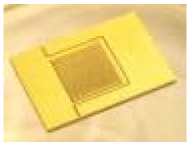
PRINCETON OPTRONICS



Princeton Optronics' Advanced High-Power Diode Lasers

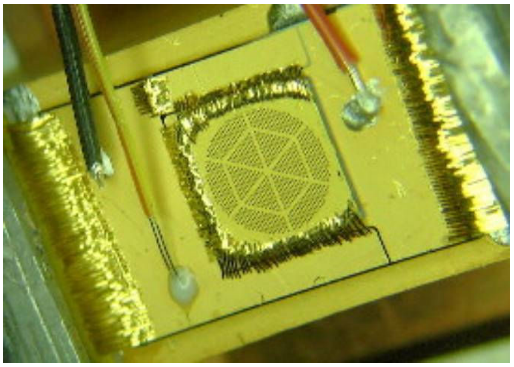
Princeton Optronics designs and manufactures advanced high-power CW and QCW diode lasers for the industrial, medical, and defense markets. Princeton Optronics' innovative approach is based on the Vertical-Cavity Surface-Emitting Laser technology (VCSEL for short), enabling us to manufacture and deliver laser diodes with exceptionally high reliability, and superior spectral and beam properties.

From Sub-milli-Watts to Hundreds of Watts (>1kW/cm^2 Power Density)

Vertical-Cavity Surface-Emitting Lasers were initially introduced in the mid-90's as a low-cost alternative to edge-emitters, for use as a low-power source (sub-mW to a few mW) in datacoms and telecoms. Within two years of their introduction, VCSELs overwhelmed and replaced the edge-emitter technology in these markets due to their better beam quality, reduced manufacturing costs and much higher reliability. Now, a new class of VCSELs has been developed for high power applications. Princeton Optronics is the first company to introduce such high power VCSEL products to the market.

Unlike edge-emitters, the light emits perpendicular to wafer surface for VCSELs. It is therefore straightforward to process 2-D arrays of small VCSEL devices driven in parallel to obtain higher output powers. The advantage of 2D arrays is that it has simple silicon IC chip-like configuration and many of the silicon IC packaging and cooling technology can be applied to VCSEL arrays.

Princeton Optronics has taken the VCSEL technology to very high power levels by developing very large (5mm x 5mm) 2-D VCSEL arrays packaged on high-thermal-conductivity submounts. These arrays are composed of thousands of low-power single devices driven in parallel. Using this approach, record CW output powers in excess of 230W from a 0.22cm^2 emission area (>1kW/cm^2) have been demonstrated, without sacrificing wall-plug efficiency.



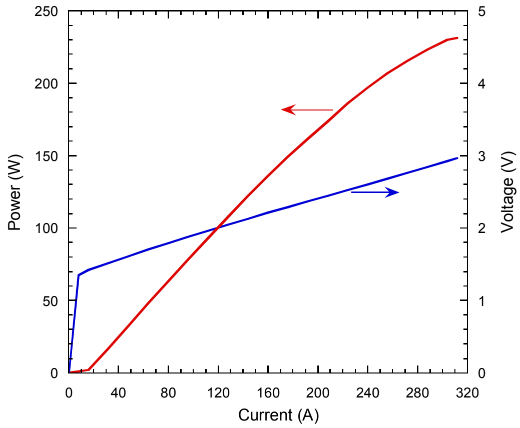


Figure 1 Picture of high-power 5mm x 5mm 2-D VCSEL array mounted on a micro-cooler and measure CW output power and voltage at a constant heat-sink temperature. Roll-over power is >230W.

High Temperature Operation

Because VCSELs can operate reliably at temperatures up to 80 °C, they do not necessarily require refrigeration. Additionally, since the wavelength change with temperature is small, the cooling system design can be considerably simplified. The cooling system thus becomes very small, rugged and portable with this approach.

Very high-power density QCW operation

In addition to CW VCSEL arrays, Princeton Optronics has developed very high power density VCSEL arrays for quasi-CW (QCW) operation. QCW powers in excess of 100W have been demonstrated from very small arrays (0.028cm^2 area), resulting in record power densities >3.5kW/cm^2. These small arrays can easily be connected in series to form larger arrays with high output powers. These arrays are ideal for applications requiring very compact high-power laser sources.

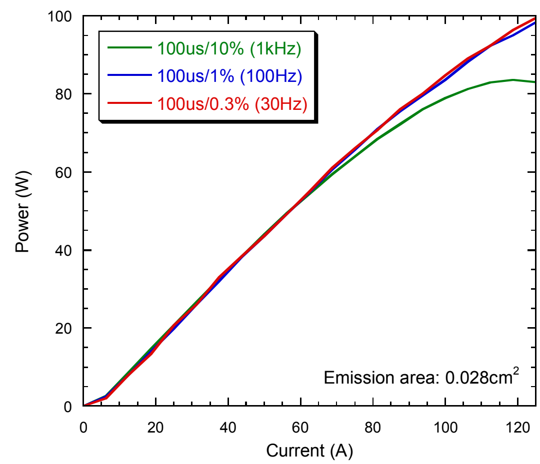


Figure 2 Power vs. current for a small VCSEL 2D array under different QCW regimes. These arrays exhibit power densities >3.5kW/cm^2.

High-brightness arrays

Princeton Optronics has also developed large 2D VCSEL arrays of small single-mode devices for applications requiring high brightness. Such arrays are made of thousands of small, low single-mode power devices. The output of this array can then be focused into a very small, low-diverging spot using a micro-lens array / focusing-lens system. This technology enables the coupling of ~100W power from a single source into a 400µm-diameter fiber for example, making these arrays ideal for fiber-laser applications. High-brightness products will be introduced in the later part of 2007.

The VCSEL reliability advantage

In terms of reliability, VCSELs have an inherent advantage over edge-emitters because they are not subject to catastrophic optical damage (COD). Indeed, the problem of sensitivity to surface conditions for edge-emitters is not present in VCSELs because the gain region is embedded in the epi-structure and does not interact with the emission surface.

Over the years, several reliability studies for VCSELs have yielded FIT rates (number of failures in one billion device-hours) on the order of 1 or 2, whereas FIT rates for the

highest telecom-grade edge-emitters is on the order of 500. The failure rate for industry-grade high-power edge-emitter bars or stacks is even worse.
Princeton Optronics has accumulated hundreds of thousand device-hours on VCSELs operating above 100°C.
This reliability advantage will be very significant for laser systems, where the end-of-life and field failures are overwhelmingly dominated by pump failure. Moreover, VCSEL arrays can be operated at higher temperatures, resulting in lower power consumption of the overall laser system. Princeton Optronics has demonstrated reliable operation up to 80°C.

High Wavelength Stability and Low Temperature Dependence

Since the VCSEL resonant cavity is defined by a wavelength-thick cavity sandwiched between two distributed Bragg reflectors (DBRs), devices emit in a single longitudinal mode and the emission wavelength is inherently stable (<0.07nm/K), without the need for additional wavelength stabilization schemes or external optics, as is the case for edge-emitters. Furthermore, thanks to advances in growth and packaging technologies, the emission wavelength is very uniform across a 5mm x 5mm VCSEL array, resulting in spectral widths of 0.7~0.8nm (full-width at half-maximum).
This wavelength stability and narrow spectral width can be very significant advantages in pumping applications for example where the medium has a narrow absorption band.

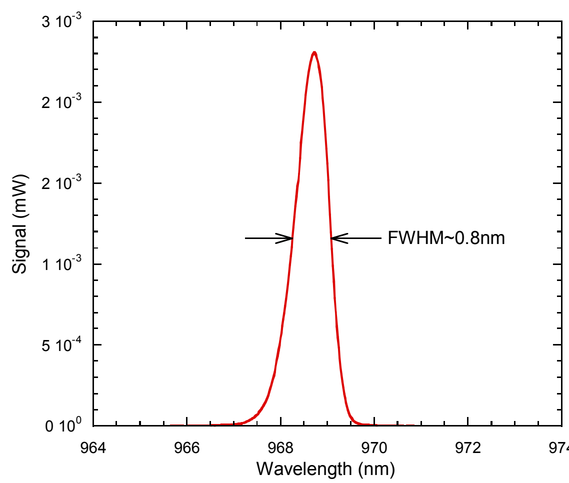


Figure 3 Emission spectrum of a 5mm x 5mm VCSEL array at 100W output power (120A).

Circular output beam

Unlike edge-emitters, VCSELs emit in a circularly symmetric beam with low divergence without the need for additional optics. This has been a tremendous advantage for low-power VCSELs in the telecom and datacom markets because of their ability to directly couple to fibers ("butt-coupling") with high coupling efficiency.
Princeton Optronics' high-power VCSEL arrays emit in a quasi-top-hat

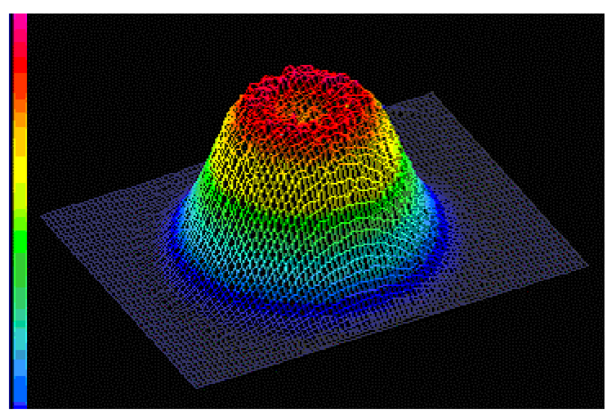


Figure 4 Far-field beam profile of a 5mm x 5mm VCSEL array at 100W output power (120A).

beam profile, making these devices ideal for direct pumping ("butt-pumping") of solid-state lasers.

Feedback insensitivity

In VCSELs, the as-grown output coupler reflectivity is very high (typically >99.5%) compared to edge-emitters (typically <5%). This makes VCSELs extremely insensitive to optical feedback effects, thus eliminating the need for expensive isolators or filters in some applications.

Low thermal impedance & ease of packaging

Princeton Optronics has developed advanced packaging technologies, which enables efficient and reliable die-attach of large 2-D VCSEL arrays on high-thermal-conductivity submounts. The resulting submodule layout allows for straightforward packaging on a heat-exchanger.

For high-power devices packaged on micro-coolers, Princeton Optronics has demonstrated modules with thermal impedances as low as 0.15K/W (between the chiller and the chip active layer). Princeton Optronics can provide its customers with several heat-exchanger and heat-sinking application notes.

Princeton Optronics, Inc. * 1 Electronics Drive * Mercerville, New Jersey 08619
Voice: (609) 584-9696 * Fax: (609) 584-2448 * E-mail: sales@princetonoptronics.com * www.princetonoptronics.com