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## FABRY-PEROT INTERFEROMETER SPECTRAL RESOLUTION OF VERTICAL CAVITY SURFACE EMITTING LASERS (VCSELS) WITH FEEDBACK

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### ARTICLE INFO

### ABSTRACT

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Coherent transmission at 100 Gigabits per second has become standard in the global fiber-optic backbone network, and more is expected to come due to the convergence of communication. Few systems are operating at hundreds of gigabits, and many experiments have exceeded a petabit ( $10^{15}$  bits per second) over single developmental fibers that can transmit light on dozens of separate paths. This paper reports high resolution spectral measurements of a multimoded Gallium Arsenide (GaAs) VCSELS. The spectra observed with a Fabry-Perot Interferometer (FPI) showed an interesting splitting of up to 60 Gigahertz which can be suitable for application in high speed communication and sensing applications.

### INTRODUCTION

The spectral characteristics of semiconductor lasers are important in determining the performance of optical fibre transmission systems and optical fibre sensors. Narrow spectral line width and low frequency wavelength stability are particularly important in optical heterodyne communication systems (Yamamoto and Kimura, 1981), and in interferometric fibre sensors with a large path length difference (Dandridge and Tveten, 1981), (Petermann and Weidel, 1982). In a conventional semiconductor lasers, changes in spectral characteristics occur under the influence of external optical feedback. Some of the feedback-induced-effects include line narrowing (Miles, 1980, Olsson & Tang, 1981 and Agrawal, 1984). Linewidth broadening, (Saito and Yamamoto, 1981) and (Nilsson, 1981), coherence collapse (Lenstra, 1990) and (Chung and Lee, 1991).

The sensitivity of a semiconductor to external optical feedback depends on the stored

energy in the cavity and coupling of the laser mode to the external field. A bandwidth of 14 GHz 3dB has already been obtained from an implant defined VCSELS operating at 780nm (Shtengel, 1993).

A mode-locked VCSEL of 25 $\mu$ m diameter lasing at 980nm was shown to produce a minimum full width at half maximum (FWHM) of 7.46GHz and a pulse width of 46ps, (Dowd P. and White, 1995). Later on, a modulation bandwidth of greater than 16GHz was obtained from an oxide confined VCSELS (Lear, 1996). Here we report an experimental investigation of the spectral characteristics of VCSELS with the use of external optical feedback.

### MATERIALS AND METHODS

The set-up is very much similar to that used by (Sumaila and White, 2015). The FPI used in this experiment as shown in Fig. 1, uses two multilayer dielectric, confocal mirrors with high reflectivity (~96%), low absorbency and a spacing which can be varied from 0 - 60mm.

By the employment of a piezoelectric Ceramics using a ramp generator, controlled minute variations in the mirror separation are obtained by (Taffano, 1992). Bias and ramp functions from the ramp generator (interferometer controller) precisely control the cavity length and parallelism to approximately  $\lambda/100$ . There are several methods in operating this FPI, here the technique used is the dynamic scanning mode of the method of the FPI where both the transmission peaks and the ramp waveform can be viewed together (Fig. 3). Linearity of 99% can also be achieved and the parallelism of the mirror is maintained throughout the scan. Also in using this method, both the collimating and the interferometer alignment can be adjusted conveniently during use.

In this work, a top surface emitting GaAs VCSEL of 10 $\mu$ m diameter operating at a lasing wavelength of  $\sim$ 840nm is used. The VCSEL has a threshold current around 2.8mA has a single mode when biased up to  $\sim$ 5mA ( $2I_{th}$ ). It has a coupling efficiency of 72% which is very suitable for optical fibre transmission.

A block diagram of the experimental set-up is shown in Fig. 1, which was similarly used by Y. Sumaila and White, (2015). The Fabry Perot Interferometer (FPI) used in this experiment was also adopted by Toffano, (1992). Also the method employed in this piece of work is similar to that used by Sumaila and White, (2015). The FPI in Fig. 1, is separated from the VCSEL by a collimating lens only. The interferometer is first adjusted using a Helium-Neon (He-Ne) laser as the source so that the mirrors are approximately perpendicular from the beam and the He-Ne is then replaced by a VCSEL. The output of the VCSEL is collimated so that the interferometer receives only parallel beams. An amplitude feedback is applied to the FPI using a ramp generator (not showing in the diagram). The transmitted output of the interferometer is focused on to a large area silicon photodiode which is then connected to DC 30 Hz bandwidth trans-impedance amplifier. A voltage feedback is applied through a bias tee using a voltage control oscillator (VCO) not shown in the circuit diagram for clarity of the figure. The amplified signal is then monitored on OS300 Gould Oscilloscope. The VCSEL temperature is

kept at a constant (20°C) throughout the experiment.

## RESULTS AND DISCUSSION

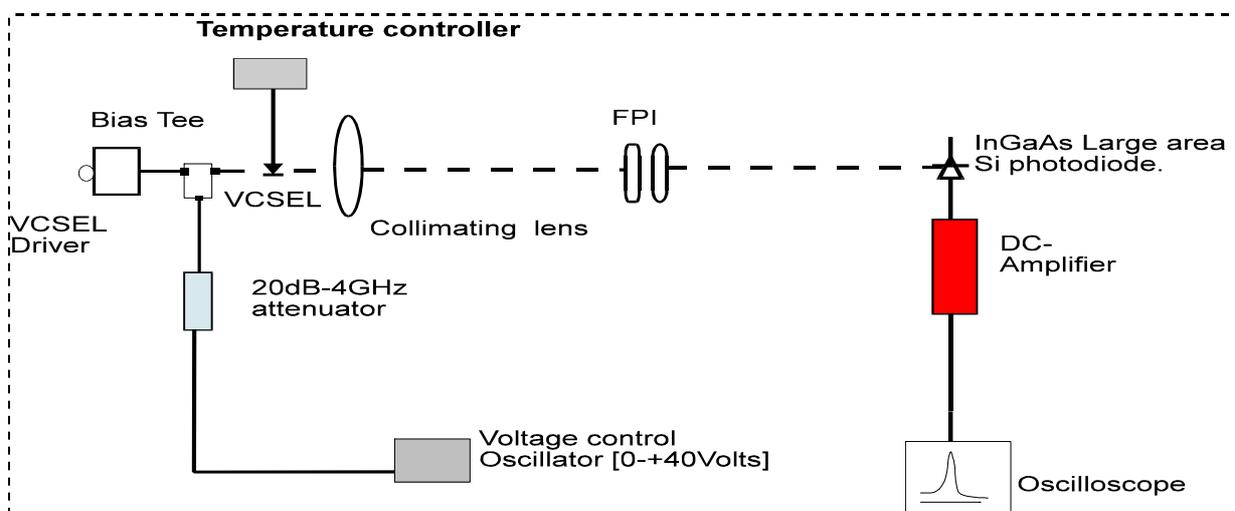
The optical spectrum of the VCSEL as measured using a HP70951 optical spectrum analyser (OSA) is shown in Fig. 2. The spectrum of this VCSEL is clearly multi-transverse mode from about  $2I_{th}$ , and broadens with higher drive current. The width of the spectrum at  $I/I_{th} = 2$  is  $\sim$ 0.5nm ( $\sim$ 213GHz). The transverse nature of this device is seen first from the spectrum recorded. However, a single mode remains dominant throughout the applied DC-bias to the laser (Figs. 3 and 4). Because the resolution of the Hewlett Packard, HP-spectrum analyser is  $\sim$ 0.08nm, it is uncertain how many distinct transverse modes are there in operation for this VCSEL and what exactly could be taken as their separation, but there appears to be a minimum of two such modes as shown in Fig. 3. The result illustrated in Fig. 3 gives the spectra at two different voltage feedback levels applied using the piezoelectric voltage at 35 GHz free spectral range. Figure 3(a), is the spectra at zero feedback voltage to the FPI and a ramp voltage of 54V. Figure 3(b) is the spectrum at a feedback voltage =17.8V from VCO, ramp voltage 250V,  $I_{bias} = 4.8$ mA. This setting in Fig. 4 gives an equivalent modulation frequency of 62GHz.

Figure 4(i), shows the emission wavelength versus the applied current to the VCSEL that exhibits spectral splitting of nearly 62 GHz, Fig. 4(ii) gives the FWHM of the emitted spectra while the peak power measured from the VCSEL is presented in Fig. 4(iii). A minimum FWHM of 0.05nm ( $\sim$ 21.25GHz) is measured which means there is probable chance of another mode, because this is quite a large line width.

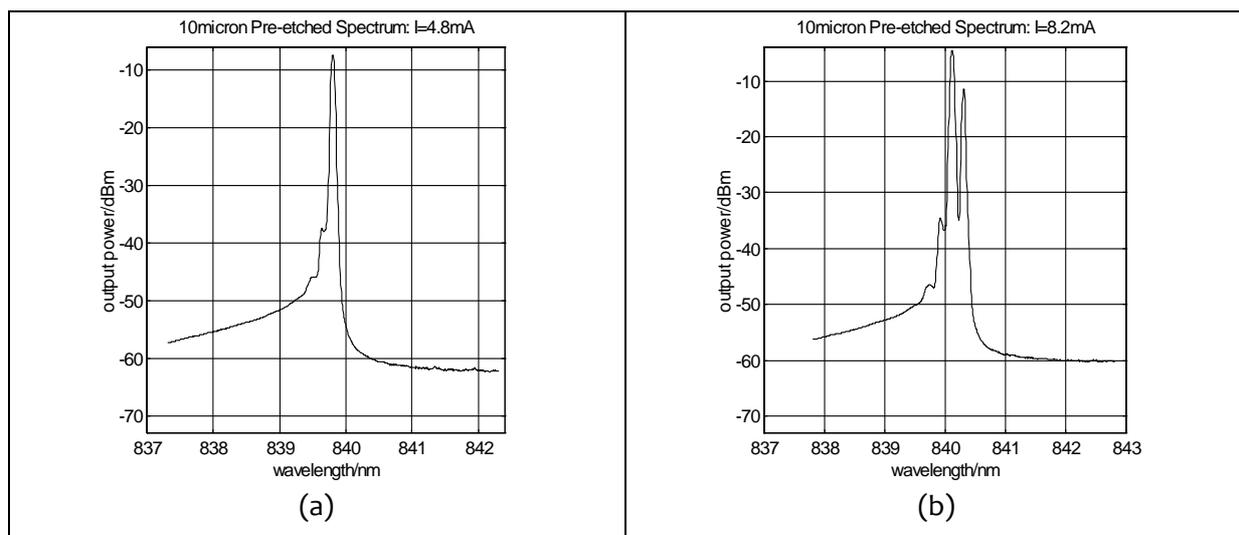
Furthermore, experimental result shows that the FWHM and the Peak wavelength plots are mirror image of each other. This explains that the spectrum is wider at lower drive currents while the peak intensity of the laser is low. However, at high currents, the FWHM of the spectrum is very narrow and hence, the high peak intensity.

At far higher current to the laser, even though the peak intensity is high, the FWHM is narrow. The reason for this phenomenon is because; the laser experiences a self internal heating effect and thus, the spectrum only broaden due to the spread of the lasing beam. These FPI results were taken at various amplitude modulation level as applied using a voltage control oscillator (VCO) at different currents. Figure 4 shows the FPI spectra at settings with feedback level of 16.7dB and an equivalent modulation frequency of 2GHz applied using VCO. Figs. 4 (ii), (iii) and (iv) give

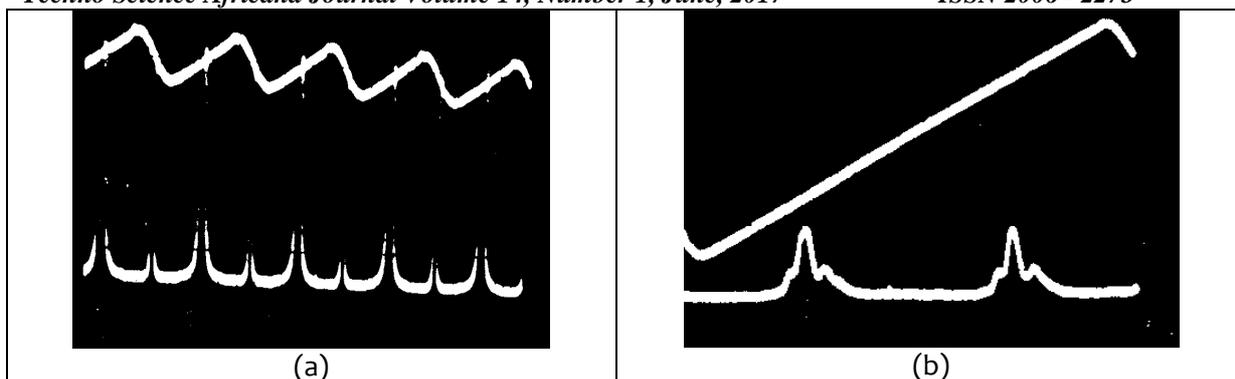
the corresponding peak intensity, peak separation and the FWHM respectively. The minimum spectral width of 2.25GHz is obtained. Here, it can be observed that the spectrum has been splitted at various peaks indicating the corresponding Speeds of the peaks. The highest peak of the spectrum has been splitted to a maximum modulated frequency of 62GHz. The combination of this circuit can thus be suitable in a high speed multimode signal transmission and other high speed applications.



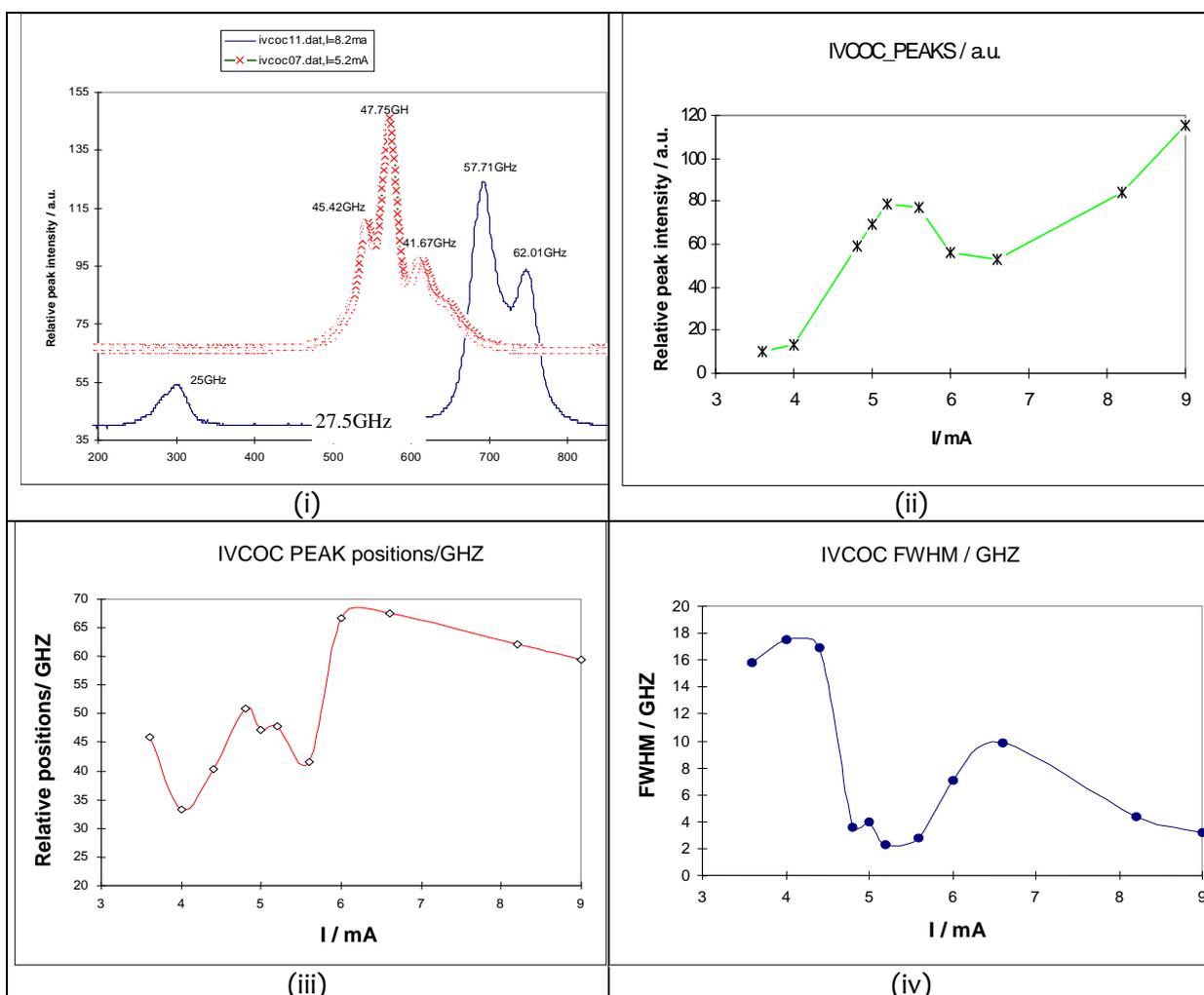
**Fig. 1;** Experimental set-up for the spectral characterisation of a VCSEL with 10µm-diameter active using Fabry-Perot Interferometer (FPI). (Similar to Sumaila Y. A. & White I. H., 2015).



**Fig. 2;** Optical spectra of the VCSEL using an optical spectrum analyser (OSA), Sumaila Y & White I H, 2015.



**Fig. 3:** Trace of a two-channel Oscilloscope showing FPI scans at various settings of a 10- $\mu$ m diameter VCSEL ( $\lambda = 840$  nm) and the piezoelectric ramp drive voltage; (a); no feedback voltage from VCO, Ramp voltage 54V,  $I_{bias} = 4.8$ mA. (b); feedback voltage =17.8V from VCO, Ramp voltage 250V,  $I_{bias} = 4.8$ mA.



**Fig. 4:** Spectra, Spectral peak intensity, peak positions and FWHM of a 10 $\mu$ m-diameter VCSEL as measured with FPI at a higher feedback level of 16.7dB.

**CONCLUSION**

The spectral characteristic of a 10 $\mu$ m-diameter VCSEL has been reported using a scanned FPI at a FSR of 35GHz. The device was modulated with a minimum frequency of 2.4GHz and was

able to yield splitted spectra up to 62GHz. The observation of the FWHM reveals that the least spectral linewidth using the FPI is of the order of 1.6 - 2GHz, while using the OSA, the minimum linewidth is about 0.05nm (~21GHz).

The finding in this work indicates that a surface emitting laser at 850nm can be suitable in a high speed communication especially when transmission of various signals of different frequency ranges need to be transmitted at the same time.

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