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A GaInAsP/InP Vertical Cavity Surface Emitting Laser for 1.5μm operation

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Abstract

We present the results of our studies concerning the pulsed operation of a bulk GaInAsP/InP vertical cavity surface emitting laser (VCSEL). The device is tailored to emit at around 1.5μm at room temperature. The structure has a 45 period n-doped GaInAsP/InP bottom distributed Bragg reflector (DBR), and a 4 period Si/Al_2O_3 dielectric top reflector defining a 3-λ cavity. Electroluminescence from a 16μm diameter top window was measured in the pulsed injection mode. Spectral measurements were recorded in the temperature range between 125K and 240K. Polarisation, lasing threshold current and linewidth measurements were also carried out at the same temperatures. The threshold current density has a broad minimum at temperatures between 170K and 190K, (J_{th}=13.2 kA/cm^2), indicating a good match between the gain and the cavity resonance in this temperature range. Maximum emitted power from the VCSEL is 0.18 mW at 180K.

1. Introduction

Long wavelength (1.3μm) emission from a vertical-cavity surface emitting laser (VCSEL) was first achieved in 1979[1]. Realising the benefits of surface emission, where wafer level testing of two dimensional arrays are possible, has attracted much research. Surface emission from VCSEL structures allows easy coupling of a narrow circular beam into the cross section of optical fibres or other low numerical aperture optical systems. The narrow single longitudinal mode micro-cavity provides low optical gain, therefore the device requires very high reflectivity mirrors.

A great deal of progress has been made at shorter wavelengths (0.8μm to 1.00μm) with Distributed Bragg Reflectors (DBRs) lattice matched to AlGaAs active regions.

For emission at 1.3μm and 1.5μm for telecommunications and long distance optical fibre transmission, attaining good quality DBRs lattice matched to the active region has remained a challenge. For InP based cavities, a great many pairs of InP/GaInAsP layers are required to form the DBRs, due to their low refractive index contrast. This demands very high quality growth control, since high quality DBRs require uniform thickness for each layer and for each period.

An alternative technique to lattice matched DBRs has been explored. Wafer bonding/fusion [2-6], where high refractive index contrast GaAs/AlAs DBRs are fused to the GaInAsP active layer using a high pressure technique, having first removed the substrate. However the long-term reliability of whole wafer fused structures remains uncertain. A combination of bonded bottom DBR and dielectric ZnSe/MgF mirror defining a cavity containing compressively strained quantum wells has been demonstrated[7]. Even high reflectivity dielectric mirrors may have a number of drawbacks such as poor thermal and electrical conductivity.

Streubel et al [8] demonstrates a 1.5μm VCSEL structure consisting of a 50 period GaInAsP/InP bottom DBR, and a 5 period Si/SiO_2 top dielectric mirror mesa-etched so that the current does not pass through the top mirror. The active region contains nine strain compensated quantum wells. They achieved VCSEL operation from approximately 110K to 310K, with a minimum threshold current density at room temperature of $13kA/cm^2$.

In this paper we report a much simplified structure consisting of an epitaxially grown bottom DBR and a dielectric mirror placed above the top contact. This type of structure retains the substrate, maintaining rigidity, and overcomes the problem of high series resistance associated with a p-type top DBR. The VCSEL was electrically pulsed, and demonstrated lasing around 1.5μm across a wide temperature range. A 10μm square VCSEL of similar structure has been reported previously, with a minimum threshold current density of 16.0 kA/cm^2 at a temperature of 140K [9].

2. Structure

The VCSEL structure used for this work has a 45 period n-type InP and n-type GaInAsP pair DBR grown by gas source MBE. The layers above were grown by MOVPE, consisting of an n-doped InP spacer layer, a bulk GaInAsP active layer, and a p-type InP spacer layer, forming a 3-λ cavity. This was topped by an n-type current confinement layer, etched away to form a 16μm diameter top window, and a p-type GaInAsP contact layer. A Ti-Au top ring contact is covered by a 4 period Si/Al_2O_3 dielectric reflector (see Figure 1). This structure was mesa-etched to form a two-dimensional array of 36 individual VCSELs with an outside mesa diameter of 56μm.

3. Experiment and Discussion

Measurements of pulsed current-voltage (I-V) characteristics at room temperature were taken on a number of devices to establish functioning VCSELs. The following experimental results presented here are from a single VCSEL selected for its good I-

V characteristics. The VCSEL array was installed in a liquid nitrogen cooled cryostat with thermal control provided by an Oxford Instruments ITC4. The VCSELs could be individually electrically pulsed using a Avtech AVL-2A-C pulse generator, with the electrical output monitored on a Tektronix 7104 oscilloscope, whilst the light output was collected by a Newport 818-IR germanium detector and a calibrated Newport 1815-C power meter.

The VCSEL was electrically pulsed with 100ns pulse widths at a frequency of 4.78 kHz, and the light output measured over a range of temperatures from 125K to 230K. In this temperature range the VCSEL had a clearly defined set of lasing threshold currents with a minimum value at 180K of 26.5±0.5 mA (see Figure 2). This corresponds to a threshold current density of 13.2 kA/cm^2.

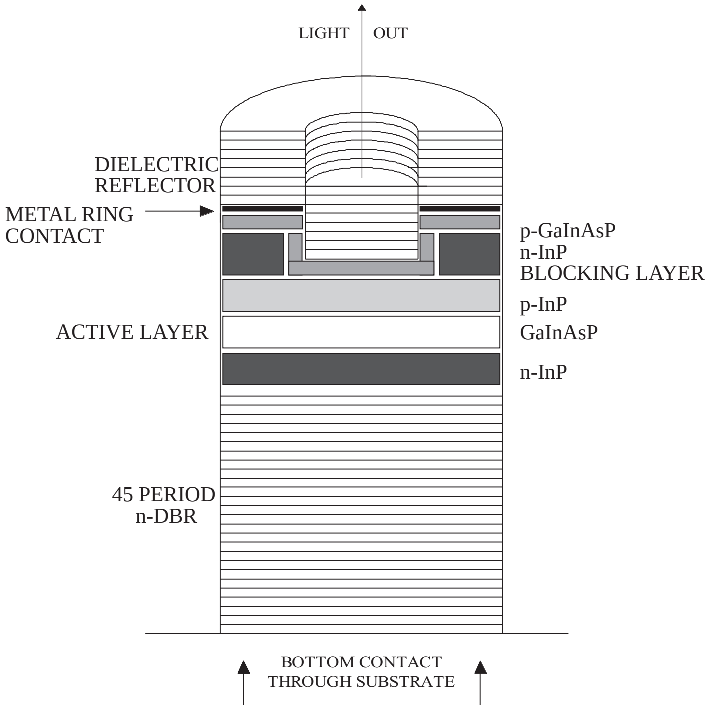

Figure 1. Schematic diagram of VCSEL structure.

The light output (L-I) curves at each temperature tend to saturate as the injection current is increased (see Figure 3). This saturation effect has been reported previously [10,11], and is characteristic to VCSELs. The L-I curves of edge emitting laser diodes, where the Fabry-Perot modes are closely spaced, do not show this effect. However, the 3-λ cavity within the VCSEL structure has very widely spaced modes, so any changes to the material gain peak relative to the Fabry-Perot mode will affect the output power. Since the current is injected into the laser diode via the bottom 45 period DBR, which has a high series resistance, the active layer's temperature can increase relative to the heat sink. Furthermore, higher current densities give rise to a higher heat density, causing a larger temperature gradient throughout the VCSEL. This is further complicated, since the optical field also increases the internal temperature at different locations within the VCSEL structure. However, on reducing the pulse width of the current injection from 100ns to 40ns and 20ns, very little change in this L-I roll-off occurred, indicating that heating may not be the entire cause of the output saturation in our device.

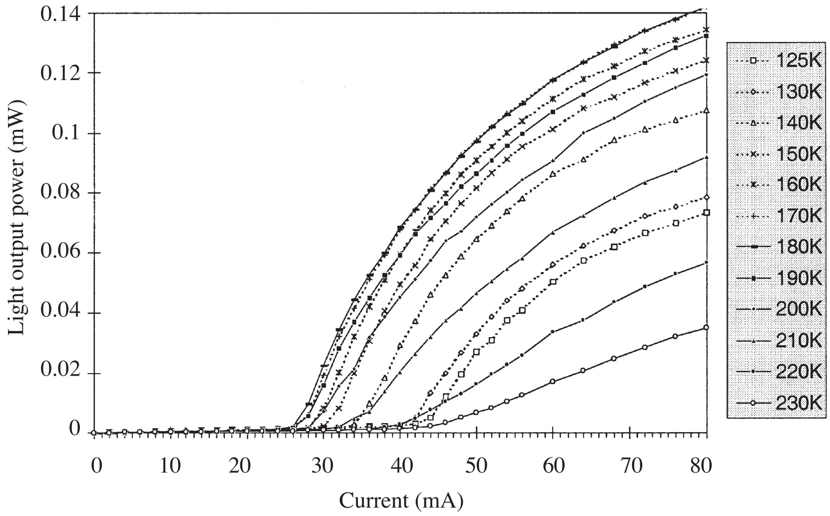

Figure 2. VCSEL light output over a range of temperatures.

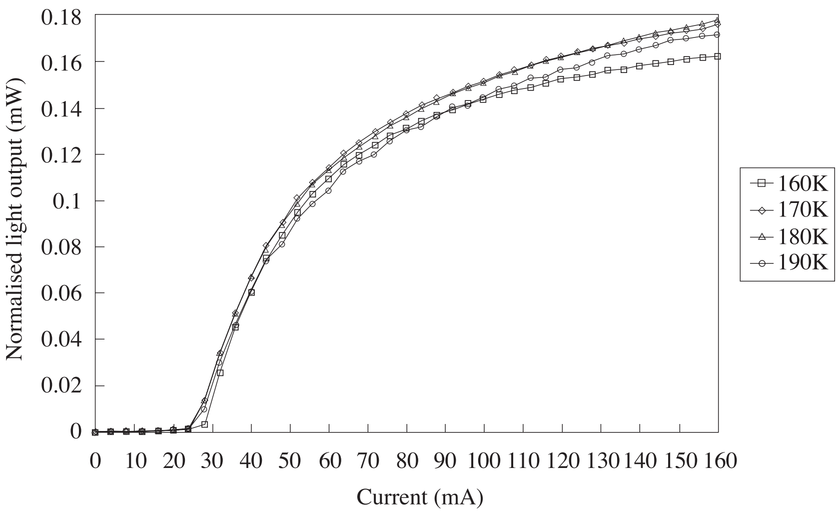

Figure 3. Power output showing saturation roll-off.

Due to the relatively large optical window, spatial hole burning (SHB) at higher current densities may have a major contribution to the L-I curve roll-off. As the centre of the optical window, where the optical mode is strongest, draws the carriers in to maintain the material threshold gain, so the carrier density around the perimeter of the window increases. The optical mode at the perimeter is weak, so the conversion of carriers into light is poor, causing a local increase in the lasing threshold current away from the centre of the optical window.

The variation in lasing threshold currents (I_{th}) with lattice temperature is shown in Figure 4. This can be explained in terms of the disparity between the temperature dependence of the material gain peak and the cavity resonance. This causes the material gain peak to red shift at a higher rate than the Fabry-Perot mode as the temperature increases. Below 180K the gain peak moves towards the Fabry-Perot mode, whilst above 180K the gain peak moves away from the Fabry-Perot mode. To obtain VCSEL operation at room temperatures, the cavity resonance needs better matching to the material gain by adjusting the carrier concentration [12].

The output power of the VCSEL at 180K with an injection current of 160mA was 0.176 mW, measured from the top surface, with no allowance for loss through the transparent substrate. To confirm lasing the output was measured through a Newport Broadband polariser, rotated through 360°C, see Figure 5. The output was highly linearly polarised, indicative of a coherent optical emission.

The spectral peak of the VCSEL output was measured across the temperature range, and the peak wavelength dependence on temperature (see Figure 6) was found to be 0.095 nm/K, with a range between 1.501μm and 1.512μm across a 100K temperature span. This is in agreement with Streubel et al [8].

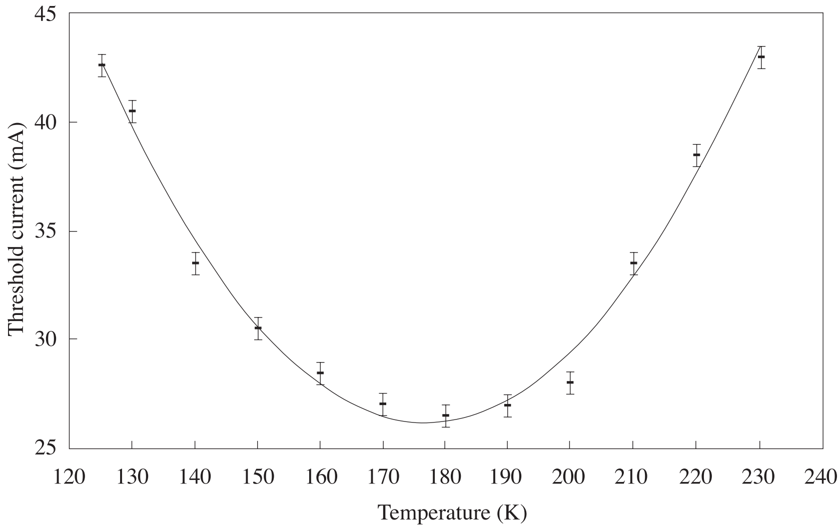

Figure 4. Temperature dependence of threshold current.

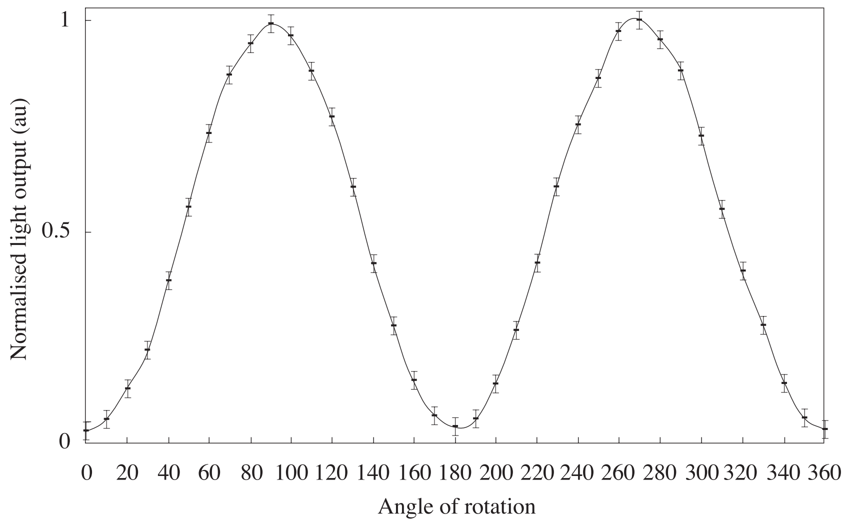

Figure 5. Linear polarisation of light output from VCSEL.

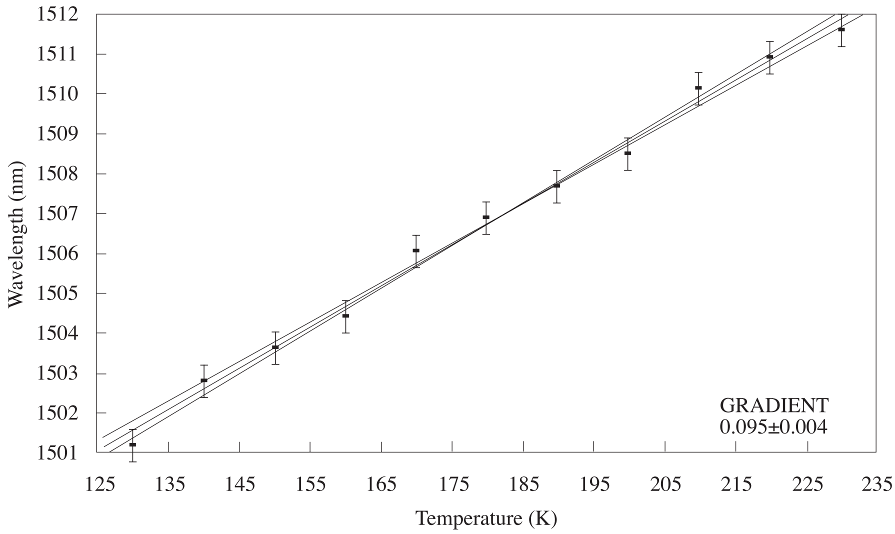

Figure 6. Temperature dependence of wavelength peak, yielding a value of 0.095 ± 0.004 nm/K.

4. Conclusion

In summary we have reported the experimental results of an InP based VCSEL, with emission between 1.501μm and 1.512μm across a wide temperature range. The output power from the top surface was measured, with a value of 0.18mW at 180K, and the output was found to be highly polarised. The minimum threshold current at 180K was 26.5±0.5 mA, equivalent to a threshold current density of 13.2 kA/cm^2.

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