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BluGlass improves novel GaN DFB laser performance for quantum applications

Highlights

- BluGlass has made significant advances in its blue single-frequency DFB performance
  - 74% increase in power conversion efficiency at 115 mW of operating power
  - Doubling of side-mode-suppression ratio
- Market feedback provides a better overview of the quantum opportunity

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Unlocking the laser opportunity in quantum

Quantum information science is rapidly advancing, driving urgent need for compact, single-wavelength (single-frequency) laser light sources. Advancements in quantum computing and quantum applications are being underpinned by stimulated light interaction with unique materials, down to the atomic scale, requiring specific wavelengths to target individual atomic interactions.

The physics of nature dictates the unique wavelengths required to interact with specific atoms, crystals, and the environment. Many of these needed wavelengths are in the near ultra-violet (UVA) and visible spectrums. Due to their unique lasing properties, gallium nitride (GaN) lasers are ideally positioned to address these nature-dictated UVA and visible wavelengths.

Emerging quantum markets present an enormous opportunity for visible laser diode manufacturers, such as BluGlass, as many of the enabling atomic transitions occur at visible wavelengths and are being increasingly sought after by customers in highly promising applications, including advanced robotics and bio-medical devices. Brain-driven prosthetic automation and atomic clocks for quantum navigation used in military and commercial applications are good examples of this next-generation tech.

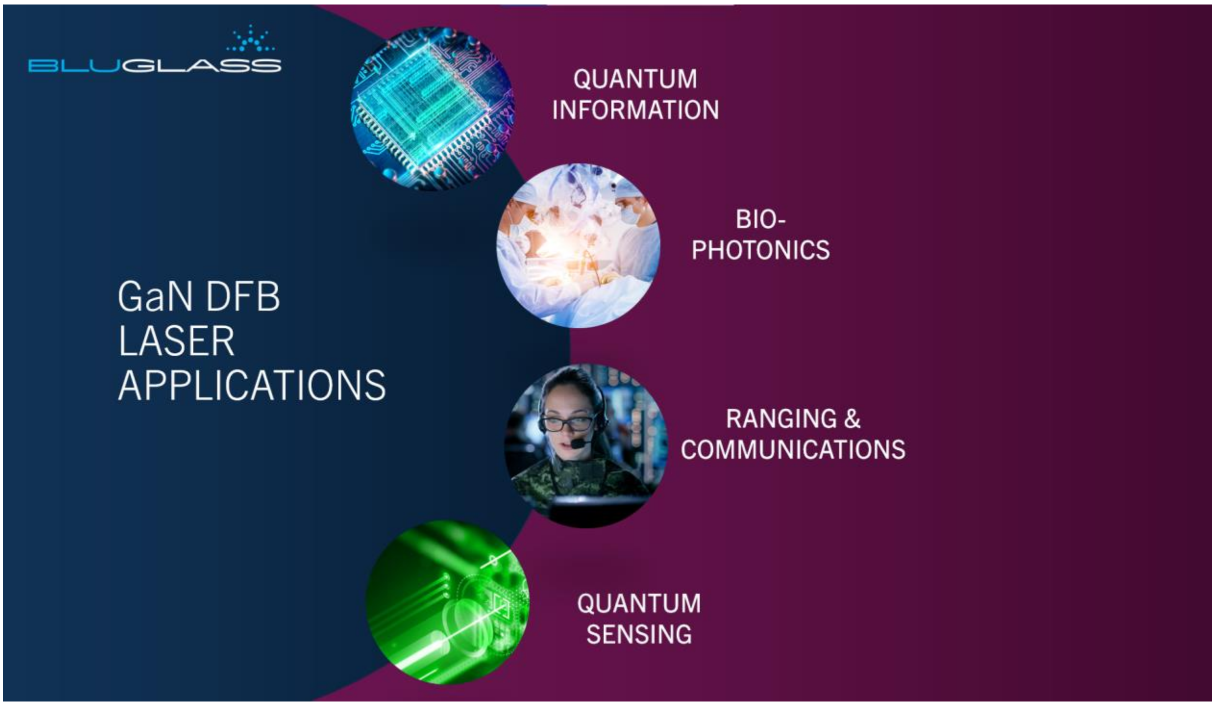
In its 2021 quantum report McKinsey & Company reported, “Quantum computing, one of the most revolutionary technologies of our time, is still a decade away from widespread commercial application. However, less well known, but of critical industrial and scientific importance, are two related technologies that are set to become available much earlier: quantum sensing (QS) and quantum communication (QComm).”

Quantum sensing technologies are advancing more quickly and are positioned to become available sooner than full-scale quantum computers. These include ultra-precise sensors for advanced defence and aviation applications for measuring gravity, magnetic fields, and time. Further, these technologies will enable atomic clocks, which serve as the backbone for quantum navigation and synchronisation.

Finally, quantum communication (QComm) is an emerging technology promising unbreakable encryption and secure communication via quantum key distribution (QKD).

Visible lasers in single frequencies will be essential for both QS and QComm systems. BluGlass' compact distributed feedback (DFB) lasers present a significant opportunity to pave the way for secure quantum communication networks. The global quantum application market is forecast by Precedence Research to reach US$125 billion by 2030, growing at ~37% year on year from 2022 to 2030.

Due to their unique performance properties, single-wavelength visible laser sources, will also enable advancements in underwater ranging and communication, and underpin next generation display and wearable technologies, including augmented and virtual reality applications.



Overcoming industry challenges

Presently, quantum computing demonstrations are relegated to room-scale applications, and quantum intelligence applications to large benchtop equipment, requiring large external cavity lasers, tunable dye lasers, and other sizeable, expensive advanced laser technologies. These advanced systems consume significant power and space, employing large, air-conditioned rooms reminiscent of 1950's computer systems; and are assembled and aligned one-at-a-time.

GaN-based DFB lasers offer a highly attractive alternative to these prohibitively large and expensive systems. These compact devices are fabricated and aligned photolithographically at the wafer level, with thousands of devices being processed simultaneously on one two-inch wafer, while still enabling the strict frequency, beam fidelity, narrow linewidth requirements, and the high power and efficiency these next-generation quantum technologies require. This is needed to facilitate both the scale-up in volume and scale-down in size for quantum applications to gain mass market penetration.

While DFB lasers are available in infra-red wavelengths, the technology to enable laser stimulations in the near UV and visible wavelengths is not commercially available due to the challenges in precision design and manufacturing of GaN-based DFBs.

BluGlass' recent breakthroughs in GaN-based DFB laser diodes offer a game-changing solution for these emerging markets. The Company's visible DFB lasers have demonstrated near single wavelengths with extremally narrow full width at half-maximum (FWHM) wavelength distribution and high side mode suppression ratio (SMSR), which is the suppression of undesirable wavelengths. These compact DFB devices enable integration onto portable platforms and volume production to address quantum markets and applications.

Distributed Feedback (DFB) Lasers

Standard laser diodes, called Fabry-Perot (FP) lasers are a commonly used type of laser that produce a relatively wide spectral width (range of multiple wavelengths). FP lasers are ideal for many high-power applications such as industrial cutting and welding, 3D printing, communications, and materials processing.

For applications that require extreme precision and ultra narrow spectral width and stability, a single frequency laser is required.

A DFB laser is a type of semiconductor laser that incorporates a periodic structure along the length of the laser. This structure, called a diffraction grating, causes an interference pattern of the light that suppresses undesired wavelengths of light while reinforcing the emission of a single, desired wavelength (and frequency). In simplest terms, DFB lasers produce a very sharp output of light of only one wavelength, creating an ultra-narrow spectral linewidth.

DFB lasers offer precise wavelength control, stability, and coherence over traditional laser structures due to the ability to produce light output with ultra-precise line widths with good side mode suppression, making them ideal candidates for quantum technologies.

Ultra-violet to green DFB applications:

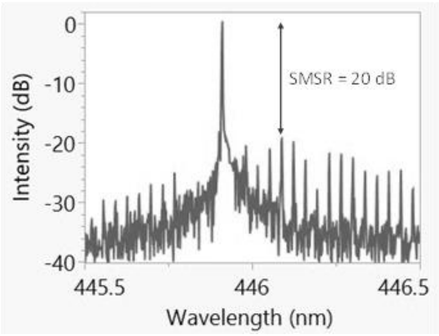
GaN lasers spanning the ultra-violet to green wavelengths from 369nm and 535nm have potential for critical applications:

- **Quantum Computing**: Near UV lasers address atomic transitions in trapped ions or neutral atoms - a fundamental requirement for quantum information processing. These precise wavelengths allow quantum computer scientists to create and manipulate quantum states and perform quantum cooling.
- **Precision Atomic and Ion Clocks**: Precise frequency references for atomic clocks rely on near UV lasers to interrogate ions' hyperfine transitions. These clocks play crucial roles in global navigation systems and cutting-edge scientific experiments.
- **Magnetic Sensing**: Visible narrow linewidth lasers interact with specific atomic or molecular transitions, allowing precise measurements of magnetic fields. These finely tuned sensors find applications in robotics, geophysics, materials science, and medical diagnostics.
- **Underwater LiDAR**: Near UV (and visible) lasers penetrate water effectively, making them ideal for underwater range-finding and imaging.
- **Atmospheric LiDAR**: Visible lasers help study atmospheric composition, wind patterns, and pollution levels.
- **Biophotonics**: Fluorescence microscopy and other biological imaging techniques benefit from near UV lasers.
- **Space Communication**: Visible lasers enable high-speed data transmission between satellites and ground stations.
- **Undersea Communication**: In underwater communication systems, visible lasers offer reliable data links.
- **Atomic Colours (also applicable in the visible wavelengths)**: These lasers enable spectroscopy and imaging of atomic energy levels, revealing "colours" unique to specific elements. By studying the "colours" emitted or absorbed during atomic interactions, engineers and scientists gain insights into atomic structure and behaviour.
- **E-Field Sensing**: Electric field sensors utilise visible lasers to probe energy level shifts caused by external electric fields.

BluGlass' DFB Laser Development

BluGlass, together with development partner the University of California Santa Barbara (UCSB) SSLEEC (Solid State Lighting and Energy Electronics) Consortium, has further enhanced the performance of its novel blue GaN DFB lasers, demonstrating significant progress in strict frequency control, beam fidelity, and narrow linewidth. Benefitting from BluGlass' proprietary Remote Plasma Chemical Vapour Deposition (RPCVD) technology, development improvements include suppression of undesired side modes, lower operating voltage, and higher efficiency. The beam linewidth has proven stable over a large range of drive currents and has wavelength-tuning capability.

1a)



1b)

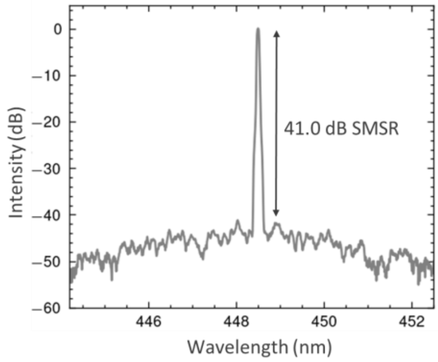
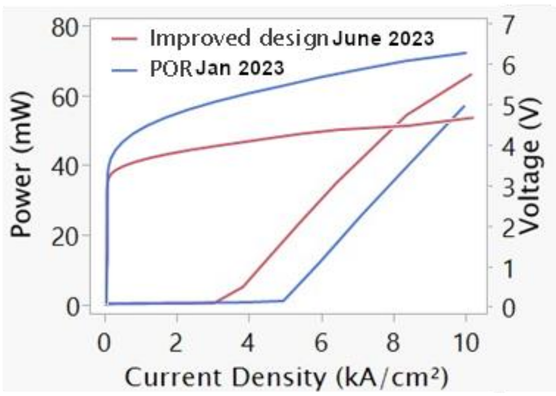


Figure 1. Emission spectra from DFB laser chips on submount under continuous-wave operation in a) previously published work and b) with improved chip and epi design.

BluGlass and UCSB have significantly improved DFB side-mode suppression ratio by more than 100% from 20 decibels (dB) to 41dB (Figure 1) since Photonics West 2023. SMSR is a critical requirement to enable single-frequency lasing performance. The Company has also advanced single-frequency performance at 450nm and demonstrated longer-wavelength DFB lasers up to 478nm.

BluGlass' latest development iterations demonstrate lower threshold and voltage performance, achieving higher powers across similar current densities (Figure 2a and 2b). Chips are packaged on a submount heat sink and electrically injected under continuous wave operation. The new grating and epitaxial design improved threshold by approximately 20%, and decreased operating voltage by 27%, resulting in a 74% increase in operating efficiency at 115mW of operating power, reducing heat generated waste.

2a)



2b)

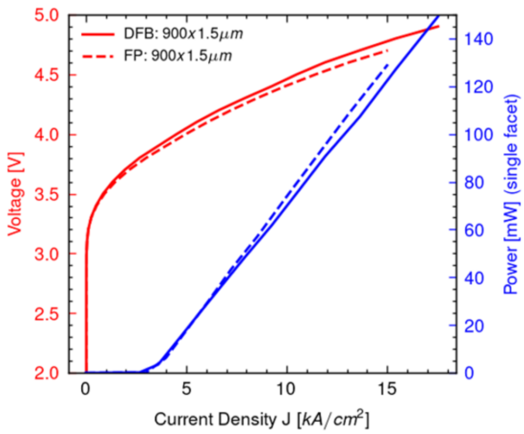


Figure 2. Comparison of previously published output power and voltage results process of record (PoR) and BLG's improved grating design with (b) recently processed chips with the improved grating, refined processing and epi design.

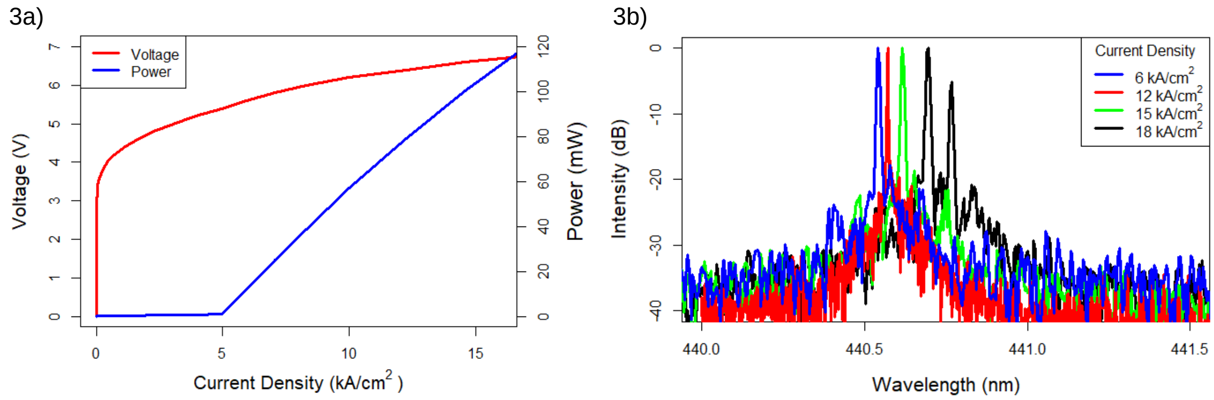


Figure 3: The previous epi and processing maintained narrow linewidths up to 15 kA/cm2, but the operating voltages were quite high (6.5 to 7 V) at ~ 115 mW (PW 2023)

Comparing figures 2b and 3a shows that at an output power of approximately 115 mW, the operating voltage has dropped from approximately 6.4 volts to around 4.2 volts (a 34.4% reduction in voltage). There was a corresponding reduction in operating current density from approximately 16 to 14 kA/cm2 (12.5%) resulting in a 46% reduction in waste heat and a 74% increase in power conversion efficiency from 8.3% to 14.5%. Note, these designs have demonstrated narrow linewidths up to 15 kA/cm2, which produces powers more than many of the levels required for quantum computing applications, often as low as 10 mW.

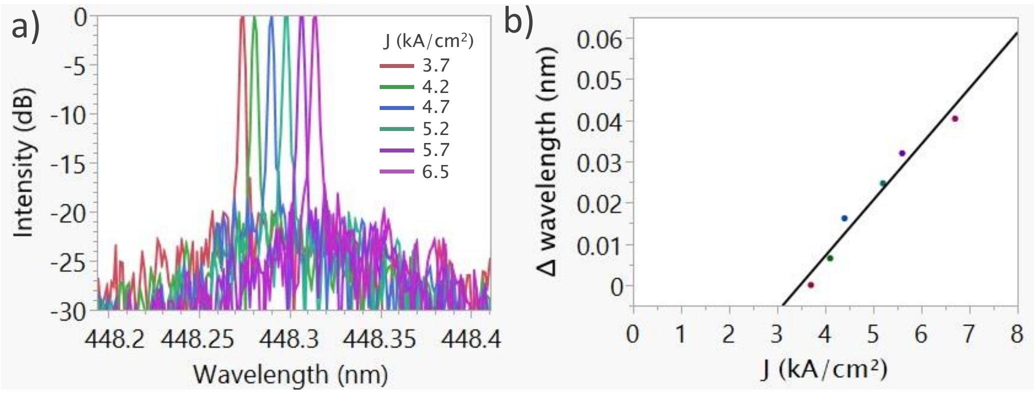


Figure 4 The improved grating maintains stable emission wavelength with increased operating current.

The emission spectra tested over a range of current densities are shown in Figure 4a), and notably maintain narrow linewidth of less than 3 picometers (pm). The emission peaks are plotted in Figure 4b) showing the range of wavelength tuning capable of a single chip. This fine wavelength tuning is useful to dial in the wavelength to interact with specific quantum states of the specific atoms used in quantum applications.

Finally, BluGlass established the capabilities to confirm its DFB lasers emit in a single spatial mode, as evidenced in Figure 5 below. A single spatial mode beam profile facilitates coupling to optical single-mode fibers and integration into advanced systems.

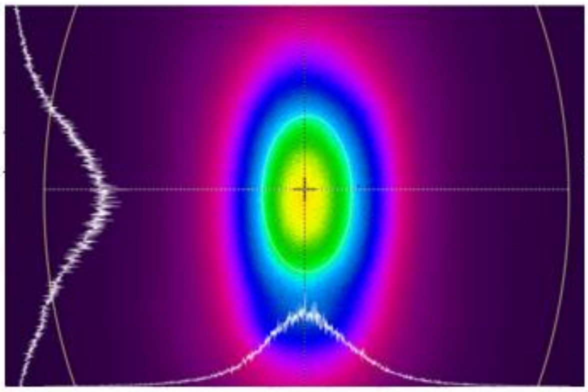


Figure 5: Beam profile measurements confirm single spatial mode operation

BluGlass' initial measurements indicate a beam profile of 30º x 50º full width at $1/e^2$. The Company will continue to refine and calibrate measurement metrics to confirm accuracy.

Conclusion

Natural principles govern the wavelengths required to enable quantum interactions with atoms, crystals, and the environment.

A significant portion of these wavelengths fall within the near UV and visible ranges. Today, single frequency laser systems in the near UV and visible wavelengths are prohibitively expensive, large and unlikely to be fit-for-purpose in the coming quantum revolution.

Conversely, compact GaN lasers are strategically aligned to match these nature-defined wavelengths and offer a highly promising solution to these challenges. Leveraging distinctive lasing characteristics, high-quality efficient UV to green light, and combined with their small size and suitability for volume manufacturing, GaN lasers are ideal for next-generation quantum applications.

BluGlass' visible DFB laser demonstrations have achieved near-single wavelengths with extremely narrow FWHM distribution and high SMSR, ensuring precise and stable operation. Their compact size and wafer level fabrication are a path to scaling up in volume and down in size enabling utilisation in quantum computers, in-flight LiDAR, robotics, and similar applications.

Quantum computing, though still in its nascent stages, holds immense promise for transforming the digital world.

Quantum neural networks and quantum support vector machines are potential AI capability game changers. Wafer scale, visible lasers, will enable precise sensing and navigation for robots, autonomous vehicles, industrial automation, and medical robotics. Biomedical applications, such as brain-driven prosthetics and neural interfaces, rely on precise laser wavelengths for stimulating and monitoring neural activity. Atomic clocks for quantum navigation also require visible and near UV laser to interact with the crystals that are the heart and soul of these devices. Visible DFB lasers stabilise atomic clocks, ensuring precise synchronisation, enabling accurate timekeeping, which is crucial for GPS, satellite communication, and navigation.

BluGlass' pioneering DFB laser technology is well positioned to redefine the quantum landscape, driving advancements in computing, sensing, and communication. As the quantum revolution continues to evolve, visible lasers will assume a crucial role in advancing technology capabilities globally.

The Company's paper entitled, *Single-Frequency DFB laser diodes at visible wavelengths grown with low-temperature remote plasma chemical vapor deposition p-AlGaN* paper can be downloaded exclusively from the SPIE Photonics West website here: [Single-Frequency DFB laser Diodes grown with low-temperature remote plasma vapor deposition P-AlGaN]

Single-frequency DFB laser diodes at visible wavelengths grown with low temperature remote plasma chemical vapor deposition p-AlGaN

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BluGlass Limited (ASX:BLG) is a leading supplier of GaN laser diode products to the global photonics industry, focused on the industrial, defense, bio-medical, and scientific markets.

Listed on the ASX, BluGlass is one of just a handful of end-to-end GaN laser manufacturers globally. Its operations in Australia and the US offer cutting-edge, custom laser diode development and manufacturing, from small-batch custom lasers to medium and high-volume off-the-shelf products.

Its proprietary low temperature, low hydrogen, remote plasma chemical vapour deposition (RPCVD) manufacturing technology and novel device architectures are internationally recognised, and provide the potential to create brighter, better performing lasers to power the devices of tomorrow.