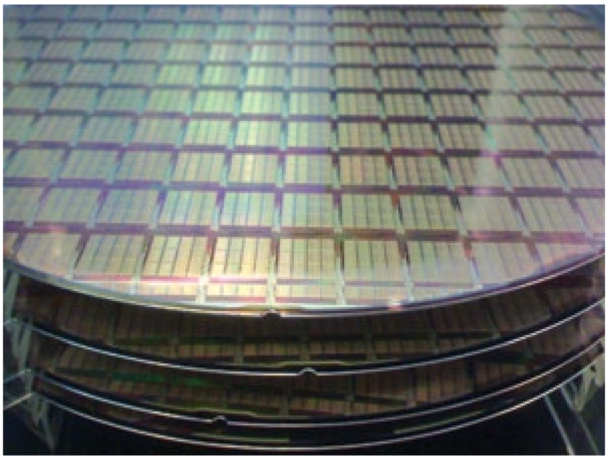
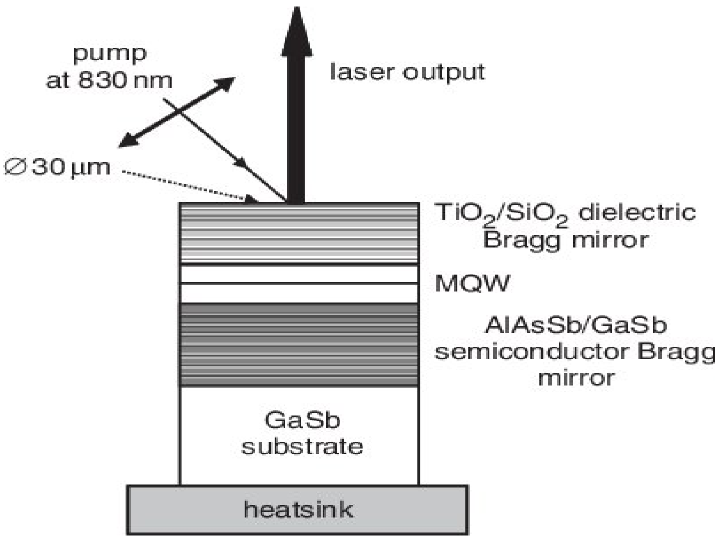
Spectroscopy in the Development of VCSEL Technology



With several advantages over Light Emitting Diodes (LEDs) and Edge Emitting Lasers (EELs), Vertical Cavity Surface Emitting Lasers (VCSELs) are instrumental in many recent technological advancements, and new applications are found every day.

Testing VCSELs by manufacturers of these devices and device integrators requires optical spectrometers featuring high resolution, high speed triggering response and short integration time specifications. Avantes is the trusted instrument supplier around the world to support applications with VCSEL technology.

Introduction to VCSEL Structure



Design and scheme of DP-VCSEL
[BY Edgar Cerda Mendez], via Research Gate

Vertical Cavity Surface Emitting Lasers are a semiconductor-based light source grown in mass production using standard thin film deposition techniques such as either molecular beam epitaxy (MBE) or metal-organic chemical vapor deposition (MOCVD) to deposit films on Gallium Arsenide (GaAs) wafers. VCSELs emit a coherent beam of light from their surface.

The structure consists of two highly-reflective distributed Bragg reflector (DBRs) mirrors parallel to the wafer surface and made by alternating layers of high and low refractive indices capable of yielding intensity reflectivities. The DBR are typically doped to form the diode junction and used to deliver a carrier signal to stimulate emissions into the active region.

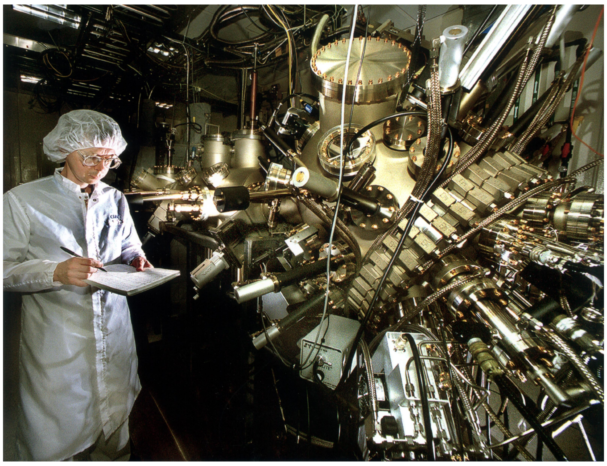
The carrier signal passes through the active laser medium which provides optical feedback and amplifies the light between the reflective matrices inciting laser propagation which is possible at a current where the round-trip gain is greater than the round-trip loss. Because the vertically oriented gain region of the VCSEL design is shorter than required for other semiconductor lasers, The VCSEL lasers consequently have a low threshold current for laser propagation. The DBR with the lowest refractivity is then out-coupled for coherent light emission.

The VCSEL Advantage

The vertical design of the VCSEL has several advantages over edge emitters. An edge emitting laser cannot be tested until the deposition processes are complete and the elements are die cut from the wafer. If there are defects in the wafer or thin films, the manufacturing time and materials have been wasted. The VCSELs, on the other hand, can be mass produced using ordinary semiconductor thin film deposition methods in a process that can be tested at various stages of production, including whole wafer testing so that thousands of VCSELs can be processed at once on a single three-inch wafer. This leads to greater production efficiency and reduced costs (Finisar myvcsels.com).

Another benefit of the VCSEL design is the ability to connect multiple elements into two-dimensional arrays for increased power output and the larger output aperture produces a lower divergence angle of the output beam for better coupling efficiency with optical fibers.

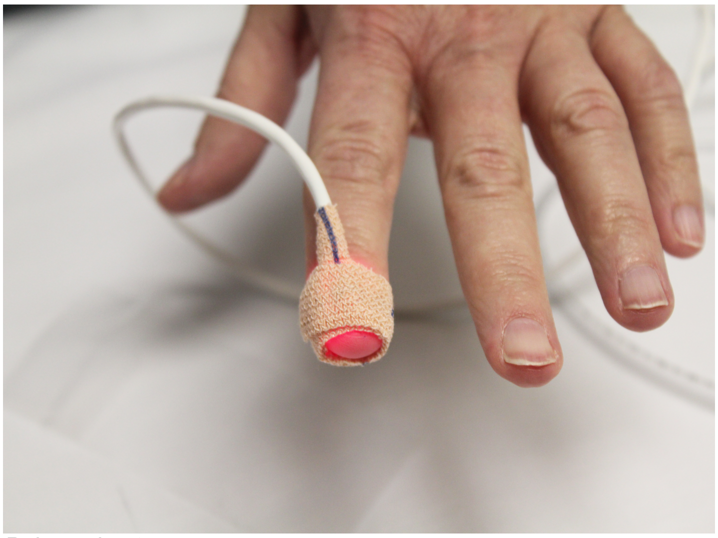
VCSELs are capable of high-power output, yet consume less power than other lasers/light emitting devices due to the placement of the distributed Bragg reflectors (DBRs) which lowers the threshold current to achieve laser propagation. The wavelength tunability, which is characteristic of VCSELs, is accomplished by adjusting the thickness of the reflector layers in the active region with the aid of microelectromechanical systems.



Molecular Beam Epitaxy System
By ENERGY.GOV [Public domain], via Wikimedia Commons

Current Applications for VCSEL Technology

In the 40 years since VCSELs were introduced, they have found their way into countless applications across hundreds of industries and markets both industrial and commercial, and today we see VCSELs all around us. One of the key functionalities of these devices is signal processing which might take the form of communications or sensing.



Pulse oximeter
By Quinn Dombrowski from Berkeley, USA
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Fiber optic communication relies heavily on the signal processing power of VCSELs emitting in the 1310 nm and 1550 nm bands, to deliver pulses of light forming an electromagnetic carrier wave that can be modulated to carry signals for telephony, cable and internet (Larson).

One of the most ubiquitous uses for VCSELs that anyone would be immediately familiar with is the laser mouse on your computer. (VCSEL Wiki). Other examples of common VCSEL applications include laser printers, miniature atomic clocks, facial recognition in mobile devices, and collision avoidance systems in equipped vehicles. (VCSEL Wiki).

The Future of VCSELs

Research conducted by Kitsmiller, Dummer, Johnson, et al. at the University of Notre Dame, Department of Electrical Engineering investigated the use of frequency domain diffuse optical spectroscopy (fd-DOS) employing near-infrared tunable VCSELs to develop a miniaturized system to perform high-resolution deep tissue scans in non-invasive biomedical imaging.

Advances in noninvasive monitoring, especially wearable sensors, have been technologically constrained by the commercial availability of miniature light sources capable of producing coherent near-infrared light in the first biological diagnostic window between 650-1350 nm. Adding spectral content can increase the accuracy, spatial resolution, and sensitivity but adding additional lasers or LED components adds to the size and complexity of the system, competing with the goal of developing handheld and wearable sensors and monitoring devices.