VECTOR® PHOTONICS

PCSEL Technology: A New Generation of High-Power Surface-Emitting Lasers

White Paper

INTRO

Photonic Crystal Surface-Emitting Lasers (PCSELs) represent a major leap in surface-emitting laser technology. By combining high brightness, scalable coherent emission, and precise beam control, PCSELs overcome the limitations of conventional VCSELs and edge-emitting lasers. This white paper highlights the core advantages of PCSELs (power, integration, and performance), positioning PCSELs as a key enabler of next-generation photonic systems.

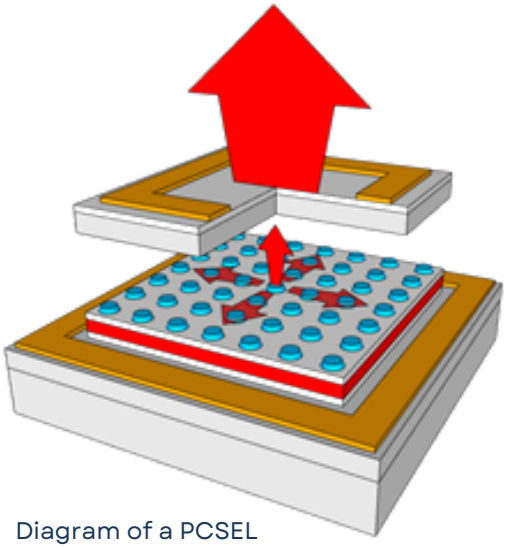
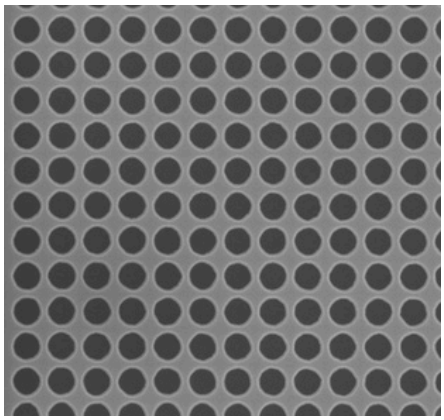


Diagram of a PCSEL

PCSEL FUNDAMENTALS

Photonic Crystal Structure: PCSELs contain a two-dimensional photonic crystal in the laser cavity to control the flow of light, enabling single-mode, high-coherence emission across a large area. A photonic crystal is a structure with a periodic variation in refractive index on the scale of the wavelength of light. Changing the shape of the photonic crystal repeating pattern allows you to control the output of the device.

Surface Emission: Unlike edge-emitting lasers, PCSELs emit light perpendicular to the wafer surface, allowing simpler integration into arrays and optical systems. By being surface-emitting, they are easier to test, cheaper to package, and allow for packaging known good devices. This reduces the cost of packaging compared to edge-emitting lasers.



SEM image of a photonic crystal

Large-Area Coherent Output: The photonic crystal lattice enforces coherent emission over a larger aperture, producing a high-brightness, low-divergence beam.

Wavelength Control: The periodic photonic crystal structure defines the lasing wavelength, providing precise control and stability without complex external optics. PCSELs allow for surface emitting lasers in any material stack, whereas VCSELs are limited to short wavelengths.

Scalable Power: By designing the photonic crystal geometry, PCSELs can scale to higher output powers while maintaining beam quality.

PCSEL EPITAXY

PCSEL devices are typically grown via standard III–V semiconductor epitaxy, forming layered structures similar to distributed feedback (DFB) lasers. The active region, waveguide, and cladding layers are deposited using established techniques like MOCVD or MBE, often with materials already common in DFB production. Most PCSEL designs resemble conventional DFB stacks, with the main difference being a two-dimensional photonic crystal pattern. This similarity allows PCSEL fabrication to leverage existing DFB processes and infrastructure, enabling a straightforward transition while retaining mature laser manufacturing workflows.

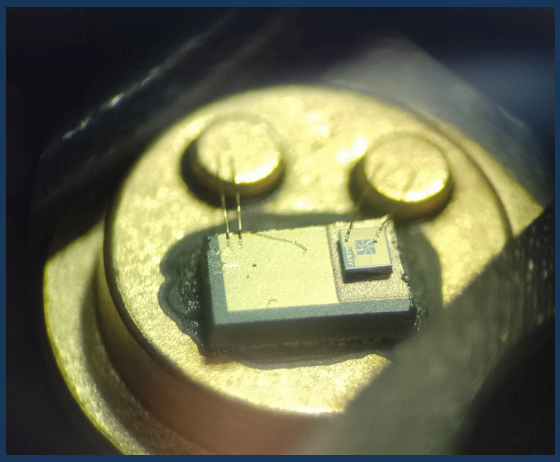
ALL-SEMICONDUCTOR FABRICATION

Photonic crystals formed using etched air holes can reduce device reliability, as the etching process introduces surface states and dangling bonds that reduce the reproducibility and reliability of devices. In contrast, all-semiconductor PCSELs form the photonic crystal through variations in semiconductor refractive index within the epitaxial layers, maintaining a continuous material structure. This approach reduces optical losses, improves thermal conductivity, and enhances structural robustness. Because the photonic crystal remains embedded within the semiconductor, fabrication is also more compatible with established semiconductor processes, supporting higher yield, scalability, and long-term device stability.

This monolithic approach enables scalable manufacturing and supports the creation of large-area coherent emitters while maintaining the reliability and reproducibility typical of semiconductor laser fabrication.

PACKAGING

Packaging is often designed to be compatible with standard semiconductor laser modules, allowing PCSELs to be integrated into existing optical and electronic systems with minimal redesign. This includes matching form factors, electrical interfaces, and thermal management solutions used in conventional laser modules. By aligning with established module standards, PCSELs can leverage existing assembly, testing, and mounting processes, simplifying system-level adoption and reducing time-to-market.



Vector Photnics' PCSEL bonded into a TO-Can

SURFACE-EMITTING

Being surface-emitting, PCSELs allow light to exit perpendicular to the wafer surface, simplifying packaging, optical alignment, and integration with other photonic components. This geometry enables compact, planar arrays and easy coupling to lenses or fibers, unlike edge-emitting lasers that require precise edge alignment. The surface-emitting nature also reduces the likeliness of catastrophic optical damage, which affects edge-emitting lasers largely. Surface emission also supports uniform beam profiles and scalable power by tiling multiple devices on a single substrate.

COHERENT ARRAYS

PCSELs are naturally suited for forming coherent laser arrays because of their intrinsic single-mode, spatially coherent emission over a broad aperture. When multiple PCSELs are arranged in an array and phase-locked, they can emit in a fully coherent fashion, producing a combined beam with much higher power while maintaining diffraction-limited beam quality. This enables scalable, high-brightness laser sources that exceed the output of a single device without sacrificing beam coherence.

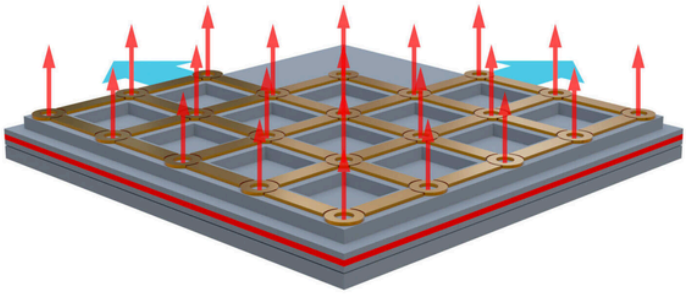
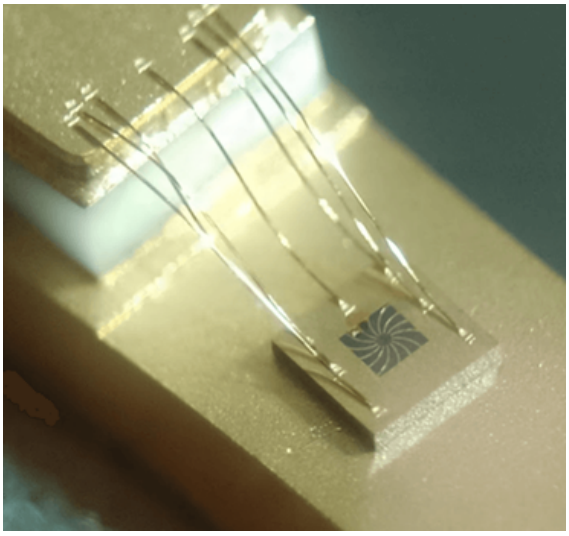


Diagram of a PCSEL array

Coherent PCSEL have potential for beam shaping and steering through controlled phase differences between elements, potentially replacing bulky mechanical systems with fast, electronic beam steering.

SUMMARY

A photonic crystal surface-emitting laser (PCSEL) is a semiconductor laser that combines a two-dimensional photonic crystal with standard III–V epitaxial structures to produce single-mode, spatially coherent light over a large area. Emitting perpendicular to the wafer surface, PCSELs simplify packaging and optical integration, while all-semiconductor designs reduce losses and improve yield and reliability. Their scalable coherence enables high-power outputs, coherent arrays, and beam shaping, making them the next generation of laser suitable for optical communication.



Vector Photonics' PCSEL bonded onto AlN tile

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