Gain Measurements on Vertical Cavity Surface Emitting Laser Material Using Segmented Contact Technique

Curtis Hentschel
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Craig P. Allford
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Sara-Jayne Gillgrass
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Zhibo Li
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Josie Nabialek
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Richard Forrest
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Jack Baker
School of Physics and Astronomy
Cardiff University
Cardiff, UK

David G. Hayes
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Wyn Meredith
Compound Semiconductor Centre
UK

J. Iwan Davies
IQE plc.
Cardiff, UK

Samuel Shutts
School of Physics and Astronomy
Cardiff University
Cardiff, UK

Peter M. Smowton
School of Physics and Astronomy
Cardiff University
Cardiff, UK

***Abstract*—We report direct measurements of the optical gain profile for a vertical cavity surface emitting laser (VCSEL) epitaxial structure, by characterising the transverse electric (TE) in-plane net modal gain using the segmented contact method.**

***Keywords*—VCSEL, gain, segmented-contact**

I. Introduction

A large growth in the vertical cavity surface emitting laser (VCSEL) market, particularly in sensing applications, is expected to continue over the next few years [1]. In addition, VCSELs which meet stringent specifications are required for certain applications such as miniaturised atomic clocks [2]. A key factor to consider is the detuning of the gain peak with the cavity resonance. Understanding the gain peak profile and its alignment with the target cavity resonance is important, so that a VCSEL epitaxy design can be optimised to reduce threshold current and improve efficiency and device yield. However, there is currently no direct way to characterise the gain profile in VCSEL structures. The highly reflecting distributed Bragg reflectors (DBR), forming the vertical cavity, make it difficult to suppress lasing and apply single pass gain measurement techniques in the vertical direction. The short, inherently single longitudinal mode, cavity of the VCSEL means the Hakki-Paoli technique [3] is not possible. Test wafers can be grown with a nominally identical active region and without the DBR layers, but this cannot be used to evaluate the actual wafer used to fabricate operational VCSEL devices and is not as useful from a manufacturing perspective.

Here, a stripe-length method [4], typically used on edge-emitting laser structures, is utilised to investigate the optical gain characteristics of VCSEL material by measuring the transverse electric (TE) in-plane modal-gain as a function of carrier injection for a range of operating temperatures. For both the vertical lasing mode of the VCSEL and the TE polarised in-plane mode, the electric field direction is in the plane of the quantum wells, so assuming an in-plane symmetric active medium, the dipole matrix element which determines the optical gain for each mode will be approximately identical, and the modal gain will be related by differences in the confinement factor of each mode. The photon momentum should be small compared to the crystal momentum, so any differences arising from an orthogonal propagation direction will be negligible.

II. Experiment

To demonstrate the methodology required to successfully characterise VCSELs by this approach we utilise two nominally identical VCSEL epitaxial structures designed to emit at 894.6nm, for use in caesium-based miniaturised atomic clocks. These structures differ by the use of either an in-phase top mirror layer or an anti-phase top mirror layer. The anti-phase top mirror layer increases the mirror loss, increasing the required threshold gain for lasing.

A schematic diagram of the segmented contact stripe is shown in figure 1. We make use of a fast-fabrication approach, whereby segmented Cr-Au p-contacts, 300um long and 100um wide with 6um gaps, were patterned and annealed onto the sample surface. The GaAs cap and top DBR pairs surrounding the contacts were consequentially etched to electrically isolate each section using the p-contact metal as the mask.

The EPSRC funded Future Compound Semiconductor Manufacturing Hub reference EP/P006973/1, provided essential resources for this study. C. H would like to acknowledge support from an EPSRC Industrial-CASE Award co-funded by IQE.

Power-current characteristics were recorded (figure 2 a and b respectively) for the resonant vertical cavity and the single pass in-plane cavity and demonstrate the value of the anti-phase top mirror design in suppressing vertical lasing. Such structures are used for the measurements of the in-plane gain using the segmented contact approach. Figure 3 shows the measured TE in-plane net modal gain, at room temperature, for current densities between 0.3-0.6kA/cm². We compare these results and similar data taken as a function of temperature with the measured threshold current density and lasing wavelengths to demonstrate the utility of this method for characterising full VCSEL structures.

References

[1] Global Industry Analysts, "Global vertical-cavity surface-emitting lasers (VCSELs) industry," April 2021. [online] Available: https://www.reportlinker.com/p06033235

[2] D. K. Serkland, K. M. Geib, G. M. Peake, R. Lutwak, A. Rashed, M. Varghese, G. Tepolt, M. Prouty, "VCSELs for atomic sensors," Proc. SPIE 6484, Vertical-Cavity Surface-Emitting Lasers XI, 648406 (2007).

[3] B.W. Hakki and T.L. Paoli, "Gain spectra in GaAs double−heterostructure injection lasers, J. App. Phys.", vol. 46, no. 3, 1975.

[4] P. Blood, G.M. Lewis, P.M. Smowton, H. Summers, J. Thomson, J. Lutti, "Characterization of semiconductor laser gain media by the segmented contact method", IEEE J. Sel. Top. Quantum Electron., vol. 9, no. 5, 2003.

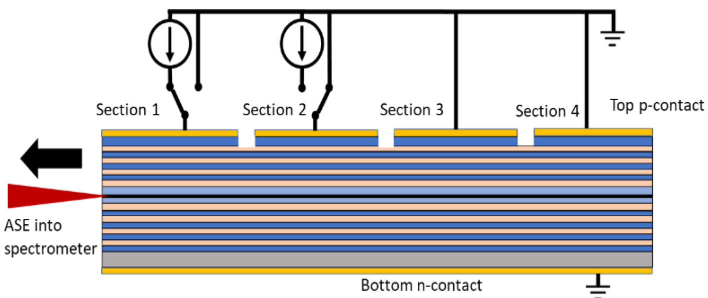

Figure 1. Schematic of segmented contact devices. A linear polarizer was placed in front of the spectrometer so only the TE polarized ASE was measured.

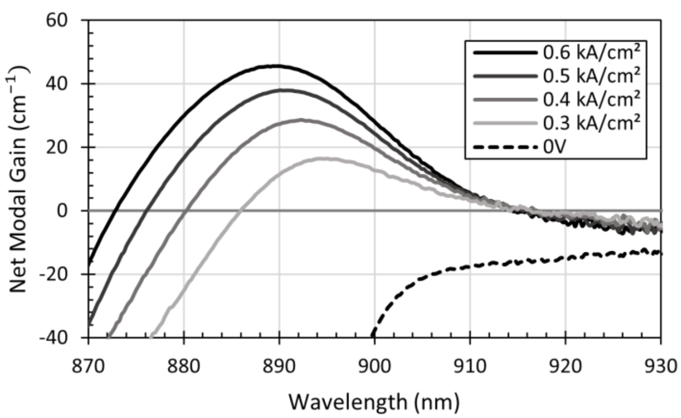

Figure 3. In-plane modal gain curves of the anti-phase top mirror device for different current densities (solid lines) and the zero-bias absorption curve (dashed line) at a temperature of 20.8°C.

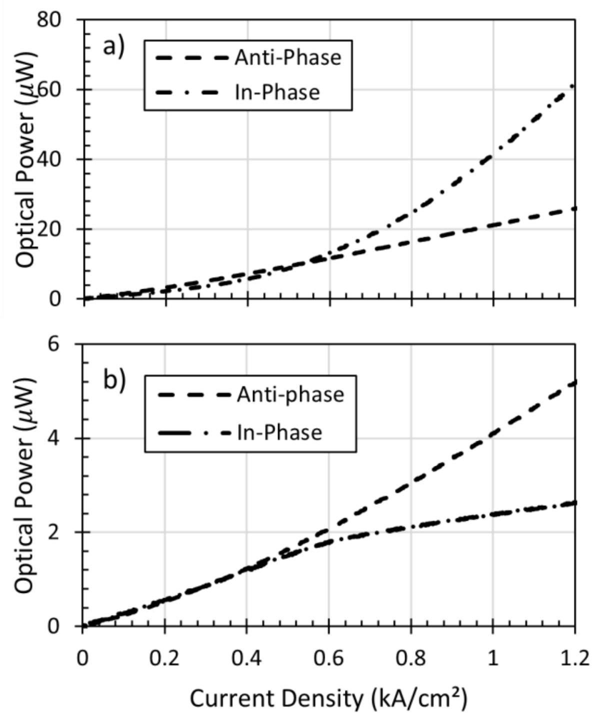

Figure 2. P-I curves of light emitted in the (a) vertical and (b) in-plane direction.