Tyndall
National Institute
Institiúid Náisiúnta

# Vertical Cavity Surface Emitting Laser (VCSEL) Research

## Researching next generation emitters and their applications.

Semiconductor lasers have traditionally been edge-emitting devices; where the light is emitted in the plane of the semiconductor wafer, see Figure 1. Testing of devices must occur after devices are broken out of the wafer as this process defines the mirrors. As such, on wafer testing is not an option, which reduces yield and increases costs. VCSELs emit perpendicular to the wafer surface and devices may be tested on wafer, reducing cost and improving yield (Figure 1 [b]). VCSELs have an optical cavity formed by a Quantum Well active region between two layered distributed Bragg reflector mirrors (DBR); all of this being formed during epitaxial growth. VCSEL technology permits accurate wavelength control in design of the optical cavity, and improved reliability due to the unexposed active regions. Other advantages of VCSELs are a reduced operating current due to the small active area and their narrow divigent circular output beam which permits simplified optics as compared to the elliptical output of an edge-emitting laser. These advantages drive research and development in VCSELs and their applications.

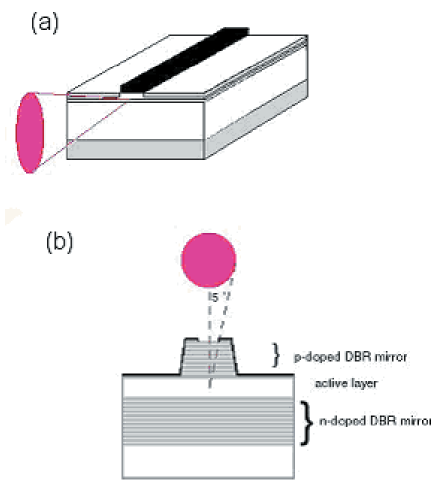


**Figure 1: Diagrams of (a) edge-emitting laser diode and (b) Vertical Cavity Surface Emitting Laser (VCSEL)**

### VCSEL Experience and Challenges

Tyndall National Institute has extensive experience in red and infrared VCSEL structures and devices [1-3]. We have capabilities to design epitaxial layers for custom wafer growth. Fabrication of VCSELs utilizes AlAs oxidation technology and is carried out in our Compound Semiconductor Fabrication facility. Characterization occurs in the Photonic Sources test lab where optical (wavelength, power, temperature performance) and electrical (voltage, current, speed performance) are carried out.

The Tyndall National Institute is focussing on the challenges facing VCSEL technology such as:

- Emission at shorter (<635nm) and longer (>1000nm) wavelengths.
- Increasing single mode ($TEM_{00}$) power.
- Higher bandwidth (>40Gbit/sec).
- Added functionality.
- Wavelength tunability.
- More robust performance

### Applications for VCSELs

The development of cheap Plastic Optical Fibers (POF) for use in short haul local area optical networks emphasized a need for VCSELs emitting at a red wavelength of 650 nm, which is an absorption minima in POF. Research into RED VCSELs began at Tyndall (then NMRC) in 1997 under the BREDSELs project [4]. Other applications requiring red VCSELs are primarily in visible display applications and communications sectors. We have developed AlInGaP VCSELs having emission wavelengths as short as 635 nm, Figure 2(a), to 680 nm, with single mode devices outputting 0.6 mW at 650 nm, Figure 2(b) and 1mW at 660 nm at room temperature [5]. Parallel arrays of red VCSELs have been fabricated capable of outputting over 50 mW at 200 mA demonstrating the scalability of VCSEL technology.

Tyndall's interest in communications and sensor applications has lead to research into 850 nm and 980 nm VCSELs. Work has progressed from standard VCSEL device fabrication to more novel structures and layouts, from high-density addressable arrays of single mode 850 nm VCSELs to flip-chip integration of 980 nm VCSELs with drivers (Figure 3 - overleaf).

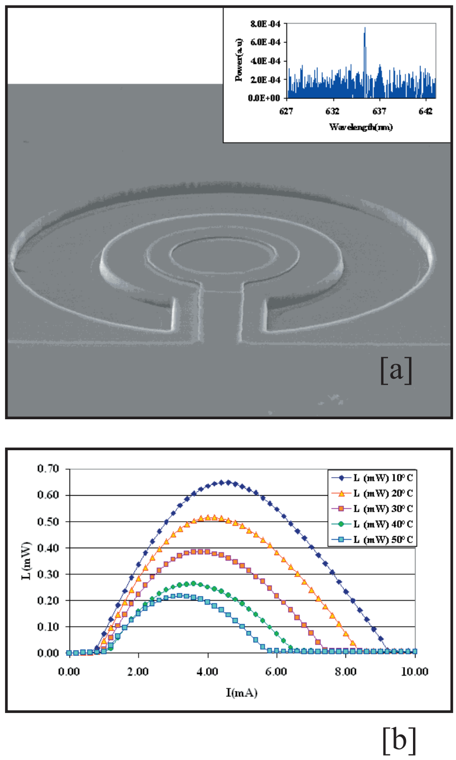


**Figure 2. (a) SEM of VCSEL emitting at 635 nm [spectrum shown in inset] (b) Power-Current (L-I) characteristic of Single mode 650 nm VCSEL.**

## Novel VCSEL structures

The Tyndall National Institute has built upon its extensive knowledge of VCSELs, carrying out research onto novel VCSEL structures and their applications. One example of this involves the direct integration of diffractive phase gratings by etching into the top surface of the VCSEL using a focused ion beam (FIB). The resultant VCSEL will have its normal vertical emission suppressed and the power diffracted into multiple output beams. The beam emission angle for the output beams is $\sin(\theta) = \lambda/\Lambda$ for VCSELs with linear gratings and $\sin(\theta) = \sqrt{2}\,\lambda/\Lambda$ for "chessboard" type gratings shown in Figure 4. ($\lambda$ is the emission wavelength in air, $\Lambda$ is the grating pitch). We have investigated and reported [6] the performance of this novel technology, and have investigated applications in interferometry [7] and other sensor systems.

## Commercialisation

Parts of the Red VCSEL technology has been used as a base for a spinout company, Firecomms [http://www.firecomms.com], from our activities.

We also work with Industry on novel VCSEL designs, for eaxmple: Nexus, FCI, DLightsys, Firecomms.

## References


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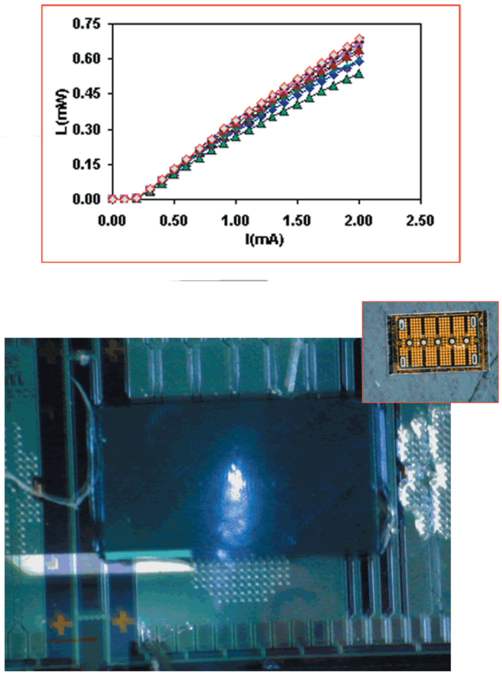


Figure 3: Infrared VCSEL research at Tyndall. (a) Array of single mode 850 nm VCSELs, 10 device L-I characteristics with treshold currents of 250 µA (b) Flip chip of 5-element 980 nm VCSEL array onto driver circuit for parallel optical link application. Chip shown inset.

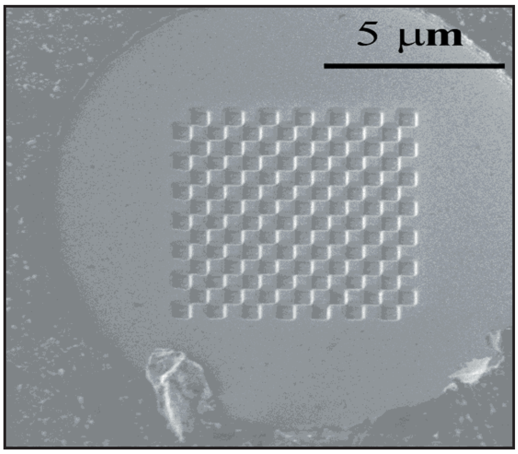


Figure 4: Surface region of VCSEL with 0.5 µm "chessboard" grating etched into the surface by FIB.


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