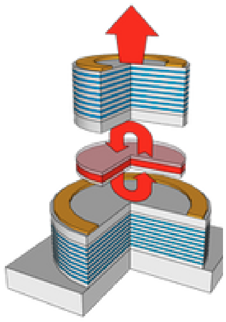
VECTOR PHOTONICS

Imagine a Surface-Emitting laser with the power to replace Edge-Emitters

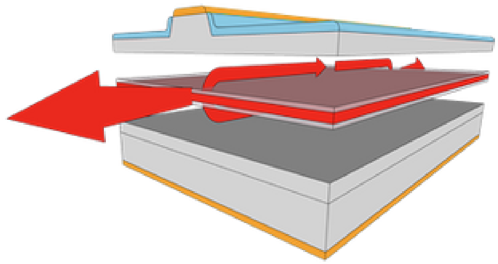
White Paper

INTRO

As photonic technologies continue to evolve, Vertical-Cavity Surface-Emitting Lasers (VCSELs) have established themselves as a superior alternative to traditional edge-emitting lasers (EELs) in a growing number of applications. However, the VCSELs have key limitations to EELs, which prevent them dominating in all market areas. This white paper outlines the critical advantages of surface-emitting lasers in terms of performance, scalability, efficiency, and integration, and explores how these benefits are reshaping the landscape of optical communication, sensing, and consumer electronics.



VCSEL



EEL

ADVANTAGES OF SURFACE-EMITTING LASERS

PACKAGING COSTS

Packaging EELs involves a complex and waste-prone process. Each device must first be singulated from the wafer, then undergo precision facet coating which often requires delicate handling. Only after individual packaging can the devices be tested, by which point any units that fail to meet performance specifications have already incurred significant processing and assembly costs.

In contrast, surface-emitting lasers offer a major advantage as they can be tested directly at the wafer level before dicing and packaging. This capability enables early yield screening, reduces unnecessary packaging of subpar devices, and supports more efficient, automated manufacturing workflows.

BEAM QUALITY

Surface emitting lasers emit a circular beam with low divergence, which makes them ideal for applications that require collimation or coupling into optical fibres. This beam shape is particularly beneficial in optical interconnects and sensing technologies. EELs produce elliptical beams due to small asymmetric apertures, meaning that they require external optics which integrated into photonics systems.

$$\vartheta = M^2 \lambda / \pi w_0$$

SPECTRALLY PURE

They can often operate in a single longitudinal mode, producing spectrally pure emission spectrum. This feature is crucial in high-precision applications such as spectroscopic sensing or high-speed optical communication, where signal clarity and stability are paramount.

VCSEL LIMITATIONS

LOW OUTPUT POWER

VCSELs have relatively low output power compared to EELs, which restricts their use in high-power or long-range applications.
To maintain single-mode operation, the VCSEL must be kept small, which inherently increases its electrical resistance. The need to inject current through the DBR stack further adds to this resistance. As a result, the device experiences significant heating at higher currents, leading to an early power rollover and limiting its maximum output power.

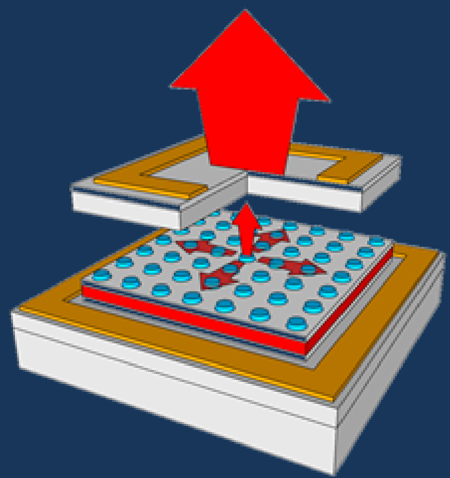
LIMITED WAVELENGTH RANGE

VCSELs face challenges operating beyond 980 nm due to material limitations, restricting use in systems requiring longer wavelengths. In GaAs, the refractive index contrast is 0.24, while in InP it's only 0.08, requiring ~19 μm DBR stacks to exceed 90% reflectivity at 1310 nm or 1550 nm. These thick stacks increase thermal and electrical resistance, complicate fabrication, lengthen growth times, and raise defect risks—ultimately reducing efficiency, reliability, and manufacturability.

Although EELs currently dominate high-power, long-distance, and long-wavelength applications, advancing surface-emitting lasers to match these capabilities would be a major breakthrough. Combining VCSELs' manufacturing advantages with broader applicability could significantly disrupt the EEL market.

PCSELS

PCSELs (Photonic Crystal Surface Emitting Lasers) represent the latest advancement in semiconductor laser technology. As surface-emitting devices, they combine the improved beam quality of VCSELs with power levels comparable to EELs. This combination of high performance and efficient packaging positions PCSELs as a promising alternative to DFB lasers in next-generation photonic systems.



PCSEL ADVANTAGES

HIGH OUTPUT POWER • GAUSSIAN BEAM

The large and symmetric aperture of PCSELs naturally reduces divergence. While grating design can ensure single mode high M^2 values. A diffuse grating can reduce lateral confinement and allow large apertures. Scaling PCSELs increases output power but at a comparatively low OPD at the facet, optical power levels achievable with PCSELs would result in COD for EELs. This combination of a high power and low divergence gives rise to ultra-high brightness:

$$L = P/A\Omega$$

WAVELENGTH FLEXIBILITY

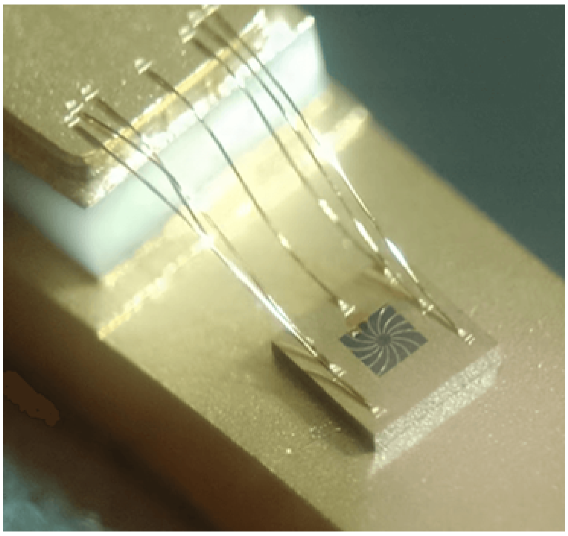
PCSELs can be designed to emit at a wide range of wavelengths by adjusting the semiconductor material system and engineering the photonic crystal pattern. The in-plane feedback provided by the photonic crystal allows for efficient lasing without relying on traditional vertical cavity constraints. This design flexibility enables PCSELs to operate from the visible to the infrared spectrum, supporting a broad range of applications across different industries.

COHERENT ARRAYS

PCSELs use 2D, facet-free in-plane feedback to enable coherently coupled arrays, with laser elements linked via coupler regions to maintain phase coherence. This allows focused, high-density beams. The in-plane coupling also supports power scaling in n×n arrays, delivering large coherent power.

SUMMARY

Surface-emitting lasers mark a major shift in optoelectronics, offering advantages in manufacturability, beam quality, and integration. While VCSELs have proven effective in specific markets, their limited wavelength range and power restrict broader adoption. PCSELs address these gaps by combining scalable surface-emitting designs with high-power, wide-wavelength performance, enabling new applications and offering a viable alternative to edge-emitters. Though EELs will remain in niche roles, surface-emitting technologies like PCSELs are set to shape the future of laser systems.



Vector Photonics' PCSEL bonded on AlN tile

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