IMM photonics

850 nm VCSELs
for Precision Sensing and System Integration

1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) operating at 850 nm have become a cornerstone of modern optical sensing and short-reach optical systems. Their appeal lies not only in efficiency and compactness, but in the degree to which optical, electrical, and mechanical properties can be engineered as a coherent whole.

The IMM Photonics 850 nm single-mode VCSEL platform is designed with this system perspective in mind. Devices emit around a nominal wavelength of 850 nm at room temperature, operate at typical currents of approximately 6 mA, and deliver optical output powers in the 1 mW class, as specified in the datasheet. Beyond nominal values, the focus is on reproducibility across production volumes, thermal stability, and predictable behavior after environmental stress.

This application note illustrates that philosophy using production-level measurements and extended characterization, showing how individual parameters — optical power, wavelength, beam quality, alignment, and monitoring — interact to define real-world system performance.

2. From Chip to Qualified Light Source: Production Testing Philosophy

For precision sensing and industrial applications, long-term stability and consistency are at least as important as initial performance. For this reason, all our 850 nm VCSELs undergo an elevated-stress burn-in process prior to final qualification.

Burn-in is performed for 24 hours at a temperature of approximately 100 °C with a drive current of 8 mA. This process is intended to accelerate early-life failure mechanisms while remaining within the absolute maximum ratings of the device.

Following burn-in, electro-optical measurements are carried out at room temperature (25 °C). Devices are screened against conservative acceptance criteria, requiring a threshold current of no more than 5 mA and a minimum optical output power of 0.55 mW at an operating current of 6 mA. These values represent screening limits, not typical operating performance. 99.5% of devices exceed these thresholds by a comfortable margin, reflecting the intrinsic robustness of the VCSEL design and the stability of the manufacturing process.

Why this matters - Early-life failures and performance drift are among the most expensive risks in optical systems. A production philosophy built around burn-in and conservative screening minimizes field failures and protects system stability over lifetime.

3. Optical Output Power and Efficiency in Context

The optical output power of the 850 nm VCSELs shows a clear and reproducible linear dependence on operating current over the intended operating range. Light–current characteristics measured at 25°C, as shown in Figure 1, confirm slope efficiencies centered around 0.4 mW/mA, in excellent agreement with the datasheet's typical value.

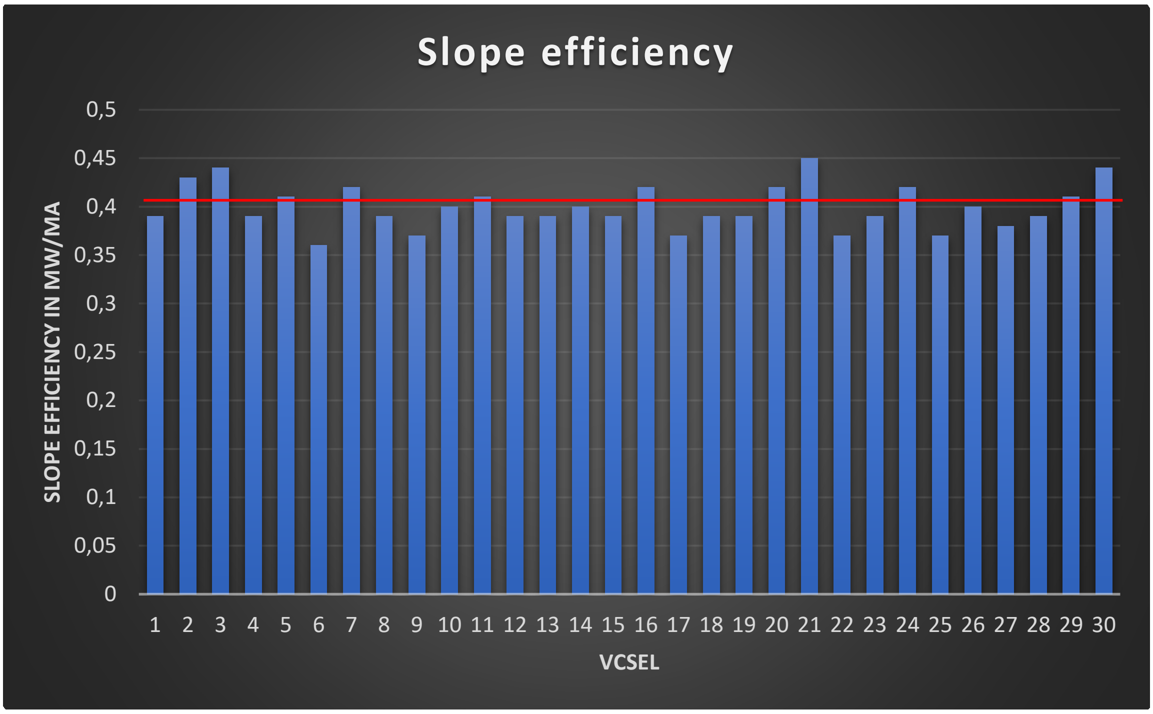


Figure 1

At an operating current of approximately 6 mA, typical devices deliver optical output powers in the range of 1 mW to 1.5 mW. In contrast, the 0.55 mW value used during production screening represents a deliberately conservative lower bound intended to guarantee sufficient margin after burn-in and over lifetime.

The relatively narrow spread in slope efficiency and output power across the measured population demonstrates a high degree of uniformity in gain and optical confinement.

Why this matters - Stable optical power and consistent efficiency directly translate into predictable signal quality, thermal behavior, and energy consumption. This reduces the need for overdesign and simplifies power budgeting at the system level.

4. Thermal Behavior and Spectral Stability

In many sensing and metrology systems, the absolute emission wavelength is less critical than its stability and predictability over temperature. The temperature dependence of the VCSEL emission wavelength and power was therefore examined between approximately 5 °C and 60 °C.

As shown in Figure 2, the emission wavelength shifts linearly with temperature, with a mean coefficient of approximately 0.053 nm/K. Device-to-device scatter around this mean value is small, and the measured coefficient aligns closely with both literature expectations and the datasheet specification of roughly 0.05 nm/K.

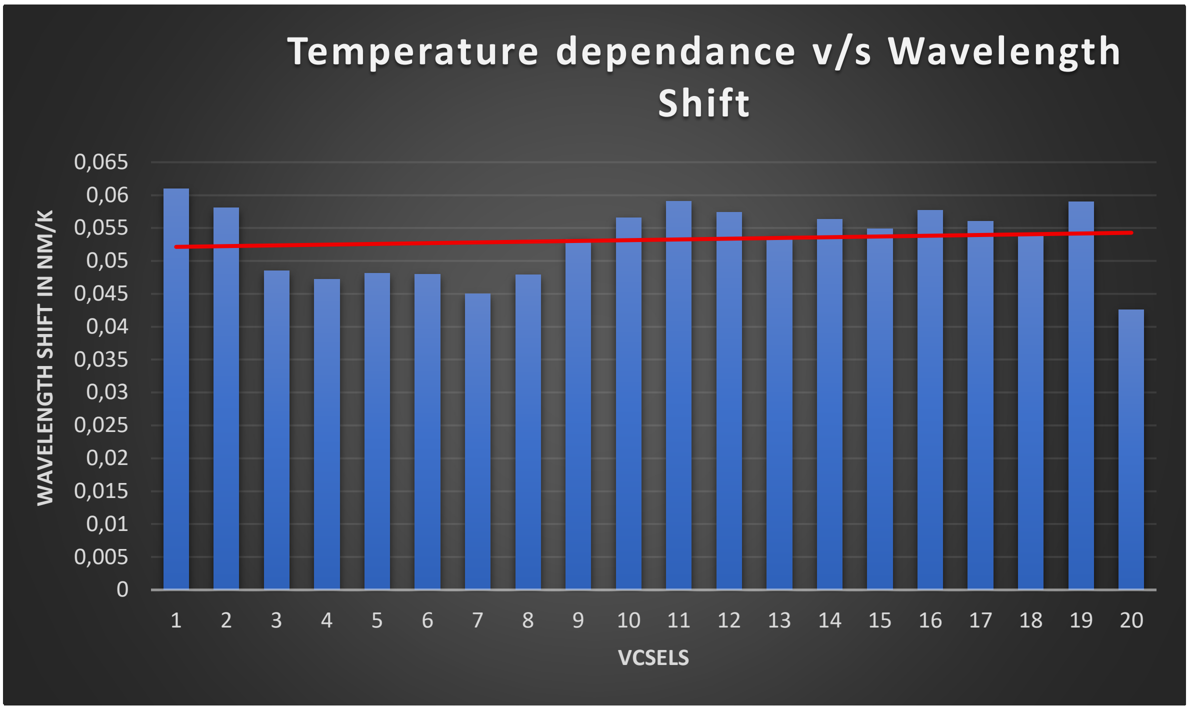


Figure 2

As can be seen in Figure 3, across 0–60 °C the devices show minimal unit-to-unit spread (≈ ±0.01 mW) and a smooth, temperature-dependent output: power rises gently from ~0.51 mW at 0 °C to a peak of ~0.56 mW near 20–25 °C (+~2.5 µW/°C), then decreases to ~0.40–0.41 mW at 60 °C (–~4.5 µW/°C).

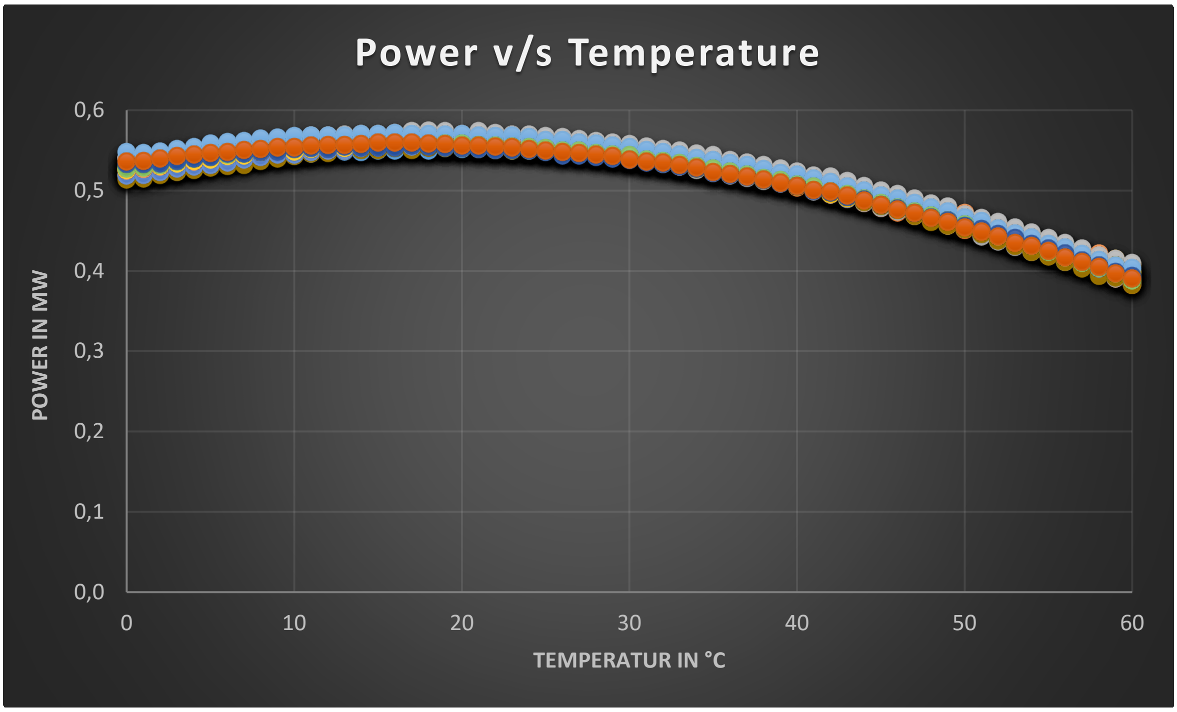


Figure 3

Why this matters - Temperature-induced wavelength shifts are unavoidable, but unpredictability is not. A well-defined and repeatable thermal coefficient allows designers to compensate analytically rather than adding complexity at the system level.

5. Beam Quality and Far-Field Characteristics

Beam quality plays a decisive role in coupling efficiency, illumination uniformity, and alignment tolerance. Far-field measurements were therefore carried out in accordance with DIN EN ISO 11146-1 using the full-width 1/e² definition.

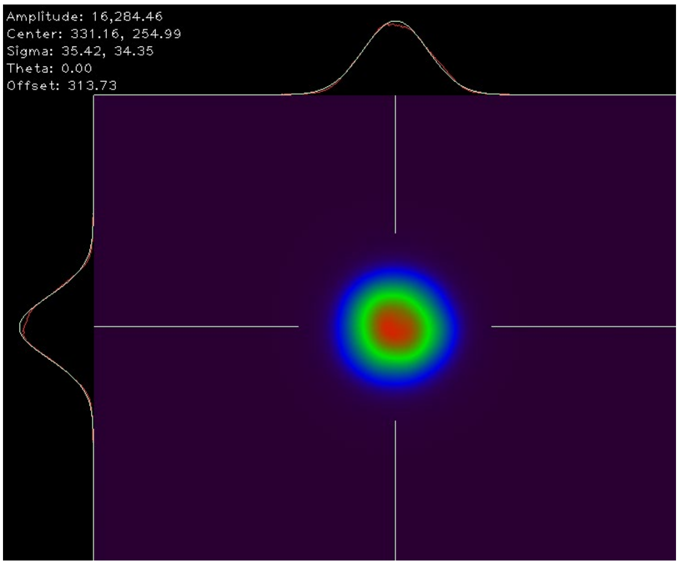


Figure 4

Figure 4 shows the beam profile while Figure 4a shows the measured far-field divergence at different operating currents. Typical values are approximately 14.35° in the X-direction and 14.70° in the Y-direction, well within the datasheet- specified range of 12° to 21° at 25 °C and 1 mW optical output.

The beam profile is close to circular and Gaussian. As can be seen in Figure 5, evaluation of beam ellipticity according to ISO 11146-1 confirms that nearly all devices satisfy the criterion ε ≥ 0.87 for circular beams. A slight increase in measured divergence with increasing drive current was observed and can be attributed primarily to measurement resolution effects at higher optical power rather than to a fundamental change in emission mode.

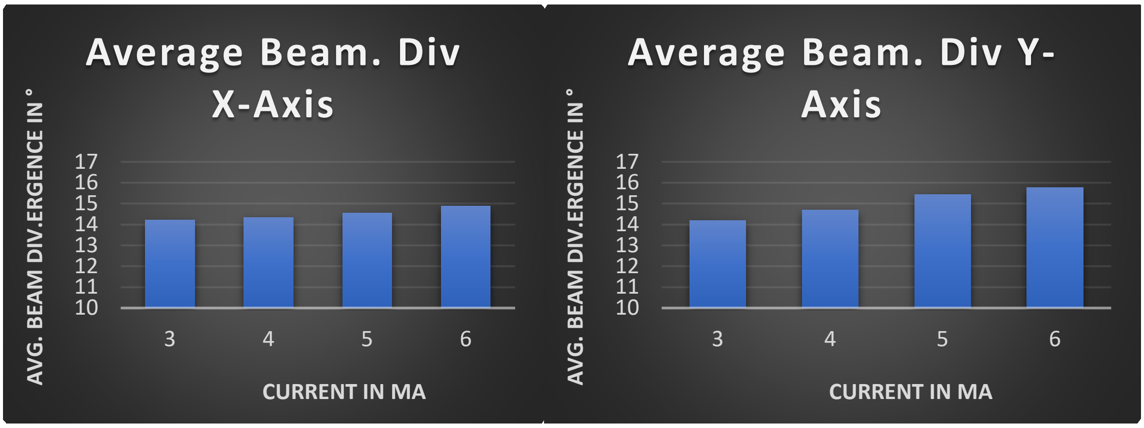


Figure 4a

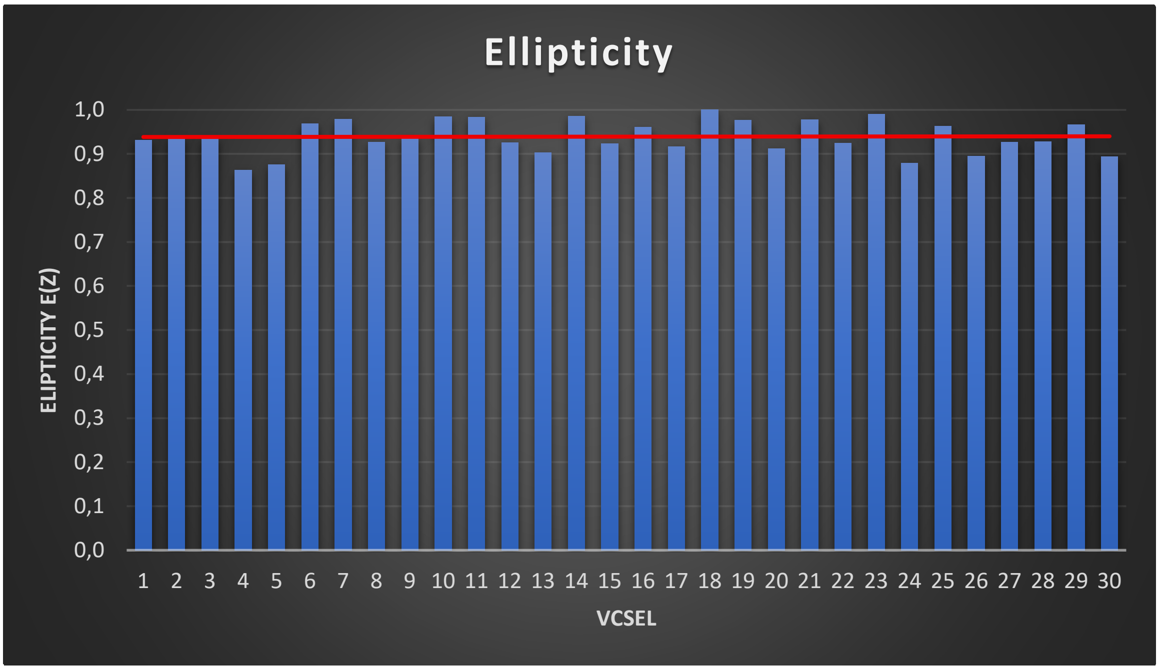


Figure 5

Why this matters - Beam divergence and symmetry determine how efficiently light can be coupled and how tolerant a system is to misalignment. Stable beam characteristics preserve performance when operating conditions or optical power change.

6. Packaging Accuracy and System-Level Alignment

In compact optical assemblies, mechanical tolerances directly influence optical performance, coupling efficiency, and feedback stability. For this reason, the positional accuracy of the VCSEL emitter within the TO-46 package is controlled and characterized at multiple integration levels.

At the chip-integration level, the VCSEL is placed on the micromodule with a lateral accuracy better than 36 µm. The micromodule itself is subsequently mounted onto the TO header with an additional placement tolerance below 40 µm. Taken together, this results in a maximum lateral deviation of approximately 80 µm between the VCSEL emitter and the TO header reference. According to package drawings and manufacturer specifications, the positional tolerance between the TO header and the TO cap is below 100 µm, leading to a worst-case total deviation of approximately 180 µm between the VCSEL emitter and the TO cap.

Angular orientation was evaluated independently and is summarized in Figure 6. The nominal design orientation of 135° is reproduced with a measured mean of approximately 133.9°, with only two clearly identifiable outliers. For the majority of devices, the combined control of lateral placement and angular alignment results in highly reproducible optical coupling conditions and stable monitor photodiode behavior.

These results illustrate that packaging accuracy is not treated as a post-process constraint, but as an integral part of the VCSEL platform design and qualification strategy.

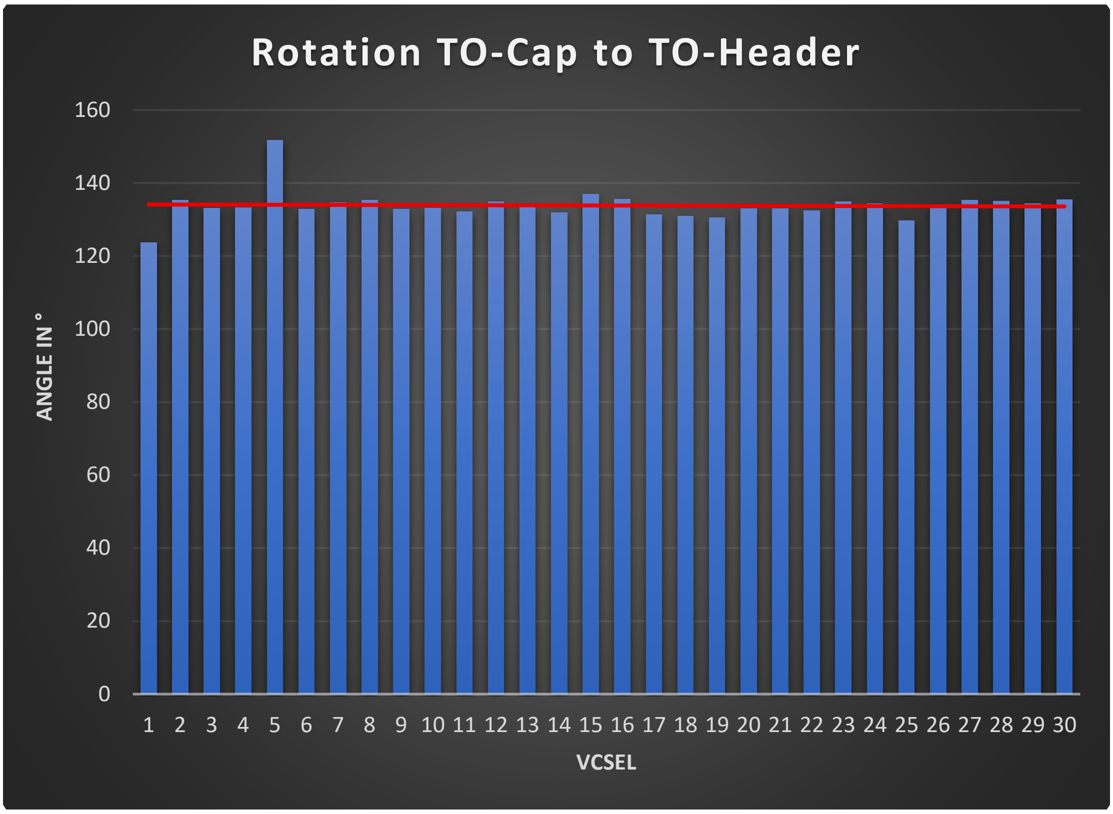


Figure 6

Why this matters - Precise control of emitter position and orientation directly determines coupling efficiency, feedback accuracy, and assembly yield. Defined and verified tolerances at each integration step reduce alignment effort and protect system performance in compact optical designs.

7. Integrated Photodiode: Enabling Closed-Loop Control

For VCSEL variants equipped with an integrated monitor photodiode, the relationship between optical output power and photodiode current was investigated in detail. Figure 7 shows a clear linear correlation between emitted optical power and photodiode current over the operating range.

At an optical output power of 1 mW, as shown in Figure 7, the measured photodiode current has a typical value of approximately 41 µA, in excellent agreement with the datasheet specification. The extracted mean responsivity is approximately 39 µA/mW.

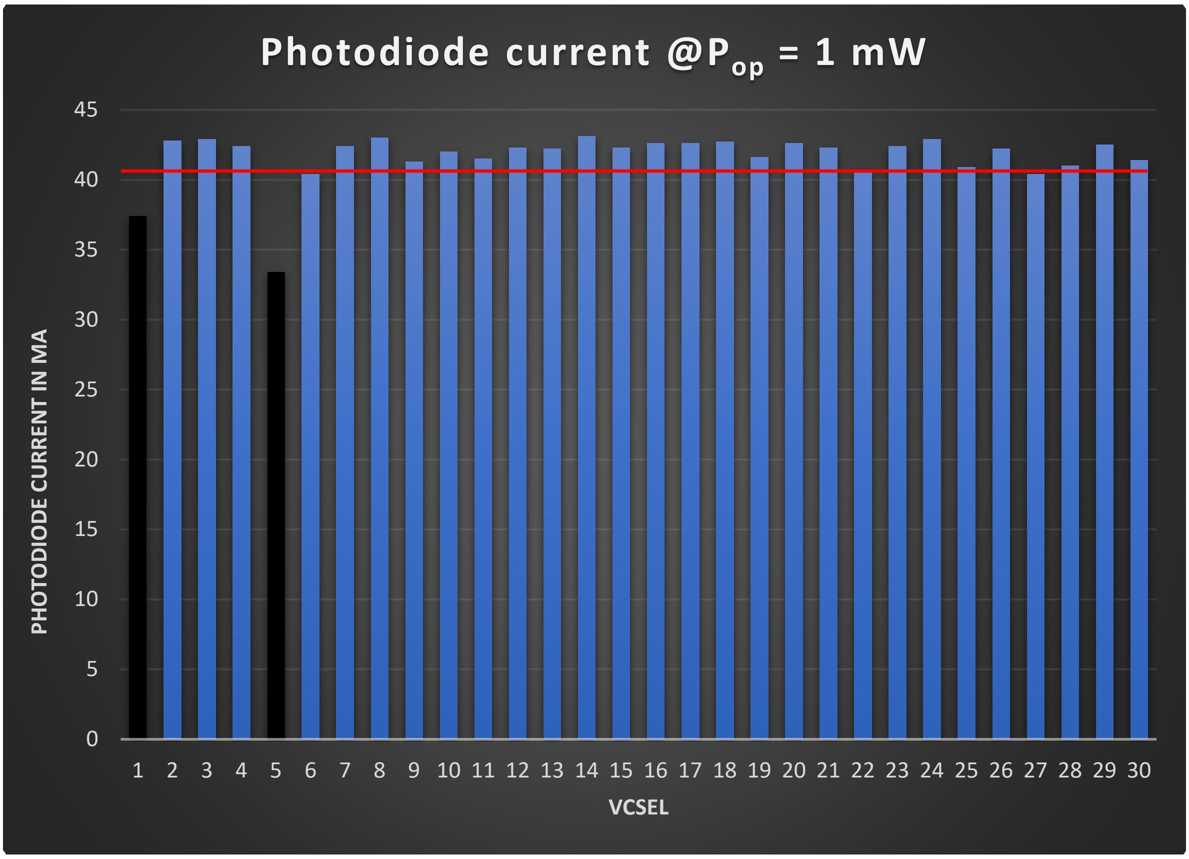


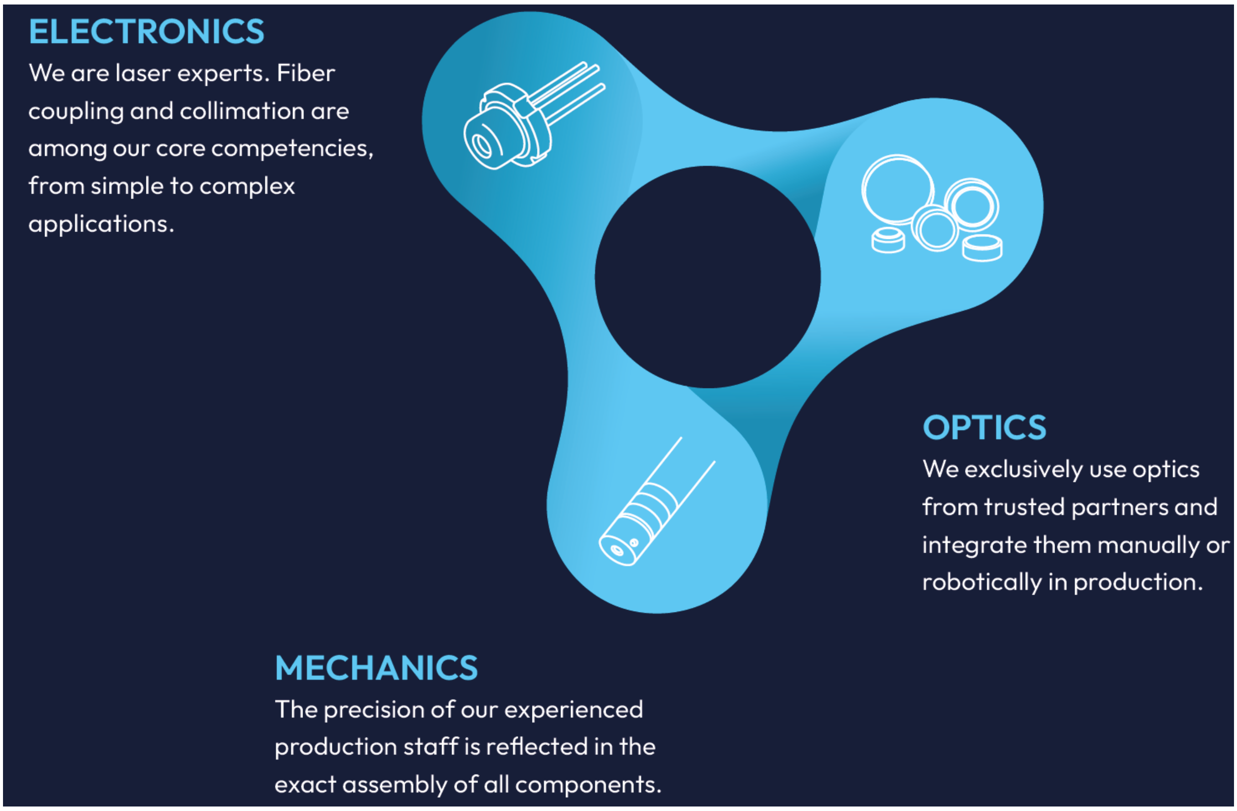
Figure 7

Only a small number of outliers were observed, and these correlate with deviations in angular alignment discussed earlier. For the majority of devices, the low scatter in responsivity makes the integrated photodiode a reliable element for quantitative power monitoring and closed-loop stabilization.

Why this matters - Mechanical tolerances directly impact optical coupling, feedback accuracy, and long-term stability. Tight packaging control reduces alignment effort and increases robustness in compact or mechanically stressed systems.

8. Customization and Integration: A Platform Perspective

While the measurements presented here focus on a specific 850 nm single-mode VCSEL configuration, the underlying intent is broader. Many applications require tailored combinations of optical output power, beam divergence, photodiode sensitivity, electronics, and package geometry — and these requirements rarely exist in isolation.



ELECTRONICS
We are laser experts. Fiber coupling and collimation are among our core competencies, from simple to complex applications.

OPTICS
We exclusively use optics from trusted partners and integrate them manually or robotically in production.

MECHANICS
The precision of our experienced production staff is reflected in the exact assembly of all components.

IMM Photonics approaches such challenges through a tightly coupled **electronics–optics–mechanics integration philosophy**. Laser drive electronics, fiber coupling or free-space collimation, and mechanical assembly are developed and optimized together, ensuring that optical performance is preserved as systems scale from simple modules to complex, highly integrated solutions.

Optics from trusted partners are integrated manually or robotically in production, while experienced assembly processes ensure that mechanical precision directly supports optical and electrical stability.

By maintaining control across these disciplines, application-specific adaptations can be realized without compromising the core characteristics demonstrated in this study — including slope efficiencies around 0.4 mW/mA, wavelength stability of approximately 0.05 nm/K, and reproducible beam quality. In this context, the VCSEL is not treated as a commodity component, but as a configurable optical engine embedded within a system architecture designed for precision, scalability, and long-term reliability.

Why this matters - System performance is defined at the interfaces between electronics, optics, and mechanics. A platform that integrates all three reduces integration risk and enables faster, more reliable deployment in real applications.

9. Outlook

As VCSEL-based systems continue to evolve toward higher integration and tighter performance margins, the boundary between component behavior and system performance will increasingly disappear. Building on the characterization results presented in this application note, IMM Photonics is extending its VCSEL platform toward actively stabilized, functionally integrated laser modules.

In the near term, this includes the integration of temperature sensors (NTC) and thermoelectric coolers (TEC) directly into VCSEL modules. By combining the intrinsic wavelength stability of the VCSEL chip with active thermal monitoring and control, these modules enable precise wavelength positioning and improved output stability under dynamically changing environmental conditions. First prototype modules with integrated NTC and TEC functionality are targeted for availability to key customers in 2026, addressing applications such as interferometry, spectroscopy, short-range LiDAR, and medical sensing.

Beyond thermal integration, longer-term development focuses on the co-integration of micro-optics directly at the VCSEL or package level. This includes microlenses and diffractive optical elements (DOE) for beam shaping, structured illumination, and application-specific far-field profiles, as well as advanced fiber-coupling concepts, including polarization-maintaining interfaces. By reducing external alignment steps and optical interfaces, such integration enables more compact, robust, and scalable laser modules.

In parallel, IMM Photonics continues to expand its VCSEL portfolio, packaging concepts, and manufacturing capabilities, supporting a broader range of wavelengths, output powers, and system configurations. The goal is not only to extend the range of available VCSEL products, but to evolve toward fully integrated optical engines that combine emitter, optics, electronics, and thermal management within a single, application-ready platform.

Active thermal control and integrated micro-optics shift complexity from the system to the module, improving stability and reducing integration effort. A continuously expanding portfolio and packaging capability ensures that future applications can be addressed with scalable, production-ready solutions rather than bespoke designs.

Taken together, these developments reflect a clear direction: as optical systems move toward higher integration and tighter performance margins, reliable system behavior can no longer be achieved through component selection alone. By combining rigorous characterization with the integration of thermal control, micro-optics, electronics, and advanced packaging, IMM Photonics is evolving the VCSEL from a standalone light source into a scalable, application-ready optical engine — designed to translate measured performance into predictable results from prototype to volume production.

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Release date: February 2026