected to significantly expand BLG's manufacturing capability and would fast-track the development timelines for higher-value products at extended wavelengths.

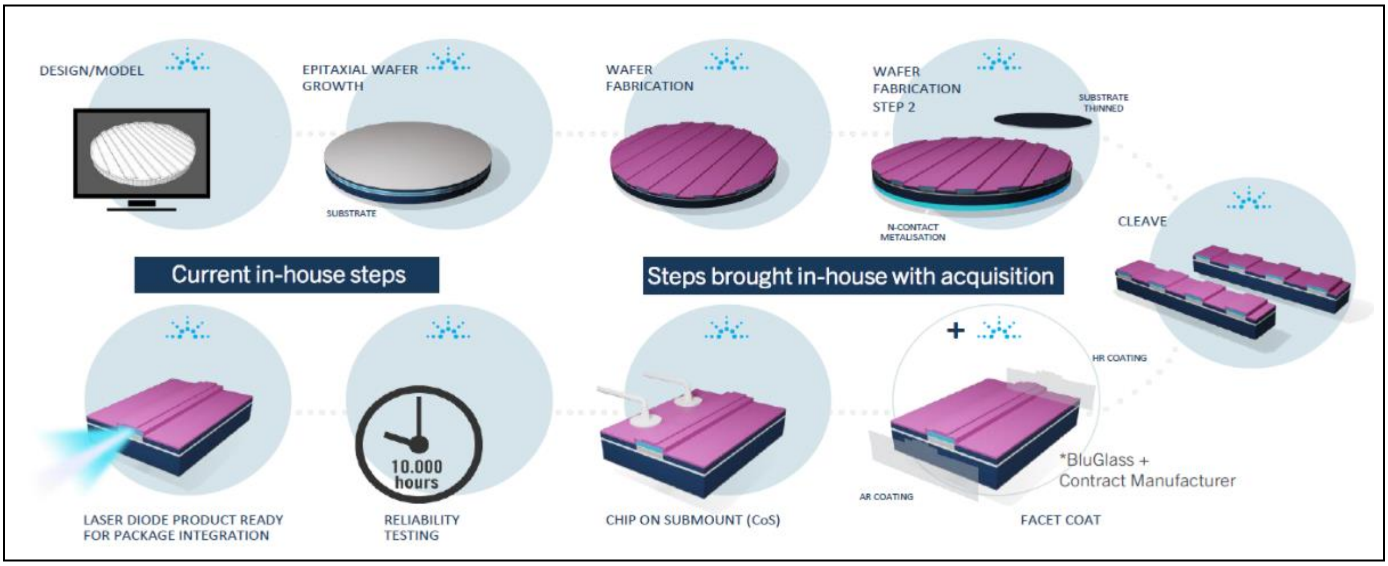
2. The Fremont fab will expedite development cycles

Simply put, BLG will now be able to carry out all the processing steps in-house (Figure 4). Prior to the acquisition, BLG performed four of the nine manufacturing steps in-house (designing and performing epitaxial growth on GaN substrates and undertaking performance and reliability testing) and outsourced the remaining steps to contract manufacturers (including wafer fabrication and chip on-sub-mount packaging).

Better process control and faster development cycles

The move to in-house will eliminate supply chain variability, improve laser diode quality and provide BLG with greater control over product development, which should eventually help the company in launching more products at a faster pace.

Figure 4: BLG's post acquisition laser diode supply chain



Source: Company

3. Simpler supply chain and lower wafer costs

The acquisition is expected to simplify its supply chain complexity and reduce wafer production costs significantly. It will also result in improved quality control, operational consistency, and higher yields. Further, the fab would accelerate higher value product pipeline.

Better access to Tech talent

Additionally, in our view the acquisition provides access to a large single-location talent pool in Silicon Valley with highly skilled semiconductor and GaN experts.

Closer to customers

BLG's US presence places the company in a much better position to win US defence and government contracts. At the same time, the company will be closer to potential customers across key target markets of miniaturised medical diagnostic devices, LiDAR sensors and augmented reality/virtual reality systems.

4. Moving to captive facility will enhance production flexibility

BLG plans to exploit the rapidly growing GaN laser diode industry, which is expected to become a US$2.5bn industry by 2025. For this, it first needs to be well placed in terms of production capacity and speed. Outsourcing part of the manufacturing process limits BLG's ability to solve technical challenges, work on product enhancement and restricts innovation capabilities. Outsourcing also entails higher production costs, which eventually results in lower profit margins.

4-8x faster turnaround means more products and greater manufacturing flexibility

With the acquisition of the Silicon Valley fab comes greater flexibility and enhanced performance along with lower costs and better margins. Moving the fabrication process in-house would result in 4-8x faster turns and development cycles.

The number of development cycles is limited to 4-5 development iterations/year under its contract manufacturers. The development of a new chip or enhanced product design often requires multiple iterations. The captive fab will allow BLG to complete design iterations more quickly since full iterations will have a faster turnaround time of about three weeks, which will allow up to 48 development iterations/year.

As the company will be able to do more development runs, it will be able to produce different products faster, at a lower cost and with higher margins.

The ability to accelerate the development cycles of core design features is very important for BLG as it is now looking to finalise product designs and release beta products.

How a proprietary fab will impact the top and bottom lines

In-house production significantly reduces manufacturing costs and enhances profitability

Once it is properly scaled up, the Fremont fab should substantially improve BLG's top and bottom lines compared to a situation where the company largely continued to depend on contract manufacturing.

It should boost the company's revenue generation capacity from US$40m to US$160m annually, a c.300% increase. The annual wafer capacity is likely to increase fourfold — from c.2,500 wafers to c.10,000 wafers annually (matching the Company's Silverwater epitaxy capacity perfectly). Production costs are expected to come down as well, which could boost the gross margin from 30% to as high as 45% (Figure 5).

Figure 5: The Silicon Valley fab acquisition improves BluGlass' financials

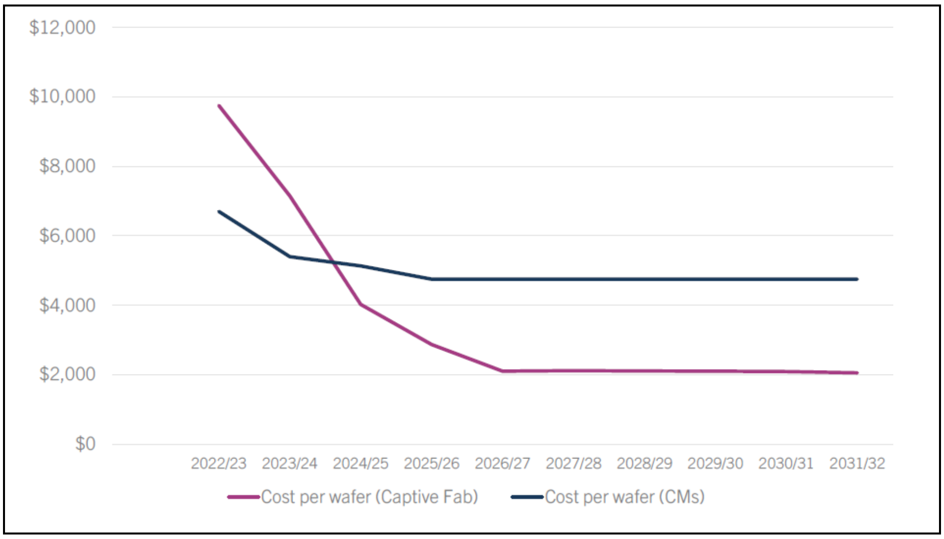
Contract Manufacturer Capacity		Owned-Fab Capacity	
Annual Epitaxy Wafer Capacity (Silverwater)	~10,000 wafers	Annual Epitaxy Wafer Capacity (Silverwater)	~10,000 wafers
Annual Wafer Fabrication Capacity	~2,500 wafers	Annual Wafer Fabrication Capacity	~10,000 wafers
Annual Development Iteration Capacity	~4-5 full iterations + 10's of short loops	Annual Development Iteration Capacity	Up to 48 full iterations + 100's of short loops
Annual Revenue Capacity	~US$40M	Annual Revenue Capacity	~US$160M
Estimated Gross Margin	~30%	Estimated Gross Margin	~45%
		Cash Flow Positive	2024/2025

Source: Company

The wafer fabrication cost is expected to reduce significantly

BLG expects wafer production costs to halve once the Fremont facility becomes fully operational. Although initially the additional cost associated with operating the facility will lead to an increase in the cost/wafer ratio, it will eventually fall as production scales up given the fixed cost nature of the fab and manufacturing equipment. Management expects the production cost crossover will likely be reached in 2024 (Figure 6).

Figure 6: Wafer fabrication costs (front and back end)



Source: Company

Remaining work to get the fab fully operational

BLG is in its last steps to get the Fremont fab operational

The Silicon Valley fab previously manufactured indium phosphide laser diodes. BLG is in the advanced stages of adapting the facility for GaN laser diode manufacturing. Besides the US$2.5m investment already made towards acquiring the facility, the company plans to invest an additional US$1.8m to adapt the facility to GaN laser diode production.

BLG also acquired several experienced manufacturing staff with the fab, hiring key personnel, such as laser fabrication engineers, wafer processing technicians, a Director of Operations and adding an expert GaN laser diode scientist. BluGlass is in the process of bringing the fab online and will continue operations with its contract manufacturers to launch initial products to market. BluGlass anticipates working with some CMs until Q2 CY23 as it brings Fremont up-to-speed.

The Company recently announced (21 September) that production fab now has several operational manufacturing processes for GaN laser diode development and is contributing to the Company's technical roadmaps. GaN wafers shipped from BluGlass' Silverwater facility have commenced processing steps at the Fremont fab, complementing and accelerating the Company's contract manufacturing development.

The fab is also being utilised for short-loop development cycles, enabling BluGlass to test iterations of the key components of laser diodes – metals, facets, and bonds - without requiring a full product. These in-house short-loops can be completed many times faster than processing cycles through contract manufacturers.

The company has obtained all the necessary Environmental Protection Authority (EPA), air quality and waste management permits that allows it to operate the facility.

BLG's President is a seasoned industry veteran

The other game-changing move for the company was the appointment of Jim Haden as BluGlass President with his industry experience, leadership and customer network. Any company will tell you that new hires have all that, but Mr Haden has something particularly valuable for BluGlass. Namely, a demonstrated track record transforming advanced technology businesses from R&D and early-stage product development to profitable high-growth commercial entities, including GaN laser companies.

In his most recent role at Soraa Laser Diode, he was responsible for guiding operations and development teams to stabilise, improve and ramp high-power blue GaN lasers and associated packaging, which enhanced thermal, electrical and optical performance and greatly improved manufacturing yields. This product development delivered several big-name customers, including BMW, rapid revenue growth and, ultimately, the company's acquisition by Kyocera in January 2021.

Prior to this, Mr Haden was Chief Operating Officer at nLIGHT helping transform the business from early-stage revenue generation to a market-leading position. During his time, he more than doubled revenue, delivered a four-fold increase in R&D return on investment, streamlined production management and improved manufacturing yields and cost margins, ultimately assisting the business to attract expansion capital of US$25m. Mr Haden's other roles include Director of Operations and Product Line Management at Coherent Incorporation, Director of operations at JDS Uniphase and Director of Operations at Spectra Diode Lasers (acquired by JDS Uniphase for US$41bn).

The market for GaN laser diodes is growing fast

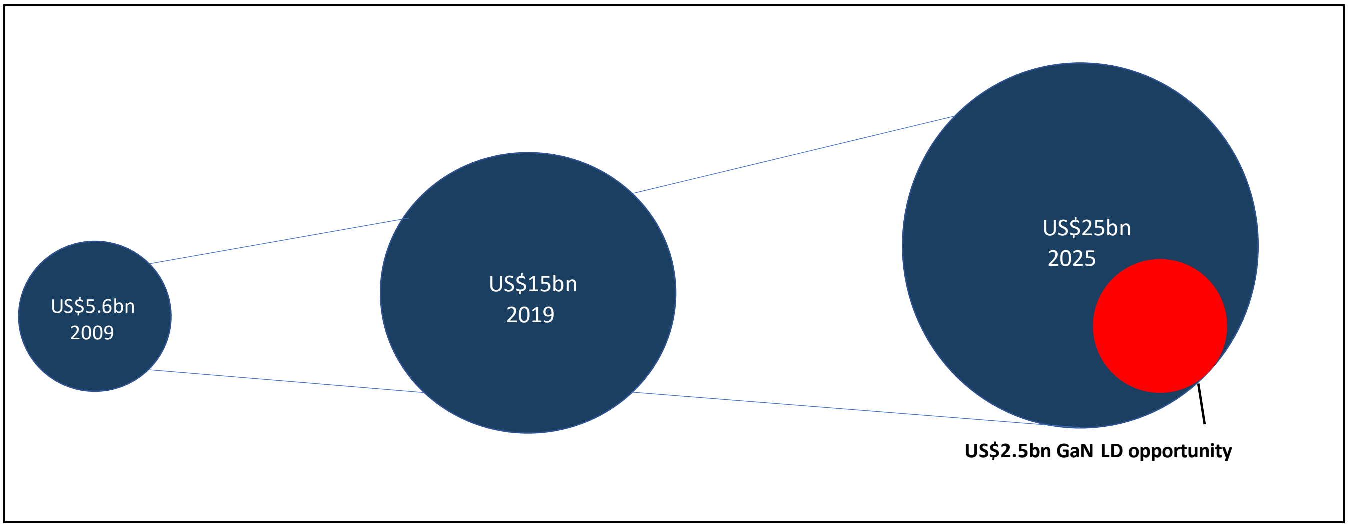
GaN laser diodes have wide ranging applications across generic and specialised needs. They offer significant advantages over conventional lasers such as small size, lightweight, wide-angle beam as well as low current, voltage and power requirements. Consequently, the growth prospects for the GaN laser diode market are highly promising.

Robust growth is expected in GaN laser diodes market

GaN laser diode market represents an emerging market opportunity that is likely to grow to US$2.5bn by 2025

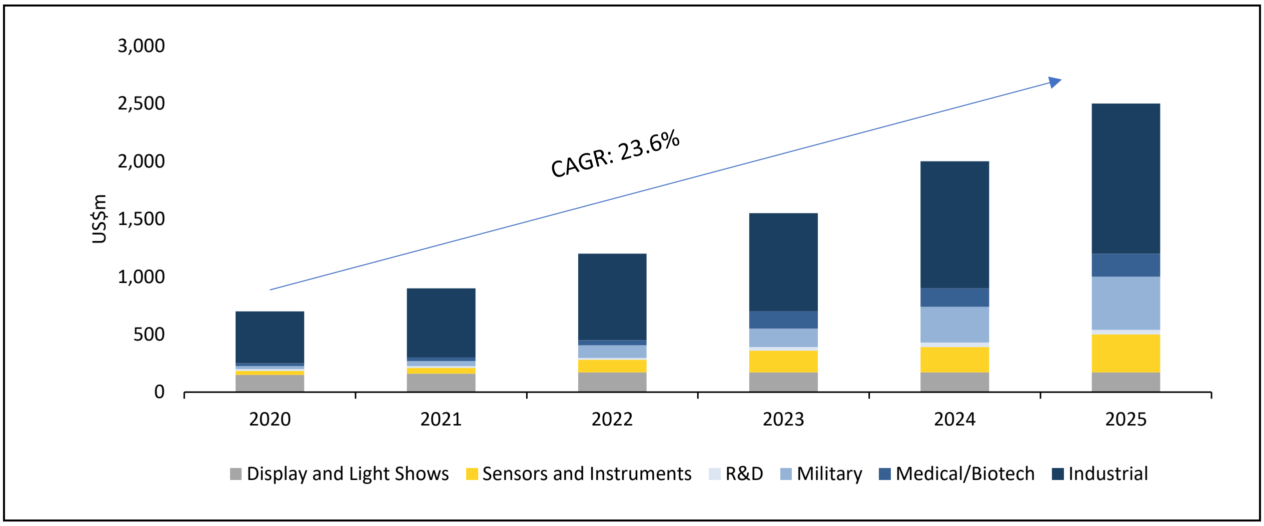
The total global market for laser applications is likely to surpass US$25bn by 2025 (Figure 7). Of this total market, about 10%, or US$2.5bn, can be attributable to GaN laser diodes. While the industrial segment will remain a dominant customer for GaN laser diodes, demand from military, AR/VR, scientific and bio-medical segments is expected to grow significantly (Figure 8).

Figure 7: Global laser revenue growth trajectory



Source: Strategies Unlimited, Company, Pitt Street Research

Figure 8: GaN laser diode revenue breakdown by segment



Source: Strategies Unlimited, Company, Pitt Street Research

GaN laser diodes and LEDs vary in value, margins and strategy for market entry, though both are semiconductor devices constructed using the same III-nitride materials. However, the internal epitaxial structures employed are different, combined with highly specialised post-growth production required to give laser diodes their different light characteristics, intensities and applications. We will elaborate on this in a subsequent chapter.

The key growth drivers for laser diodes market

Strong growth in the laser diode market is anticipated due to the following factors:

- **Deployment of laser diodes in material processing applications.** Demand for GaN laser diodes is gaining momentum, with material processing forming an important part in the automotive, aerospace, heavy engineering, and consumer electronics manufacturing industries.
- **Increasing investment towards the development and production of autonomous vehicles.** A key factor driving the laser diode market is the higher usage of laser diodes in autonomous vehicles for light detection and ranging (LiDAR) and radar systems. A LiDAR system serves as the eyes of a vehicle and performs regular checks on its surrounding environment to ensure that the vehicle is safely guided to its destination. Currently, combinations of LiDAR, radar and cameras are being used by many self-driving vehicles to create a 3D map of the surroundings.

Growing investments in autonomous vehicles is likely to be a key demand driver

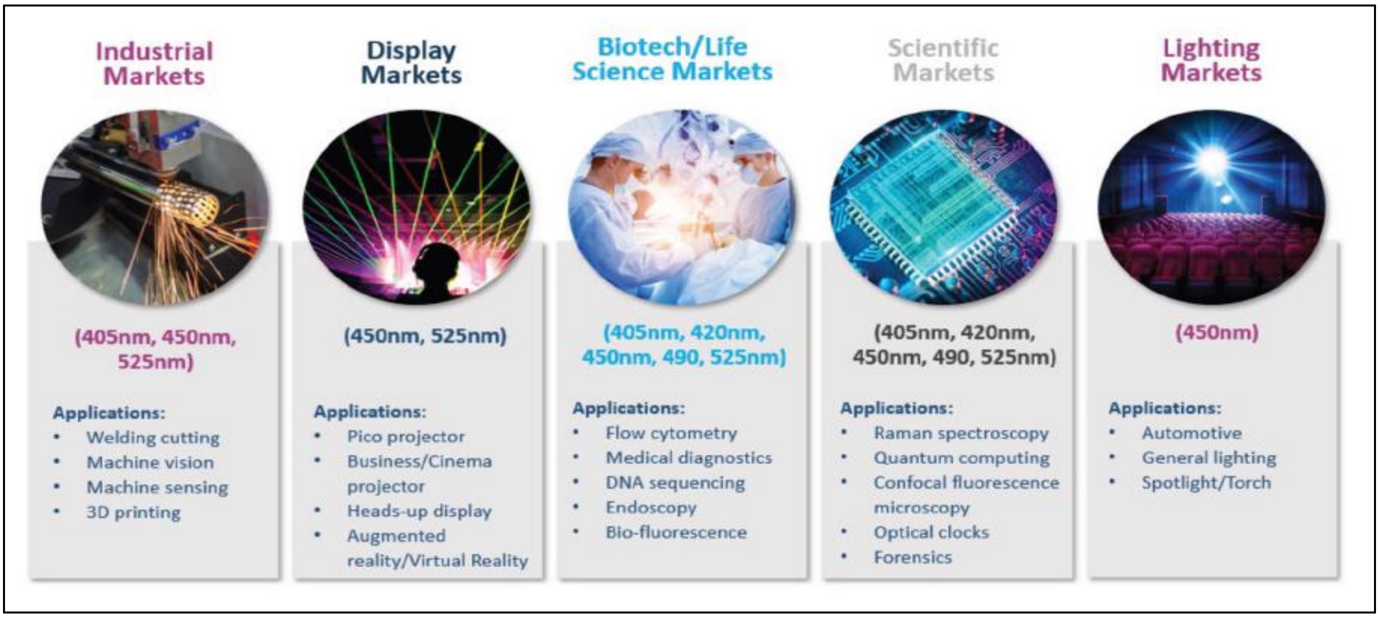
- **Expanding directed energy application of laser diodes.** An increasing use of directed energy (DE) applications has been witnessed recently, with continuous evolution in the diverse requirements and technology.
- **Miniaturisation of headlights in automobiles.** Increasingly, car manufacturers are focussing on the miniaturisation of headlight systems without compromising on light intensity. This is likely to result in increasing adoption of automobile laser headlamps, boosting demand for laser diodes.
- **Technological innovations.** Constant innovations in the laser diode space are likely to boost convenience, accuracy and endurance of these devices.

Multitude of end-market applications

Revenue capacity of US$160m in the medium term

There are numerous growing end markets for laser diodes (Figure 9), but BLG's management is clear that its initial target segments will be the industrial, scientific and biotech end markets. Thus, the serviceable addressable market opportunity for BLG based on these three segments is estimated to be US$380m currently and this is forecasted to grow to US$735m by 2025 (~14% CAGR). Management further estimates that once the manufacturing process is fully set up, it will have the capability to target US$160m in revenue in the medium term.

Figure 9: Laser diodes have application in numerous end markets



Source: Company, Pitt Street Research

BLG's blue lasers could take significant market share

GaN blue laser diodes create new opportunities in medical, manufacturing and automotive applications

BLG is anticipating strong demand from the industrial segment on the back of preference for blue laser diodes for additive manufacturing. This segment is currently served by infrared laser light and research shows that a base metal such as copper can absorb ~5% of infrared light compared to ~65% absorption of blue laser light. Thus, as BLG's blue laser diodes gain reliability, the company and its customers are expected to take market share from fibre lasers.

The other end markets that excite us are the use of BLG's laser diodes for quantum clocks that are vital for autonomous vehicles, and biotech applications that need to be highly sophisticated and customised. The laser diode incumbents are not particularly keen on working with customers in their research and development phase due to their advanced requirements and many design phases. This provides opportunities for new market entrants, such as BLG.

Two main peers in the laser diode market

BLG is one of only a handful of end-to-end GaN laser diode manufacturers globally and faces competition from two global players, Nichia (Japan) and OSRAM (Germany). Both provide laser diodes as a part of broader product portfolios comprising highly commoditised products, such as LEDs.

We also note Kyocera SLD (KSLD) (US) is a GaN manufacturer but it is not a direct competitor as it is mainly focussing on generating white light from blue laser diodes because it has developed its own unique technology for night vision purposes. A broad comparison of the key competitors in this space is provided in Figure 10.

Figure 10: Comparison snapshot of key GaN laser diode manufacturers

	BluGlass	Nichia	OSRAM	KSLD
Size/market presence	It has not yet reached the commercialisation stage of laser diodes	Largest player in GaN laser diodes	~US$3.4bn in revenue from laser-related businesses	~US$780m in revenue from laser-related businesses
Wavelength range of laser diodes	It has expanded from violet to blue laser diodes but currently does not produce green laser diodes	Capability to produce laser diodes of violet, blue and green wavelengths but does not focus regularly on products of 420nm wavelength	Capability to produce laser diodes of violet, blue and green wavelengths but does not focus regularly on products of 420nm wavelength	Produces only white light using blue laser diodes
Product focus	Pivoting its strategy to laser diodes and moving away from LEDs and micro-LEDs	Main focus is on high-volume low-mix business	Main focus is on high-volume low-mix business; also, slowly shifting focus on the LED market	Focussed on white light applications
Segment focus	Industrial, scientific and biotech	Display and industrial; not actively targeting scientific and biotech segments	Display and industrial; not actively targeting scientific and biotech segments	Mainly lighting applications
Mode of laser diode	Single and multi-mode blue laser diodes	Single and multi-mode blue laser diodes	Multi-mode blue laser diodes	Generation of white light using multi-mode blue laser diodes
Form factor	Flexibility in form factor	Limited form factors	Limited form factors	Limited form factors
RPCVD technology	Low temperature, low hydrogen RPCVD technology helps achieve brighter, more cost-effective laser diodes	Does not use technology similar to RPCVD	Does not use technology similar to RPCVD	Does not use technology similar to RPCVD
Cost efficiencies	Focussing on cost efficiencies through use of the RPCVD technology	Generating cost efficiencies through scale	Generating cost efficiencies by leveraging low-cost, mid-power packaging technology with high-power chips	Focussing on manufacturing efficiencies of white light
Reliability	Yet to achieve high level of reliability for blue laser diodes in its end markets	Its 1W continuous wave GaN-based laser diode of 445nm is highly reliable due to its high power, high efficiency and long life	Its advanced packaging technology helps ensure robust reliability; further, its 520nm green laser diodes are designed and manufactured to ensure long-term reliability	Incorporates the innovative semi-polar GaN laser technology enabling industry leading performance and reliability

Source: Company, Pitt Street Research

Nichia

Over the years, Nichia has grown through the development, manufacture and sale of fine chemicals, particularly inorganic luminescent materials (phosphors). It successfully developed the world's first high luminous blue LED, in turn becoming the global pioneer in the blue LED and laser diode domain.

Nichia's invention of nitride-based LEDs and laser diodes have resulted in innovation of light source in display applications

Subsequently, it developed the world's first white LED by combining yellow phosphor and blue LEDs. Diversification in wavelength range and enhancement in optical output power have further enabled Nichia to successfully develop GaN-based laser diodes. Nichia has created violet laser diodes with pulsed operation and continuous wave operation. Subsequently, Nichia expanded its emission wavelength from the UV-A region to the visible blue and green regions.

The invention of nitride-based LED and laser diodes by Nichia has resulted in technological innovation of light sources in areas such as display, general lighting, automotive, industrial equipment and medical devices. Among these areas, Nichia is heavily focussed on the display segment in the high-volume, low-mix business.

Nichia's strengths over BLG

- Global leader in blue LED and laser diode industry
- Capability to produce violet, blue and green laser diodes.
- Largest competitor with substantial revenue and capital base, and deep marketing network.
- Pioneer in GaN laser diodes field with a strong R&D focus.
- High reliability of its multimode continuous wave pure blue GaN- based laser diode with 445nm wavelength due to its high power, high efficiency and long life.

Weaknesses that BLG can take advantage of

- Lack of a technology, such as RPCVD, that employs a low-temperature manufacturing process with low level of hydrogen requirement.
- Lack of flexibility in form factors. As a result, customers have unmet requirements and need to undertake significant and expensive customisation processes.
- It is underserving certain wavelengths in industrial design, scientific and biotech applications. Certain customers have expressed interest in shifting from Nichia to BLG as the former does not focus on products at the 420nm wavelength.

OSRAM

OSRAM offers top-quality solutions in sensor technology and laser systems with its expertise ranging from basic semiconductor technologies to individual customer applications. OSRAM's Semiconductors Automotive business is a global leader in automotive LED lighting for exterior and interior lighting applications.

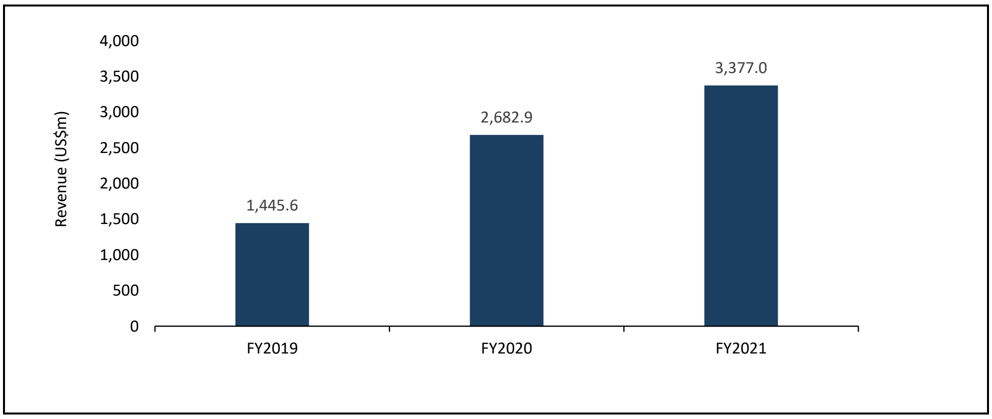
Its Semiconductors Consumer business supplies sophisticated sensing and optical solutions used in smartphones and consumer devices. OSRAM also provides blue multi-mode laser diodes for industrial and automotive applications. Furthermore, OSRAM's product portfolio includes green laser diodes (used in pico projectors).

Impact of consolidation following the acquisition by ams boosted the company's performance in 2020 and 2021

The revenue base of OSRAM's segments relevant to laser applications has grown rapidly from ~US$1.4bn in 2019 to ~US$3.4bn in 2021, on the back of industry growth as well as acquisitions (see Figure 11).

In FY19, its top line was mainly driven by a robust performance of the consumer segment and solid demand from automotive, industry and medical segments. In FY20, the group revenue increased to reflect the impact of OSRAM's consolidation for six months following its acquisition by ams. This outweighed the impact of the COVID-19 pandemic. In FY21, OSRAM's revenue base grew against the backdrop of significant growth in the global semiconductor market. Moreover, this strong revenue growth reflected the impact of OSRAM's consolidation for the entire 12 months for the first time in 2021.

Figure 11: OSRAM's revenue base has grown rapidly



OSRAM's latest fiscal year represents the period from January 2021 to December 2021

Revenue represents sales of the Consumer segment in 2019, and that of the Semiconductor segment in 2020 and 2021 following the acquisition by ams

Source: Pitt Street Research

OSRAM's strengths over BLG

– Like Nichia, it is global leader in the LED industry.

– It has capability to produce laser diodes across violet, blue and green wavelengths.

– A strong financial base, customer relationships and marketing network.

– Solid R&D investments which have paved the way for its subsidiary OSRAM Opto Semiconductor to set international standards in the field of illumination, visualisation and sensor technology.

– Robust reliability owing to its advanced packaging technology. The technology's reliability is close to that offered by ceramic packages used traditionally with high-power chips. Additionally, its 520nm laser diodes are designed to ensure reliability in the long term.

Weaknesses that BLG can take advantage of

OSRAM's focus remains in the LED and microLED market, lack of flexibility in form factors and underserving certain segments can be potential opportunities for BLG

– Gradually, shifting focus to the microLED market and reducing emphasis on laser diodes. Lack of investment in the high-mix, low-volume segment due to the company's focus on high-volume, low-mix segments.

– Lack of a technology such as RPCVD that can make the manufacturing process of laser diodes more cost and resource efficient.

– Lack of flexibility in form factors.

– Not focussed on certain wavelengths in industrial design, scientific and biotech applications that will require greater specialisation or customisation.

Kyocera SLD (KSLD)

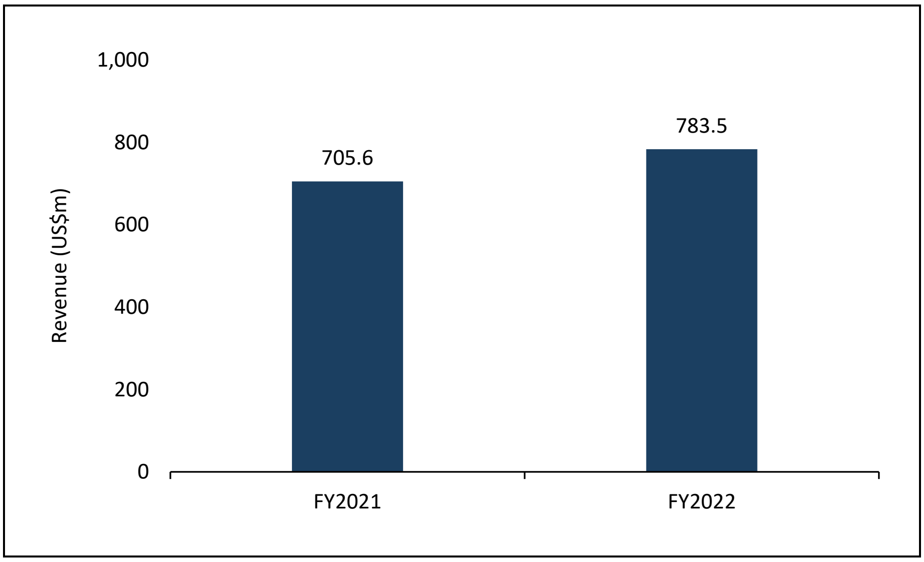
In January 2021, Kyocera acquired SLD Laser to become KSLD, a world leader in commercialisation of GaN-based laser light sources. The integration of SLD's advanced GaN expertise with Kyocera's production technologies and R&D capabilities in fine ceramic-related businesses is likely to culminate in positive synergies for the combined entity.

KSLD uses high brightness outputs from blue laser diodes and a phosphor wavelength converter to produce its white light offerings

KSLD is engaged in the commercialisation of revolutionary semi-polar GaN laser light for display and automotive applications. Laser light sources are used directly in single colour and red-green-blue applications or embedded in phosphor architectures pumped by lasers. The laser light technology has been invented and commercialised by KSLD through the combination of high brightness outputs from blue laser diodes and a phosphor wavelength converter. With the converter, some of the blue light can be converted to yellow light with the resulting output being a bright safe white light.

KSLD's revenue declined in FY21 due to effects of the COVID-19 pandemic and aggressive capital expenditures culminating in increased depreciation charges. In FY22, an improvement in business environment and higher demand for components from the 5G and semiconductor related markets resulted in a recovery in the revenue growth of the company (Figure 12).

Figure 12: KSLD's revenue growth recovered in 2022



KSLD's latest fiscal year represents the period from April 2021 to March 2022

Source: Pitt Street Research

KSLD's strengths over BLG

- Established company with strong financial base and marketing network.
- High reliability of its products. KSLD uses the innovative semi-polar GaN laser technology enabling industry-leading performance and reliability.
- Potential to move into new target markets via acquisitions.

Weaknesses that BLG can take advantage of

- Focus on white light only for applications mainly in the lighting and automotive segments.
- Lack of single mode products in the portfolio.

Laser diodes 101: Shining a light on complex technology

RPCVD is expected to bring substantial performance improvements to the laser diode market

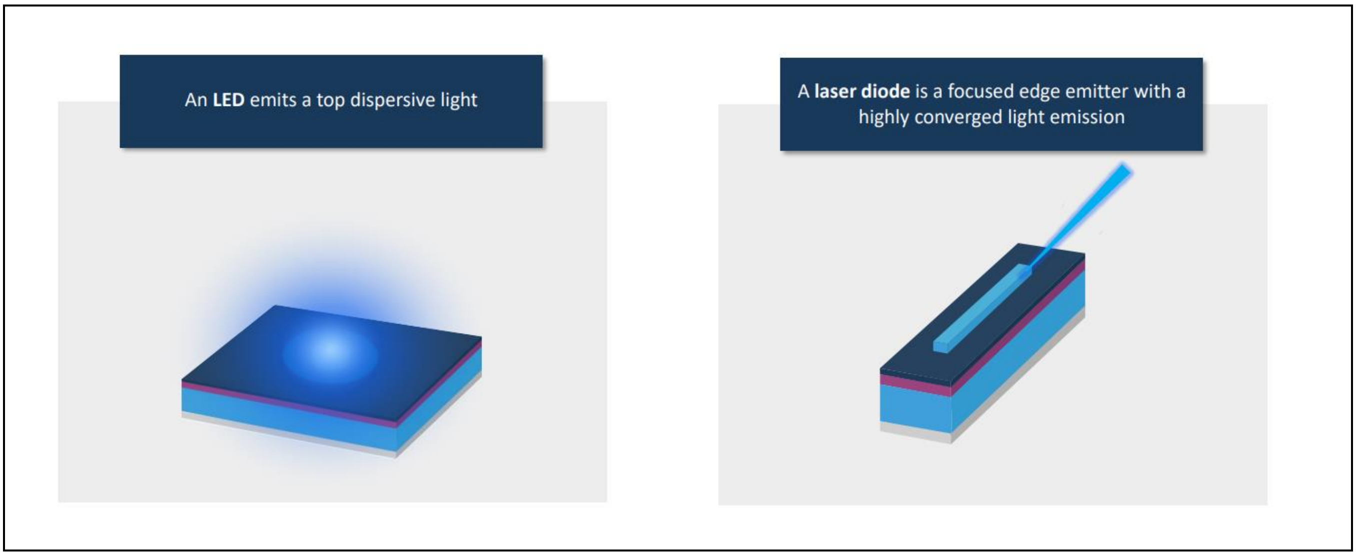
In this chapter we look at the complex process required to make laser diodes, why BLG's technology has inherent advantages for laser diode manufacturing, and future opportunities for the Company. These include addressing underserved segments of the market with products that are similar to what industry peers are already selling as well as laser diode products that offer substantial improvements on today's mainstream products. The latter should become a reality through BLG's Remote Plasma CVD process technology.

What is a laser diode and how does it work?

Laser light is coherent and doesn't shoot off in all directions

A laser diode (LD) is a semiconductor device that converts electrical energy into a high-intensity beam of coherent light. Unlike a light emitting diode (LED) that emits incoherent light in all directions, the light waves emitted from a LD are all at the nearly same frequency and in phase (Figure 13). It is this enhanced coherency that enables the beam size to remain highly focused even when projected long distances. Laser diodes emit light in a very narrow line-width, meaning the light is not spread across a wide range of wavelengths or colours, but is a more pure monochromatic colour. These properties provide many unique performance and application advantages.

Figure 13: Light dispersion in LED's versus laser diodes



Source: Company

The p-n junction is where laser light is created

As for an LED, the fundamental aspect of an LD is the conversion of electrical energy into light and this is achieved using a p-n junction. The structure of both LED and LD chips consists of positive (p-type) and negative (n-type) semiconductor layers. When the p-type and n-type layers are sandwiched together they form a p-n junction. When the p-n junction is connected to a power supply (such as a battery) electrons in the n-type layer will flow away from the negative terminal towards the p-n junction, while holes will flow away from the positive terminal also towards the p-n junction.

Spontaneous versus stimulated emission

A hole can be thought of as a place that is missing an electron - like an empty bucket waiting to be filled. When these electrons and holes meet, they recombine (the electron fills the hole) and a photon of light is produced. This recombination process happens spontaneously, and so it is referred to as **spontaneous emission.**

All the light generated in an LED is via the spontaneous emission process and the overall design of an LED chip will aim to extract as much of the spontaneously emitted light as possible.

Photons stimulate further recombination processes

This is where LEDs and LDs differ. In an LD, rather than trying to maximise the light extraction, the chip is designed to confine the light inside a long thin optical cavity, such that the emitted light gets trapped and can only move in one dimension along the cavity length. As the light traverses this cavity back and forth it interacts with the electrons and holes and stimulates further recombination processes. In other words, rather than the electrons and holes pairs waiting to spontaneously recombine, the passing photon triggers the recombination in a process referred to as **stimulated emission.**

LASER = Light Amplification by Stimulated Emission of Radiation

A photon that is created via the stimulated emission process is coherent with the photon that triggered the emission. So, the two photons then traverse the optical cavity together and in phase with each other. These photons then interact even further with the electron and hole pairs leading to further stimulated emission, so two photons become four and so on, with the light amplifying and increasing in intensity with each pass of the cavity. This amplification or optical gain is the critical phenomena of laser behaviour. Indeed, the terms **LASER** is in fact an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

With each pass the emitted light in the laser cavity is reflected by the LD reflective facet back into the laser diode. At one end, the facet is engineered to be highly reflective (HR) using advanced optical coating techniques, so that close to 100% of the light gets reflected and confined to the cavity. At the other end the facet has an anti-reflective (AR) coating that is designed to reflect a precise fraction of the light back into the cavity, while allowing the remainder to be transmitted through, ready to be used in whatever application the LD is designed for.

RPCVD has potential to improve laser diode performance through two pathways

During this whole process, some of the photons get re-absorbed inside the semiconductor material and some of the photons escape from the AR facet as intended. As long as the rate of photons being generated is greater than the rate of photons being lost (i.e. total gain is greater than total loss), the device will exhibit lasing behaviour.

Improved performance can therefore be achieved by either increasing the rate of production of photons (increasing the gain) or decreasing the undesired loss of photons (decreasing the loss). BluGlass aims to leverage the unique benefits of RPCVD to improve the performance of LDs via both these pathways (improved gain and/or reduced loss).

Advantages of gallium nitride (GaN) laser diodes

Blue laser diodes have many inherent advantages over traditional infrared laser applications, including superior brightness and higher energy absorption in metals, combined with more accurate, cleaner, faster materials processing – essential for today's increasingly miniaturised high-tech applications.

There are many key markets where GaN laser diodes are disrupting the very large infrared laser market due to their unique performance advantages (Figure 14).

Figure 14: Blue laser versus infrared laser absorption in metals

Key Metals	Blue to Infrared energy absorption ratio
Gold	66x
Silver	17x
Copper	13x
Aluminum	3x
Nickel	1.5x
Steel	1.5x

Industrial manufacturing

Blue laser diodes are highly beneficial for gold and copper cutting and welding compared to the widely used high-power infrared (IR) laser diodes. Blue laser wavelengths are much shorter than those of IR laser beams, meaning they have excellent absorption by key industrial metals, including copper or gold, whereas IR beams are largely reflected (up to 95%) by these metals (Figure 15).

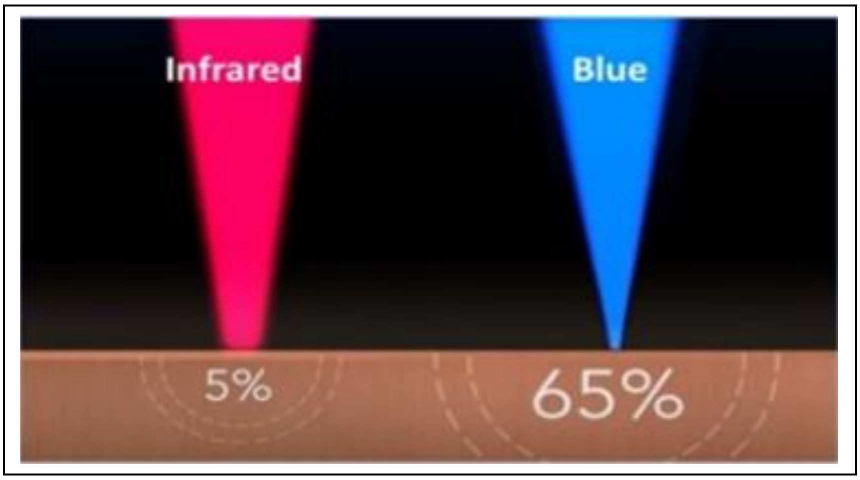
As an example, an IR laser needs almost 10-15 times the output power of a blue laser diode to facilitate similar materials processing. Additionally, blue laser diodes can help to smooth welding seams and thereby greatly enhance weld shapes and product qualities, while also enabling new products, not possible with IR lasers.

Automotive applications

Blue laser diodes have been well accepted in automotive applications because of their higher optical power, better electro-optical efficiency, wider temperature range and longer lifetime compared to those of historic products.

Today, blue industrial lasers can provide stable and high output power as required for metal processing applications, including welding of lithium batteries for cars and storage for renewable energy in large scale and home applications.

Figure 15: Infrared versus blue absorption



Source: NUBURU

Optical communication

Laser diodes have enormous potential for high-speed communication (e.g., 5 Gbit per second error free data transmission) in free space, underwater or in fiber applications. The compact laser beam can be modulated at a very high speed and will be highly suited for defence and security applications.

Conventional underwater acoustic communications are very slow and not suitable for long-range applications. They can also be easily intercepted. Laser-based, high-speed communications using high power laser arrays or bars will solve these problems, allowing quantum encrypted, long-range communications.

Medical applications

In opto-genetics, blue, green and red laser diodes can stimulate or inhibit the response of nerve cells depending on their photon energy. Since these laser beams can be focused or narrowed to a very narrow width, they can be integrated with neuro-probes and can provide new avenues for medical diagnosis and treatment.

Additionally, high power single mode GaN laser diodes are being employed in highly delicate retinal and blood vessel surgery.

High-density storage

Due to the short wavelength, the beam spot size of a blue laser diode can be decreased drastically on a CD or a DVD and thereby the data storage capacity can be dramatically increased, enabling high-density memory for the same physical disc size. This market is more commoditised than other GaN laser diode market segments and as it is being consumed by solid-state-storage, and is not of interest to BluGlass.

Atomic clock or space transmission

Distributed feedback (DFB) lasers emitting at a single wavelength are being developed for special applications requiring high spectral purity, such as atomic clocks or filtered free space transmission systems. These will be highly advantageous in autonomous vehicle applications for pinpoint time/space location accuracy compared to GPS navigation.

Stage and cinema lighting

Like LEDs, high power blue laser diodes are being used to create artistic lighting for displays and pico-projectors, including white light with the use of phosphors. Red-green-blue (RGB) applications are also highly desirable in the industry. Because each of these base colours has over 250 different shades, when you mix and blend these primary shades, they can provide over 16 million distinct colours in a single device.

Other applications

Due to various advantages as discussed above, InGaN-based laser diodes have found applications in bio-chemical analysis, general lighting, full-colour displays, laser-based TVs, sensing, portable projection, laser processing, laser pumping and laser lithography. We believe they will continually attract creative people from various fields to exploit the unique properties for novel applications.

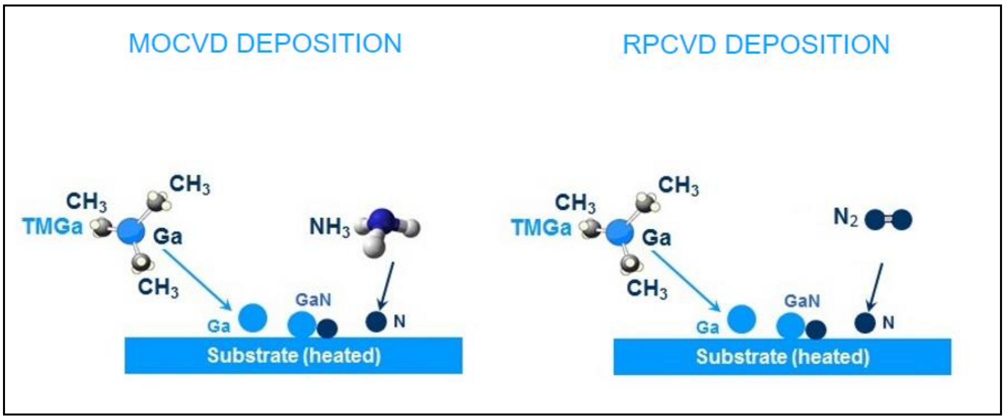
The challenge of high-temperature growth

MOCVD is a highly complex process used to deposit (grow) very thin layers of atoms onto a substrate to produce compound semiconductor materials, such as gallium nitride (GaN). When producing gallium nitride (GaN), organometallic compounds are reacted with ammonia inside a deposition chamber. This gas mixture is precisely delivered to a heated substrate (up to approximately 1,200°C).

The precursor molecules undergo pyrolysis (thermal decomposition) leaving the desired atoms, e.g. Ga (gallium) and N (Nitrogen) available for growth. These atoms bond at the surface and crystalline layers of GaN are formed in neatly stacked layers.

For the growth of GaN, MOCVD uses high volumes of expensive and toxic ammonia (NH_3) as the nitrogen source. MOCVD relies on very high temperatures to effectively break the highly robust nitrogen-hydrogen bonds to deliver a high-quality deposition (Figure 16).

Figure 16: MOCVD versus RPCVD deposition



Source: BluGlass

MOCVD can't grow high performance p-GaN layers at low temperatures

In MOCVD, the higher temperature growth of the p-type layer compared to the multi-quantum well (MQW) layer (the active region of the device) can cause some of indium (In) to diffuse out of the active MQW layer and reduce the light output, in particular with longer-wavelength devices, such as green.

MOCVD struggles to effectively grow high-performance p-GaN at lower temperatures.

RPCVD has great potential to improve device performance by growing a low temperature p-GaN layer, which in turn improves the stability of the InGaN layer during growth.

How RPCVD Works

RPCVD works in a similar way to MOCVD where chemicals are introduced into the reaction chamber for decomposition. Whereas MOCVD uses ammonia (NH_3) as the source of nitrogen, RPCVD uses nitrogen gas (N_2) passed through an electrical coil that generates a plasma. This arrangement provides a direct source of nitrogen used for the deposition of GaN.

RPCVD can deliver better quality devices at lower temperatures

The nitrogen plasma generation is not dependent on high temperatures to provide a source of reactive nitrogen atoms. This allows for the growth of GaN and InGaN to be carried out at much lower temperatures than those used in MOCVD while maintaining the critical crystalline quality necessary for high performance devices.

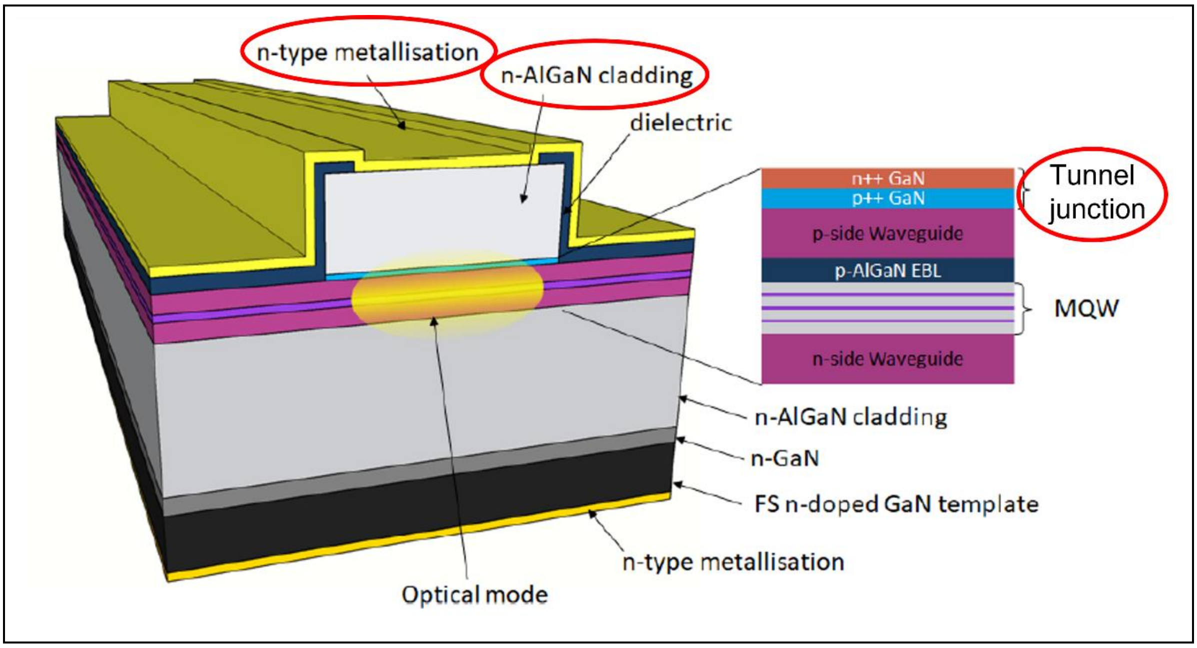
In turn, this allows for better tunability and variability of InGaN in the semiconductor devices to enable longer wavelength devices, in particular green laser diodes.

Manufacturing hybrid devices

RPCVD will be used to build specific layers in laser diodes

BLG's initial laser diode product range will be manufactured using the industry standard MOCVD manufacturing process. BLG also has advanced laser diode roadmaps to introduce RPCVD-enhanced laser diodes (hybrid MOCVD/RPCVD devices) to leverage the strengths of each manufacturing process in a single device, to improve the performance and the brightness of laser diodes (Figure 17).

Figure 17: Structure of a Tunnel Junction Laser Diode with RPCVD processed layers marked in red



Source: BluGlass

While MOCVD does deliver the required nitrogen atoms to react with gallium to form nitride layers, there are two intrinsic limitations with this process:

1. Too many hydrogen atoms end up in the p-type semiconductor layer.
2. The high process temperatures diminish the Indium-richness of the active region and impact the overall performance of the laser diode.

Fewer hydrogen atoms means less magnesium, which means improved conductivity

Ad 1. In MOCVD the excess hydrogen atoms bond with magnesium atoms that are needed to create the electron holes in the p-type semiconductor layer. So, to ensure sufficient numbers of holes in the p-type layer, more magnesium needs to be added.

However, more magnesium increases the resistivity of the layer, which is an unwanted side effect. So, ideally the CVD process for laser diode manufacturing should substantially limit the number of hydrogen atoms involved in the chemical reactions to reduce magnesium levels and associated resistivity.

High process temperatures negatively affect the performance of the laser diode

Ad 2. The MOCVD process ideally uses temperatures above 1,050°C to achieve active nitrogen. However, certain other layers, such as the active region of the laser diodes that use high indium content, must be grown at lower temperatures. These critically important active layers degrade when exposed to higher growth temperatures, as required by MOCVD in growing the subsequent magnesium doped p-type layers.

Here RPCVD brings tremendous benefits as it can grow the subsequent p-type layers on top of the active region at much lower temperatures (hundreds of degrees cooler) compared to temperatures needed for MOCVD growth of similar quality. Therefore, RPCVD growth of the p-type layers will not cause degradation and performance loss of the light emitting active region, enabling higher-brightness and higher performance laser diodes, in particular for longer-wavelength lasers, which require even more indium content, such as green laser diodes.

These two advantages combine to offer even greater performance advantages due to the low hydrogen nature of RPCVD growth. It will enhance the Mg incorporation efficiency and thereby reduce the resistance of p-type layers leading to an improvement in overall device efficiency.

RPCVD p-type layers are active as grown

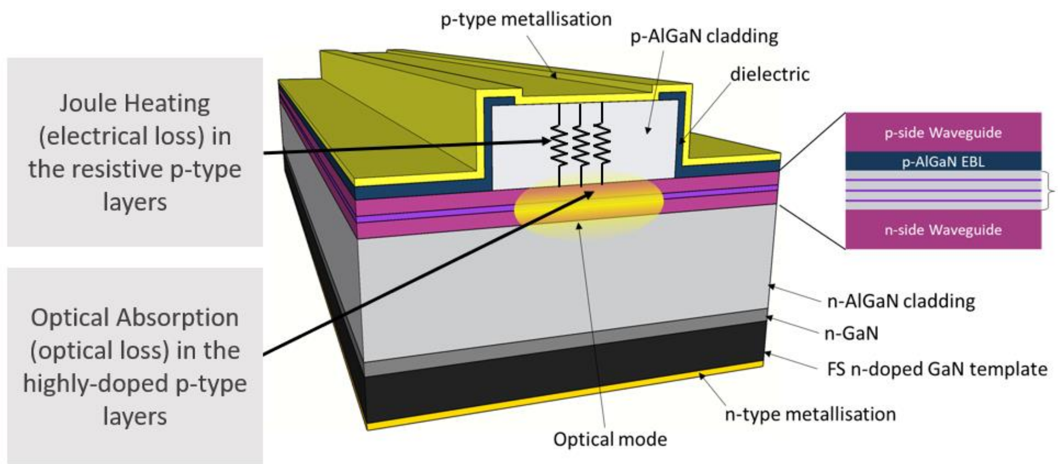
As an additional advantage, the RPCVD p-type layers are 'active-as-grown', meaning they do not require any post growth annealing or activation process, which can be required in MOCVD devices. This will simplify the device fabrication process and will not cause further deterioration in the device performance.

RPCVD tunnel junctions enable novel device architectures to solve performance losses

Today, GaN laser diodes suffer from significant optical and resistive loss in the magnesium-containing layers (p-type layers), resulting in low conversion efficiencies. Conversion efficiencies of state-of-the-art GaN-based laser diodes around 45%, compared to the +90% approached in GaN-based LEDs. At high current densities Joule heating from contact and series resistance can account for up to 50% of the power consumed in GaN-based laser diodes. This loss occurs in the p-type layers of the device (Figure 18).

Tunnel junctions in LDs can be used to replace the heavily lossy (optical and resistance) p-type layers (both the p-AlGaN cladding layer and the p-Ohmic contact layers) in the laser diode with significantly less lossy and less resistive n-type device layers.

Figure 18: Traditional laser diodes suffer optical and electrical losses in the p-type layer



Source: BluGlass

BluGlass' novel approach, enabled by the unique benefits of low temperature, low hydrogen RPCVD growth, can eliminate the need for these highly resistive and performance losing p-type layers. RPCVD-enabled novel designs replace the p-type cladding layer with an RPCVD tunnel junction and second n-type cladding layer - called a dual n-wave laser diode, paving the way to significantly improve laser diode performance in the future.

So, in summary, the key benefits of BLG's RPCVD process for laser diode manufacturing are:

1. Lower process temperatures, of approximately 800°C, which is ideally suited to satisfy the lower growth temperature requirement for post InGaN MQW layers growth and results in better laser diode performance.
2. The low growth pressure in combination with the low hydrogen process eliminates the need for a post-growth activation process of p-type layers at high temperatures, avoiding the risk of deterioration in the device performance.
3. RPCVD can replace the highly resistive and performance lossy layers in a laser diode (the p-AlGaN layer) with significantly less lossy layers (tunnel junction and n-AlGaN layer) to exploit its unique active-as-grown and low temperature growth advantages to deliver superior performances arising from reduced resistivity and heat loss during operation of the laser diode.

In simple terms, BLG's RPCVD process in combination with MOCVD should result in more efficient, higher power, and higher-value lasers.

Conclusion

We believe that the combination of the company's new Fremont fab, its proprietary RPCVD process and the leadership of industry veteran Jim Haden bodes very well for BluGlass' prospects in the fast-growing laser diode market.

With few blue laser manufacturers globally, BluGlass is focused on leveraging its key strengths and competitive advantages, offering customers greater design and manufacturing flexibility with the aim to become the industry's 'easiest to use laser light'. We expect the company to carve out an attractive niche in the global market.

In the longer-term, when it combines its unique RPCVD technology and novel device architectures to its product offerings, BluGlass should be able to expand on the initial revenue base by offering superior products compared to those offered by today's incumbents.

While there are obviously execution risks related to BluGlass' entry into the laser diode market, the company has been significantly de-risked with the Fremont facility acquisition, which has expedited the Company's development, production and revenue capacity.

We believe all the major building blocks are now in place for BluGlass to enjoy a successful future in this market.

Appendix I – SWOT Analysis

Strengths:	Weaknesses:
– The acquisition of the laser diode fab in Fremont in Silicon Valley is likely to be a game changer for BLG and fast tracks its transition to a product company. – BLG will be focusing on blue laser diodes across high-potential segments (industrial, scientific, biotech) with unmet needs and strong customer demand – BLG provides flexibility in form factors. This enables customers to avoid undertaking extensive customisation and packaging work at the post-purchase phase. – There is a management team in place with the required expertise in laser diode manufacturing. It has a clear vision and realistic plan of action to achieve its medium-term targets. – In the short term, BLG aims to release products by relying on contract manufacturers. In the longer run, it aims to transfer its manufacturing capabilities in-house to its facility in Fremont. This will provide BLG complete control of its manufacturing processes. – BLG is debt-free and has sufficient capital resources to continue operations until FY23. – BLG's revolutionary RPCVD technology operates at low temperatures and utilises substantially less hydrogen while depositing layers. This technology helps achieve brighter and more cost-effective lasers.	– BLG is facing some product reliability challenges that it is in the process of resolving. Reliability testing of its laser diode prototypes has highlighted processing flaws and degradation of optical facets at high power and in continuous wave conditions. – Production is currently in the alpha stage and the company has not yet reached the commercialisation stage. Qualification processes with some larger clients can take a long time. – BLG needs some time before transitioning all its manufacturing capabilities in-house from contract manufacturers. The longer the reliance on contract manufacturers for development, the longer it will take to launch new products. – While the company has sufficient short-term cash resources, it is unlikely to turn into a cash flow positive company until 2024/25. – There remain technical risks in demonstrating the performance and manufacturing advantages of BLG's RPCVD technology.
Opportunities:	**Threats:**
– BLG is targeting underserved wavelengths for use in industrial, scientific and biotech applications. These target segments hold promising potential for growth. – Potential to grow in the green laser diodes space. Development work for green laser diodes is currently in the epitaxy phase with next generation products likely to be expedited by the acquisition of the fab to fast track BLG's advanced roadmaps. – Scope for improvement in state-of-the-art facet coating capabilities through potential capital investments. – BLG is one of only a handful of end-to-end GaN laser diode manufacturers globally. – Market growth is currently constrained by limited players, and immaturity of GaN laser diode performance (~45% efficiency in state-of-the-art laser diodes today, compared with the +90% efficiency of LEDs).	– BLG's competitors are established players in the market and are substantially bigger in size. – Larger R&D budgets at its competitors could threaten BLG's currently perceived niche segments in GaN laser diodes. – Adverse financial market conditions may limit BLG's ability to raise additional funding at attractive terms.

Appendix II – Analysts' Qualifications

Marc Kennis, lead analyst on this report, has been covering the Semiconductor sector as an analyst since 1997.

- Marc obtained an MSc in Economics from Tilburg University, The Netherlands, in 1996 and a post graduate degree in investment analysis in 2001.
- Since 1996, he has worked for a variety of brokers and banks in the Netherlands, including ING and Rabobank, where his main focus has been on the Technology sector, including the Semiconductor sector.
- After moving to Sydney in 2014, he worked for several Sydney-based brokers before setting up TMT Analytics Pty Ltd, an issuer-sponsored equities research firm.
- In July 2016, with Stuart Roberts, Marc co-founded Pitt Street Research Pty Ltd, which provides issuer-sponsored research on ASX-listed companies across the entire market, including semiconductor companies.

Nick Sundich is an equities research analyst at Pitt Street Research.

- Nick obtained a Bachelor of Commerce/Bachelor of Arts from the University of Sydney in 2018. He has also completed the CFA Investment Foundations program.
- He joined Pitt Street Research in January 2022. Previously, he worked as a financial journalist at Stockhead for more than three years.
- While at university, he worked for a handful of corporate advisory firms.

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