January 2025

White Paper

SA-Series for Commercial 3D-Sensing

Introducing: the first SWIR VCSEL sensing solution

Our SA-series product unlocks a high-performing and cost-effective Short-Wave Infrared (SWIR) Vertical Cavity Surface Emitting Laser (VCSEL) solution for cutting-edge applications: consumer mobile and AR/VR sensing, biomarker monitoring, to datacom and interconnects networking, automotive and industrial LIDAR.

This whitepaper provides an in-depth look at the challenges of existing SWIR solutions, the innovative InP technology behind the SA-series, its unique characteristics, and its wide array of current and next-generation applications.

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I. Why is this important?

The SA-series VCSEL products provide unmatched efficiency, scalability, and integration capabilities—empowering our customers to unlock the full potential of SWIR sensing, unattainable in the current market.

Short-Wave Infrared (SWIR) wavelengths, typically in the range of 1.0–2.5 microns (1,000–2,500 nm), play a crucial role in various technologies due to their unique optical properties. SWIR sensing is important for its ability to interact with materials and environmental conditions in ways that visible and other infrared wavelengths cannot. Existing and emerging applications in imaging, material detection, remote sensing, industrial automation, medical diagnostics, autonomous driving, data communication, to name just a few, have generated a lot of interest in semiconductor-based SWIR sources and detectors.

Currently SWIR sources (or light emitters) are based on decades-old technologies, namely light-emitting diodes (LEDs) and edge-emitting lasers (EELs). In the mature Near Infrared (NIR) wavelength range (700-1,000 nm), VCSELs have emerged as a more desirable choice due to its beam quality, compactness, compatibility with mobile applications, and ease of integration. The table below shows a high-level comparison for these three types of semiconductor light emitters.

Table 1. *State of semiconductor SWIR light sources (1,300~2,200 nm), desirable qualities highlighted*

	LEDs	EELs	VCSELs
Device footprint	100~1,000 µm	100~1,000 µm	**5~50 µm**
Integration	**Excellent**	Difficult	**Excellent**
Radiance	Low	**High**	**High**
Power consumption	High	High	**Low**
Efficiency	Low	**High**	**High**
Beam quality	Incoherent	Elliptical asymmetry	**Circular symmetry**
Spectral linewidth	Broad	**Narrow**	**Narrow**
Commercial availability	**Available** (Dowa, Ushio)	**Available** (Coherent, Vertilas)	**Not available before now**

Despite the clear advantages of VCSELs, it has not been feasible to volume-manufacture SWIR VCSELs. In Section II we recap the industry's challenges in the last 30 years to find a commercial solution, before describing our innovative breakthrough technologies in Section III.

II. Background and historical challenges

VCSELs require highly-reflective mirrors, which have been very challenging to create outside the conventional GaAs-AlAs material system in the NIR wavelength range. Industry and academia have tackled the SWIR VCSEL technology for over 30 years.

Crucial building blocks for VCSEL devices include (i) an active region that can provide high optical gain, (ii) high-reflectivity distributed Bragg reflector (DBR) mirrors at the bottom and top to form a vertical cavity.

Over the past 30 years, NIR VCSEL technology (700-1,000 nm) has made cheap, high performance, mass-producible lasers ubiquitous in a wide variety of mass-market commercial and industrial applications [1]. The commercial success of NIR VCSELs can be attributed to the unique material properties in the GaAs-AlAs alloy system. GaAs and AlAs are almost lattice-matched to each other yet with a remarkable contrast in the index of refraction (Δn=0.5). Highly reflective GaAs/AlAs DBR can be prepared in a homoepitaxial manner on GaAs substrates. Meanwhile, active regions with high optical gains can be epitaxially grown on the GaAs/AlAs DBRs.

When it comes to SWIR VCSELs [2], the most developed active regions (InGaAlAs, or InGaAsP) have to be prepared on InP substrates. Two common epitaxial DBRs grown on the InP substrate, InGaAsP/InP and InAlGaAs/InP [3], do not support a high index contrast (Δn ~0.2); more than 60 pairs of the quarter-wavelength layers are required for these DBRs to reach a high reflectivity. The Sb-based quaternary AlGaAsSb DBR on InP supports a greater contrast in optical index [5], but Sb-based epitaxy has not reached the state of maturity compared with As- and P-based compound semiconductors [3]. To circumvent the challenges in heteroepitaxial DBRs on InP, other approaches have also been pursued including:

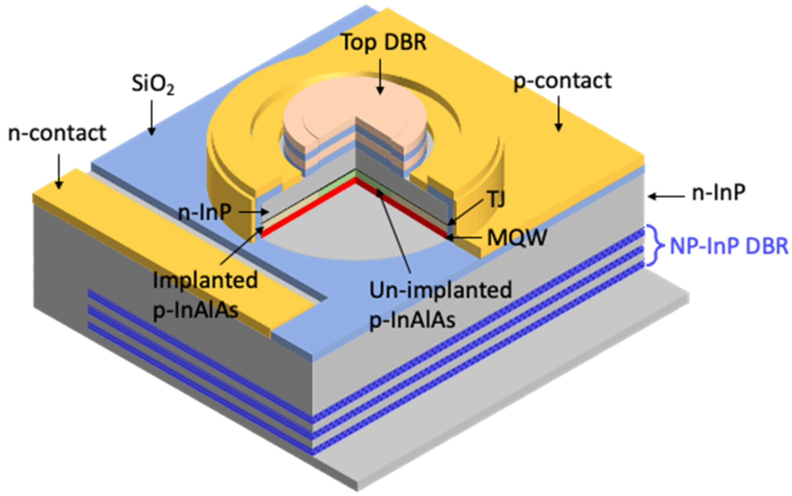
1) growth of long-wavelength active regions on GaAs substrates (InAs quantum dots, and dilute nitrides) [6,7];
2) use of InP/airgap DBR [4];
3) double-dielectric DBR [8,9]; and
4) wafer fusion of InP active region with AlGaAs DBRs [10,11].

However, none of the aforementioned approaches have successfully realized a scalable, mass-producible SWIR VCSEL; if not limited by complicated epitaxial growth, then by costly fabrication and processing.

III. How are we solving this problem?

Proprietary nanoporous InP (NP-InP) technology

We have developed a SWIR VCSEL that combines our proprietary homoepitaxial NP-InP bottom DBR with the mature InAlGaAs active region standard for 1,550 nm telecom lasers. Using a postgrowth, wafer-level electro-chemical process, we can fabricate highly-reflective NP-InP DBR mirrors (figure on the right). The fabrication process is monolithic and has been proven in semiconductor foundries.

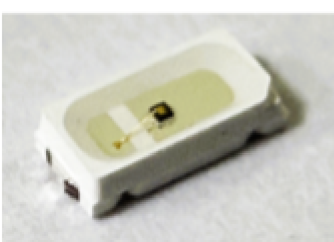


Compared to other existing SWIR VCSEL technologies, our process adopts a simple and mature epitaxial process with volume-manufacturable fabrication processes—and we are partnered with leading commercial foundries to deliver products at commercial volume.

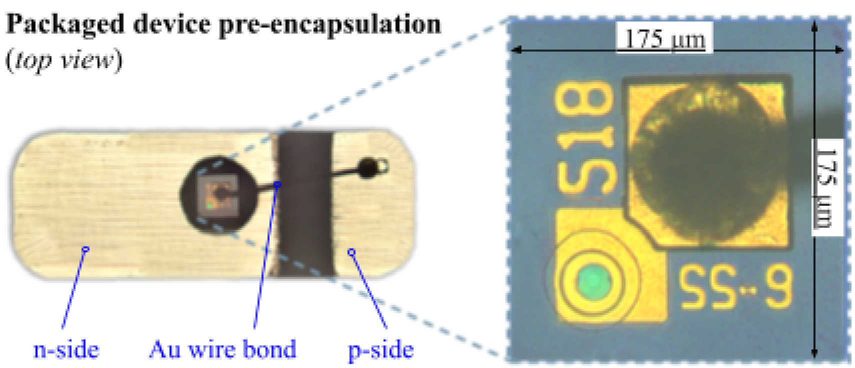
Key features of the SA-series

The SA-series are single aperture VCSELs designed for high-quality, single-mode emission in the 1.3-2.3 μm range, while maintaining low power consumption, low operation current, and high thermal stability, in a small form factor.

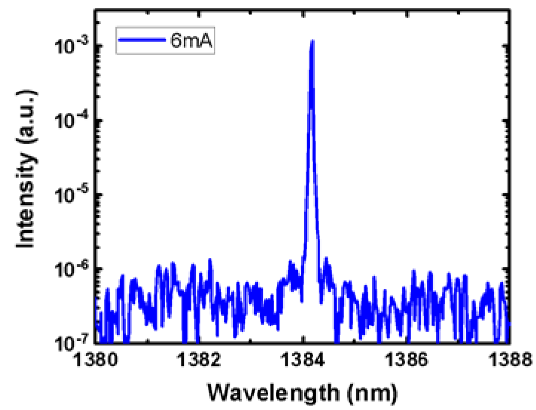
SMD packaged device
(*3D view*)



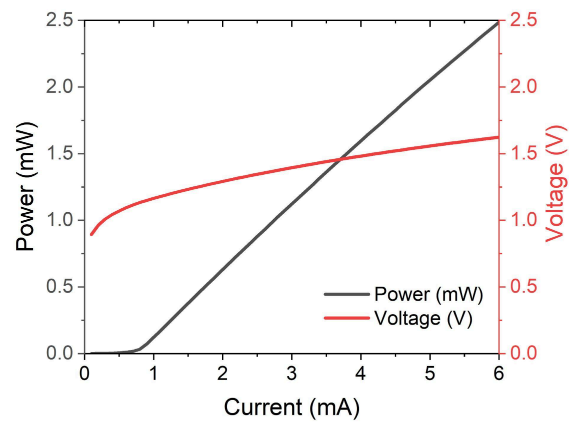
Packaged device pre-encapsulation
(*top view*)



- **High Efficiency:** Our products output at 2-3 mW (per aperture) with 30% peak power conversion efficiency (PCE) and a solid roadmap to be higher, and are otherwise comparable to 850 nm and 940 nm Near Infrared (NIR) VCSELs, which are the current industry solution for short-range and low-power consumer or industrial sensing applications. Compared to near-infrared (NIR) emission, the SWIR wavelength provides better eye safety, signal clarity, and under-display sensing.



- **Low lasing threshold:** Threshold current density is around 1 kA/cm^2, threshold current can be made as little as 0.5 mA for low-power, mobile applications.



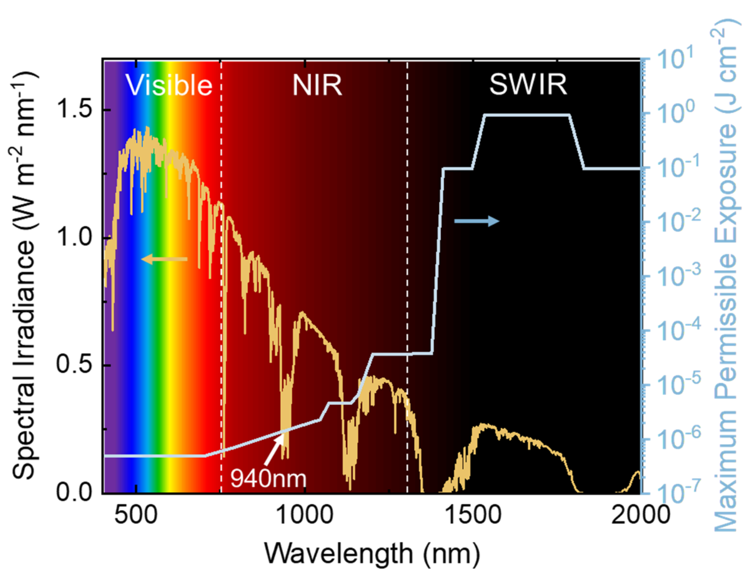
- **Single model and low divergence:** Single mode operations with a side-mode-suppression ratio (SMSR) close to 30dB. Depending on the aperture size, the divergence is between 10 to 20 degrees.

- **Reliability:** Our products have been qualified by industry standard wet and high temperature operating life testing (WHTOL) and environmental reliability testing.

IV. Applications

1) Immediate applications

Compared to NIR VCSELs, SWIR wavelengths remain eye-safe at higher power, while experiencing low solar background noise, resulting in higher signal-to-noise ratio (SNR) and significantly better image quality. SWIR is also better for all-environmental sensing, including night-time, rainy, cloud, dusty, and other adverse low-light



conditions. Combined with pulsed time-of-flight (TOF) operation, SWIR VCSELs can provide 3D-imaging with sharper depth contrast and real-time scanning.

- **Mobile & Consumer Sensing:** Our SA-series products are ready for “plug and play” use in mobile and consumer sensing applications currently using NIR VCSELs, e.g. proximity sensors in smartphones and other consumer electronics, household robotics, biorecognition security systems, etc.

- **Augmented Reality (AR) / Virtual Reality (VR):** The SA-series meets the increasing demand for precise depth sensing, real-time outdoor environmental mapping, and compact form factor for lightweight wearables.

- **Environmental Monitoring:** SWIR spectroscopy can be used to pollutants or trace gases in a variety of environmental, agricultural, and industrial settings. A SWIR VCSEL has efficient power consumption and stable operation at a wide temperature range, making it suitable for deployment in remote or harsh environments.

2) Next-generation applications

- **LiDAR (Light Detection and Ranging):** The eye-safe SWIR wavelengths are critically important for long-range LIDAR (>200 m), where high power laser operation is necessary to accurately map the environment for autonomous vehicles, drones, and more. SWIR VCSELs have the high power, low divergence, and cost-effectiveness necessary to support precise object sensing and recognition.

- **Data communications and Networking:** Currently NIR VCSELs (850 nm) are used for short-haul (<100 m) optical links in data centers. SWIR VCSELs are ideal as direct-modulated transducers to replace 1,300 and 1,550 nm edge-emitting lasers in mid-haul (100 m-10 km) applications in LAN, MAN, regional hub applications.

- **Biomarker Sensing and Imaging:** SWIR light is particularly effective in penetrating biological tissue, while also optically sensitive to many biomolecules of interest (blood glucose, blood oxygen, cortisol, and more). SWIR VCSELs are ideal for non-invasive wearable monitors or medical imaging applications because of their cost-effectiveness, miniaturized form factor, and low divergence, to enable high-quality imaging modalities.

- **Optical Computing:** SWIR VCSELs may enable silicon photonics integrated circuits (PIC) of future computing.

3) Customization available on request

We currently offer a 1,380 nm VCSEL (the SA-E02 VCSEL) but custom wavelengths, output power levels, and emission profiles are also available on request. Our simple design and process allow for on-demand and rapid integration with high-volume production lines to deliver specific customer needs.

We are customer-centric and eager to work closely with customers to understand specific requirements, use-case specifications, and develop a tailored solution for you. Please contact us at info@inphred.com for further inquiries.

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