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# Small and Scalable RGB Laser Engine for Augmented Reality

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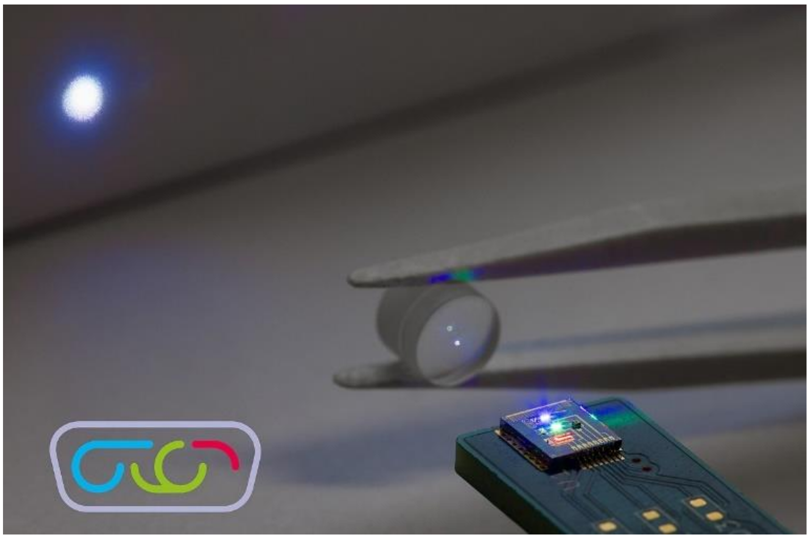
## Abstract

In this paper, we explore the challenges and current limitations within AR technology, particularly focusing on the challenges posed by display engines, such as lack of miniaturization and efficiency. The Neptune Laser Engine is the first fully integrated miniature RGB laser engine, and demonstrates great capabilities of tackling the issues limiting AR use cases. Neptune integrates PIC technology and Laser Beam Scanning (LBS) to provide a compact, efficient, and high-performance solution.



## KEY TAKEAWAYS

- AR technology needs to achieve comfort to be accepted by the market.
- PIC technology brings a new paradigm compared to conventional electronic technology, with miniaturization and higher performance.
- Brilliance RGB designs the first Silicon photonics laser light sources necessary to meet the requirements of the next generation indoor and outdoor wearable AR displays.

# Contents



# General introduction to AR

## What is AR?

The term Augmented Reality (AR) first appeared in 1968, when Harvard computer scientist, Ivan Sutherland, created an AR head-mounted display system. AR is a transformative technology that enhances the real world by superimposing digital content, such as images, sounds, and interactive features, on the real environment of the user in real time. Unlike Virtual Reality (VR), which immerses users in a completely fabricated digital environment, AR blends digital elements into their current surroundings, resulting in a mixed and interactive experience.

The ultimate AR device combines advanced technology, including:

1. Hardware, devices such as smartphones, tablets, AR glasses and headsets with cameras and sensors to capture the user's surroundings.
2. Software, process visual or audio input, and use computer vision, machine learning, and spatial mapping to position virtual objects correctly.
3. Display Engine, which is founded at the beginning of the optical chain and integrates a more complex network of optics and photonics. It has a significant impact on critical factors vital to the immersive experience of the user. For example, overall image quality, peak brightness, efficiency, colour purity, and so on.

Overall, in an AR system, the display engine generates the light, which is then coupled into a waveguide. The waveguides can be diffractive, holographic, or reflective, and they use optical elements (input couplers, output couplers, and so on) to guide light at the right angles for imaging projection. The output couplers lead the light out of the waveguide and into the optical path of the light from the real environment.

## Current status AR

AR and VR were present 15 times in the Gartner Hype Cycle and were removed in 2018, suggesting that they are now entering the plateau of mature technologies. However, their presence is still seen in developing technologies, such as the metaverse, digital beings, and AR avatars.

In particular, AR has experienced significant improvements in recent years, with more powerful standalone headsets such as HoloLens 2 by Microsoft (2019) and Magic Leap 2 (2022) by Magic Leap being released. Recently announced devices include Meta Orion from Meta and Spectacles from Snap, both of which are causing excitement in the AR community.


Meta Orion and Spectacles offer impressive advancements and deliver real AR experiences. However, challenges in high power consumption, reduced battery life for efficient pixels, and high costs hinder their potential for mass production.

Some of the key innovations of AR include advanced waveguide display technologies, which enable lightweight devices and immersive visual experiences; μLED and laser beam scanning (LBS) systems, which deliver high brightness and compact designs; AI-powered spatial mapping, which enhances interactivity; and the integration of 5G and edge computing, providing seamless real-time performance in connected environments. Advancements in ultra-precise positioning sensors and dedicated SoCs, such as those from Qualcomm, are enabling highly accurate spatial tracking and optimized processing, critical for seamless and responsive AR experiences.

In addition, advancements in AI and 5G have contributed to the acceleration of AR progress as well, resulting in a positive ecosystem that promotes innovation in several high-tech fields. On the social aspect, society has normalized the use of AI in daily life, both personally and professionally. Therefore, leveraging on AI can make the concept of using AR seem less foreign to the average user, creating an open mindset to the acceptance and curiosity regarding AR technology. On the other hand, this creates more space for the presence of AI, making this a symbiotic relationship for both technologies.

Last year (2024), the AR/VR market size was evaluated for USD 59.81 billion, and is predicted to surpass the USD 589 billion mark by 2034[1]. Some popular examples of current AR use cases include Sephora's Virtual Artist, which uses facial recognition

[1] More information here

software that allows users to try on lip products virtually, and IKEA's app, which helps customers design interiors by visualizing furniture in their space. Interestingly, in the field of healthcare, in 2021, the first spinal surgery using an AR headset was performed. This procedure combined Medtronic's Mazor X robotic platform with Augmedics' AR technology, and reduced the surgery time from the usual 6–7 hours to under 2 hours.

## What issues arise for AR?

Major industry companies, including Microsoft, Google, and Meta, have expressed interest and attention to AR, which has been backed by optimistic market forecasts. This is especially true in sectors such as retail and e-commerce, where consumers are excited about the ability to visualize products from the comfort of their own homes, and in healthcare and medical training, where AR is viewed as an innovative tool for reshaping how healthcare professionals learn and interact with patients.

Despite this positive outlook, there is still a significant gap between industry and mainstream consumer use. This is due to some of the issues that AR currently faces, such as:

1. Hardware constraints, where AR devices are often bulky, expensive, and lack the proper design for everyday use.
2. Battery limitations, as current devices suffer from inadequate battery life, limiting prolonged usage.
3. Narrow Field of View (FoV) and low Pixel Per Degree (PPD) resolution limit the immersive experience.
4. Lack of High Dynamic Range (HDR), as it can translate to limited brightness, restricting the use of the wearable AR devices outdoors.
5. Lack of readiness for consumer-affordable mass production.

In the end, as Bernard Kress, Director for XR engineering at Google Labs, has expressed before, the design and size of a device determine its comfort, which can be visual, social, or wearable, and in exchange, this determines the market acceptance and how AR is perceived by the regular consumer. The use cases should also be attractive, by adding convenience, personalization, and entertainment, this way AR is able to meet both functional and emotional needs of the user. Therefore, while there are clear advances in AR technology, it is crucial to address the challenges associated with AR-based devices, particularly wearables and the needs of the consumer. Ensuring comfort and usability

Brilliance RGB delivers the smallest RGB laser engine – Neptune Laser Engine.

is vital for AR technology to achieve mainstream adoption and become accessible to a broader audience.

# Laser-based AR

## General concepts and advantages

In recent years, laser-based AR has emerged as a strong candidate to bring AR into the mainstream by addressing some of the issues mentioned earlier.

Unlike other technologies such as LCOS and µLED, which use LEDs as the optical source integrated into the display engine, laser-based AR, as the name suggests, utilizes lasers as the optical source and as part of the display engine. A well-known technology that uses lasers for AR applications is LBS technology. This technology has been previously incorporated into AR glasses such as in Microsoft HoloLens 2 and in Focals by North (2018). The concept behind this technology is the use of highly focused laser beams with precise optical systems, such as micro-electron micro-mechanical systems (MEMS) to generate and project the image. This image must be optically transferred to the eye and magnified on a transparent display or on the user's FoV.

The use of a coherent light source, such as a laser in the display engine, has several advantages:

1. High brightness and contrast leading to a good HDR, making the AR device suitable for outdoors environments.
2. Lasers have very well defined wavelengths, resulting in pure, monochromatic and saturated colours.
3. Simpler to integrate, because the laser produces a well-behaved beam, allowing the output optical power to be focused into a submicron spot.
4. Easier to be coupled with other optical elements, such as waveguides, without sacrificing too much optical power, leading to higher efficiencies.

In summary, laser-based AR systems provide significant advantages in brightness, colour purity, and integration, making them a promising foundation for advanced AR applications. Building on these strengths, the next section explores the role of photonic integrated circuits in further enhancing AR technology.

# Photonic IC technology

## Introduction and basic concepts

Photonic Integrated Circuit, also known as PIC, is a microchip that integrates photonic components, such as lasers, waveguides, modulators, and detectors, onto a substrate.

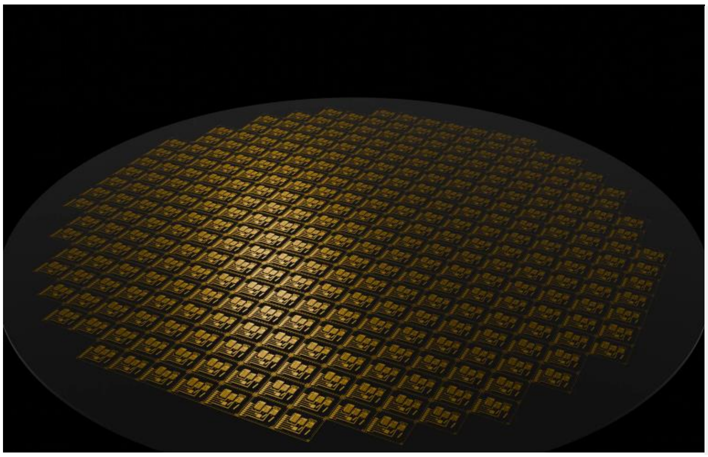
Unlike traditional electronics that rely on the movement of electrons to generate and process electrical signals, PICs uses photons to manipulate and process light in order to distribute information.

The fundamental shift from electricity to light, opens new prospects in technology and allow us to overcome the limitations of conventional electronical devices, bringing new features, such as electromagnetic interference immunity, increased bandwidth, and the ability of a single waveguide to transmit several signals of different optical wavelengths simultaneously – typically ranging from 850 to 1650nm for telecommunications.

Currently, three waveguide materials stand out as versatile and effective substrates in PIC technology, each with unique strengths and utilities:

1. Indium Phosphide (lnP) - this material stands out as a highly efficient material in light generation, working in the range of infrared wavelengths – 1000 to 1600 nm. It also excels in the integration of active photonic components, because it can emit, amplify and detect light. However, the strength in active functionality leads to the material to also be relatively lossy for passive waveguides.
2. Silicon Nitride ($Si_3N_4$) - presents a dielectric nature and is known for two reasons. First, as an ultra-low- loss material capable of supporting light transmission over a broad range of wavelengths, from the visible to the infrared spectrum – 400 to 2400 nm. Second, it can manage high optical power, making it suitable for demanding applications in the fields of sensing, quantum photonics and telecommunications.
3. Silicon - offers a significant advantage in its compatibility with existing electronic technology, particularly with Complimentary Metal-Oxide Semiconductor (CMOS). This leads to a higher capacity of integrating high density photonic configurations with electronic components. This material is transparent to infrared light with wavelengths above 1100 nm.

The choice of material often depends on the specific requirements of the application, such as wavelength range, functionality, and cost.



PICs technology offers advantages that include precise control of light, compact form factor and reliability. It also presents good manufacturability, leveraging on scalable processes, such as wafer-based fabrication, making them capable of achieving mass production.

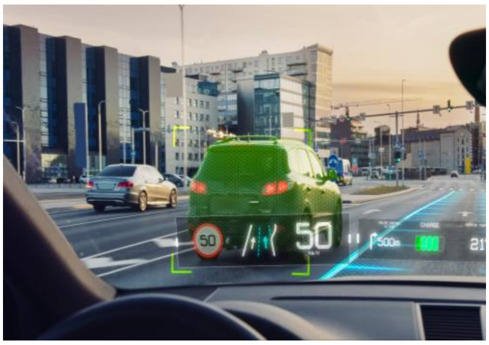
## General trends in PICs

With the advantages of using PICs highlighted in the previous section, it is clear the presence of this technology at cutting-edge advancements, driving innovation among different industries. Additionally, the PICs ecosystem continues to attract significant investment, not only from the R&D community, but also from the industry players. The PIC Market size is estimated at USD 18.20 billion in 2025, and is expected to reach the USD 46.19 billion mark by 2030, growing at a CAGR of 20.47% during the forecast period (2025-2030)[2].

The evolution of PICs is driven by the increasing demand for more complex, scalable and densely integrated devices, resulting in products that are compact, high performance and capable of being scalable for different applications.

Some of the general trends making PICs stand out include:

1. The advancement of telecommunications and data centres, where there is a never-ending demand for higher data rates, bigger bandwidth, smaller footprint and lower power consumption.
2. Automotive industry is also embracing the PICs, particularly LiDAR and sensing applications for autonomous vehicles. The need to miniaturize complex systems and reducing costs, makes PICs a very attractive and adequate option to achieve high-performance, real-time sensing for navigation, obstacle detection, and mapping. In the case of Heads-Up Displays (HUD), the use of PICs can significantly improve performance by using compact, high-efficiency optical components, leading to reduced power consumption, and the ability to integrate advanced functionalities such as AR directly into the display system.




3. Consumer electronics industry with an increase interest in integrating PICs into devices such as smartphones, wearables, and AR/VR systems, positioning them as key components in the next generation products within this sector.

Other growing trends are in quantum computing and quantum communications, where PICs allow the integration of quantum light sources and detectors on a single chip, and in healthcare, particularly biosensing and medical imaging technologies. AI and machine learning are also benefiting from the ability of PICs to handle large volume of data at high speed.

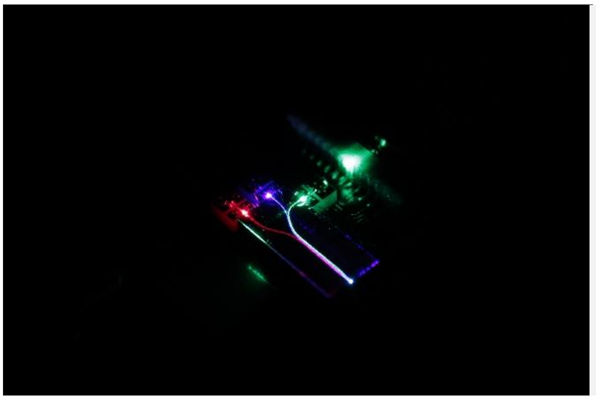
[2] More information here

Nonetheless, as miniaturization and high integration push boundaries and reach new limits, it is critical to continue paying attention to parameters, such as thermal management. Optical sources and waveguides, among other photonic structures, suffer from intrinsic temperature effects, such as thermo-optic effects and coefficients of thermal expansion, which can have more impact when working in smaller scales. Packaging also needs to be robust, compact, and capable of protecting delicate elements integrated in the PICs, as this can limit the commercialization and scalability of PIC based devices. Furthermore, the absence of standardised designs and manufacturing processes might result in fragmented development efforts and slower acceptance across industries.

## PICs for AR

Given the context established so far, it is now the time to focus on how PICs can seamlessly integrate into the consumer electronics industry, particularly emphasising their role in advancing AR devices. When designing an AR device, such as a head-mounted displays (HMDs) or wearable AR glasses, it is evident how different components are intrinsically related to photonic technology. One such component, previously mentioned, is the display engine. The display engine generates light that projects AR content, serving as a foundation for the immersive experience these devices aim to deliver. Equally important in AR systems is the combiner optics. While VR systems prioritize maximization of the fill factor to block an external light, AR systems require a balance. A certain degree of transparency is required to merge digital content in the real-life user's surroundings. This leads to combiner optics being important to integrate light from the display engine and the light from the environment.

Additionally, the compact and lightweight design of AR devices is crucial, especially given the complexity of their optical systems. PICs can address these challenges by streamlining AR systems. By reducing the number of optical components such as lenses and couplers, PICs simplify the design, enhance efficiency, and contribute to a more compact form factor.

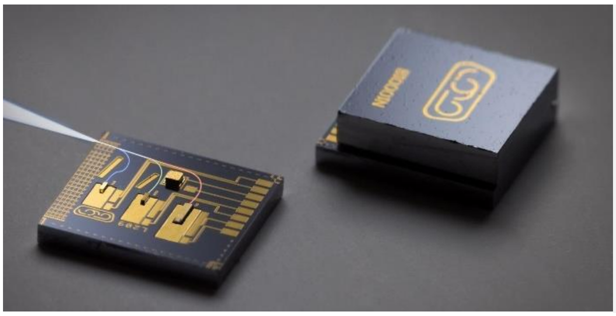


Neptune Laser Engine uses Silicon-nitride based PICs, which has demonstrated reliable performance in visible wavelengths and power levels reaching watts [1].

# LBS on PICs by Brilliance RGB

## Description of Neptune laser chip

Taking into account the discussion so far, it is fitting to introduce the Neptune Laser Engine, developed by Brilliance RGB. This laser engine seamlessly integrates PIC technology and LBS technology to provide a compact, efficient, and high-performance solution for AR applications, as well as other applications that require projection displays.



Brilliance RGB presents a laser chip based on PIC technology – Neptune Laser Engine. Compared to LBS, LCOS, and µLED displays, Neptune Laser Engine technology can offer up to 10x efficiency improvements.

The Brilliance miniature RGB laser BRL-02a-P-L, also known as the Neptune Laser Engine, is the smallest light engine to integrate RGB (Red, Green, Blue) laser diodes in projection applications. Neptune currently represents the status quo, with future advancements expected to further reduce its size significantly.

The Neptune Laser Engine utilizes the TripleX® technology [2], which features a high refractive index contrast. TripleX® technology has emerged as a stable and highly advanced Silicon-nitride waveguide platform, characterized by exceptionally low propagation losses—ranging from 0.1 dB/cm to an impressive 0.1 dB/m. This platform, enables flip-chip assembly process for hybrid integration [3], allowing for the passive alignment of red, green, and blue laser diodes into precisely etched pockets/cavities within the substrate. Additionally, the system can incorporate a Negative Temperature Controller (NTC) for temperature measurement, sensing, and control, also integrated using a flip-chip method.

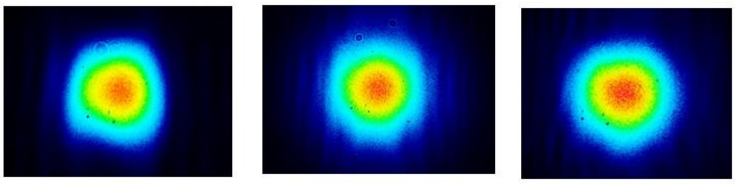
The TripleX® Silicon-nitride platform technology uses alternating layers of $Si_3N_4$ and $SiO_2$ with refractive indices of 1.98 and 1.45, respectively, at a wavelength of 1550 nm. The high refractive index contrast of the TripleX® enables strong light confinement and the design of smaller photonic components while minimizing propagation losses. This material also provides control over the optical field's mode shape. By tapering the waveguides, the optical mode size can be adjusted and adapted, making it possible to optimize the laser output for projection systems. Furthermore, efficient coupling of the laser diodes requires that the waveguide mode align with the relatively small, non-linear mode shapes of the lasers, ensuring high-quality performance.

Regarding the flip-chip assembly process, as mentioned, the laser diodes are aligned passively. For the two lateral directions a vision system is used that aligns features of the laser diode to features on the PIC with an accuracy <0.5 µm. For the height, the process relies on the use of etched features, such as pillars, placed within the laser diode pockets, with a controlled accuracy of ±50 nm during the fabrication process. The lasers are attached to each respective pocket, that is covered in gold, through laser soldering process, and with a pad solder located between the pillars. This solder connection also provides electrical connections to the bottom side of the diode, whereas the top side of the diode can be wirebonded to a metal pad on the PIC.

## Specifications and features

The Neptune Laser Engine features:

- Numerical aperture (NA) that is equal over wavelength with a X:Y ratio 1:1 (±5%).
- Circular Output Beam with a X:Y ratio 1:1 (±5%).
- $M^2$ = 1.0 ± 1% - beam very close to a Gaussian beam profile.



- Single mode lasers in wavelengths of [450,520,640] nm combine into 1 RGB laser beam.
- Typical optical output power (CW): 25 mW (450 nm), 15 mW (520 nm), 25 mW (640 nm) (Tc = 25°C)
- Small package 4 x 4.5 x 1.5 mm, already including a cap of 1mm that protects the laser diodes and wirebonds.
- Operation temperature: ≈ [-10,70]°C.
- On-chip temperature sensor (NTC).

Among these features, it is also possible to add other components depending on the application, such as collimating lens and IR laser for eye tracking, as well as heat sinks for thermal management.

Moreover, the specified optical power for Neptune is a representative value. Our technology platform is adaptable and can support higher or lower power levels, up to Watts range, depending on requirements.

It should be noted that for projection applications, such as AR, a circular optical output mode is necessary to achieve images with high quality. A circular beam in laser systems offers an efficiency advantage primarily due to its symmetric intensity distribution, which improves coupling efficiency into projection systems, as well, as an uniform behaviour. Discrete laser sources, with their inherent asymmetry and divergence, cannot match the performance of integrated solutions like TripleX® to deliver superior beam quality and coupling efficiency.

In general, the efficiency of the Neptune Laser Engine depends on the wallplug efficiency of the bare laser diodes and the overall optical transmission efficiency of the system. In this case, the optical transmission efficiency is mainly affected by the coupling efficiency between the laser diodes and the waveguides (efficiency typical above 70%) and by the propagation losses in the PIC, which are negligible. For the future, it is expected for laser diodes to reach 40% efficiency, and a PIC efficiency of above 85%. This leads to a typical AR use case benefit of 20x efficiency improvement compared to today's LCOS projectors.

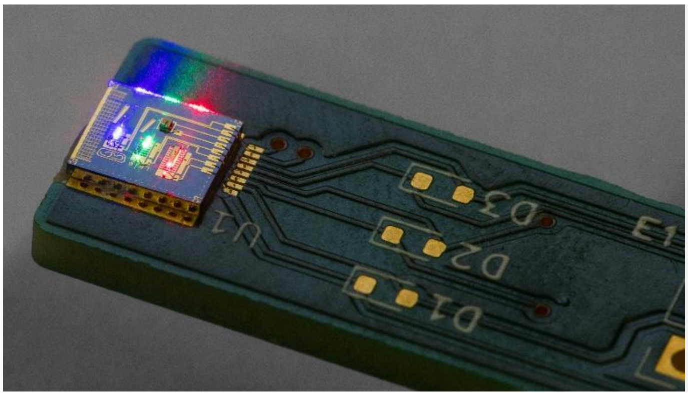
## Advantages

The Neptune Laser Engine combines the advantages of PIC technologies and Lasers optical source. It provides flexible system integration and optimization capabilities due to its optimal optical output properties and compact form factor.

Equally important, the fabrication and assembly processes of the Neptune Laser Engine are designed to support wafer-level laser diode integration and wafer-level hermetic packaging, enabling scalable volume manufacturing.

Furthermore, on one hand, the Neptune Laser Engine benefits from a simplified design with fewer optical elements by integration and light optimization on-chip. This not only facilitates integration into various systems with a smaller form factor but also leads to higher transmission efficiencies with reduced optical losses compared to discrete LBS or LCOS technologies, that require relay optics.

On the other hand, the Neptune Laser Engine employs laser diodes as its optical sources, achieving higher brightness levels and better HDR performance compared to µLEDs. The µLED technology faces inherent trade-offs among pixel size, efficiency, and brightness. Specifically, as each µLED functions as an individual pixel, downsizing the pixel size reaches a critical limit where the LED cannot maintain sufficient brightness or efficiency. At this scale, a substantial proportion of energy is dissipated in heat forms rather than being utilized for effective light emission, limiting its applicability in high-performance AR systems. By using laser diodes integrated in a photonic circuit we can achieve a higher



Brilliance RGB unveiled their 2nd generation laser engine 'Neptune' in 2024. It's the world's first fully integrated RGB laser for miniature projection applications.

The current chip size is 4x4.5x1.5 mm, and it is expected to decrease for next generations products.

efficiency leading to less power consumption, and therefore it is possible to reduce battery sizes and increase their lifetime.

## Outlook for further integration

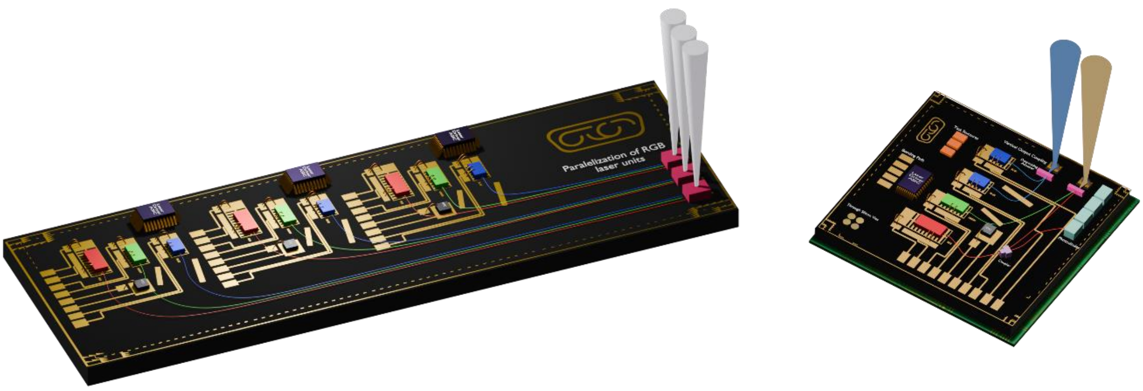
### More functionalities

The 2nd generation hardware of the Neptune Laser Engine, which represents the first fully integrated miniature RGB laser to our knowledge, has been successfully developed and is currently undergoing testing and integration into various customer systems.

Looking ahead, the 3rd generation hardware is envisioned to deliver more functionalities and refinement. Potential advancements include:

1. **Integration of photodiodes:** Incorporating photodiodes as light sensors for active monitoring and feedback, enables dynamic adjustments to optimize performance.
2. **On-PIC ASIC Drivers:** Embedding ASIC drivers directly onto the PIC to facilitate faster data connections, reduce latency, and enhance the overall speed and efficiency of the laser engine.
3. **Multiple Optical Outputs:** Providing multiple optical outputs and enabling parallelization of RGB lasers to achieve higher power outputs for demanding applications.
4. **Test Structures:** Adding test structures to improve quality assurance and ensure precise control over the performance of the final product.
5. **Perpendicular out of plane beam outputs.**

These developments aim to expand the functionality, reliability, and scalability of the Neptune Laser Engine, solidifying its position as a cutting-edge solution for AR and other photonic applications.



## Final remarks

This paper has explored the demands and current limitations within AR technology, particularly focusing on the challenges posed by light engine design. The light engine remains a critical bottleneck in advancing AR displays to meet the design requirements for mass-market adoption. Competing technologies such as LBS, LCOS, and µLEDs strive to balance form factor, efficiency, and brightness. However, achieving an optimal solution, especially for outdoor usability, continues to be a significant challenge.

To address these issues, in this paper, Brilliance RGB introduces the Neptune Laser Engine, representing an innovative step forward. Leveraging on PIC technology and hybrid integration of laser diodes, the Neptune Laser Engine delivers the smallest light engine developed to date. The miniaturization enabled by the Neptune Laser Engine holds the potential to make AR wearables more compact and lightweight, paving the way for the comfortable, everyday use that consumers desire.

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## About Brilliance RGB

Founded in 2023 in Enschede, The Netherlands, Brilliance RGB is a pioneering startup specializing in cutting-edge photonic technologies. Leveraging a patented silicon-nitride-based platform and laser integration techniques, the company delivers innovative solutions for next-generation light engines and optical systems. With over 20 years of expertise ranging from Photonic Integrated Circuit (PIC) design to automotive industry, manufacturing and high volume scaling, our team combines technical excellence with scalable, high-quality, and cost-effective volume production capabilities.
Our mission is to redefine the standards of photonic integration and empower transformative advancements in AR, consumer electronics, and beyond.

Tim Tiek, co-founder & CEO
Automotive & semiconductor veteran

Douwe Geuzebroek, co-founder & CTO
Integrated Photonics expert

## Get in touch with us!

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