Frequency Dependent Polarization Dynamics in Vertical Cavity Surface Emitting Lasers with Electrical Injection

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Abstract—We report on the polarization dynamics in VCSELs with a small frequency modulation. The polarization state of a VCSEL is shown to be controlled by only changing the frequency of the modulation to electrical injection.

Understanding and controlling the polarization properties of vertical cavity surface emitting lasers (VCSEL), is of critical importance for the applications in communication networks with polarization sensitive elements, as well as other important applications, such as, medical imaging, environmental monitoring and military. VCSEL modes are transverse electromagnetic (TEM) in nature due to the vertical structure. The polarization orientation in the lateral direction is hard to control due to the symmetric nature of typical VCSELs. Crystalline symmetries generally give rise to two dominant linear polarization directions, oriented along <110> and<1$\bar{1}$0> axes. These linear polarization modes are usually bistable and exhibit polarization switching at certain bias currents. Various techniques have been previously used to control the polarization state of a VCSEL, such as, asymmetric current injection [1], controlled stress etc. In this paper we report, for the first time, on the complex high frequency polarization dynamics occurring near the polarization switching point. We demonstrate that the polarization state of a VCSEL can be altered by changing only the frequency of electrical modulation, while keeping all other parameters fixed. These results not only enable a new method for polarization control in VCSELs, but also underline the complex dynamics near the polarization switching point.

Highly strained VCSEL material with InGaAs/GaAs quantum well active region, operating at 1060nm was chosen for this study. The VCSEL under test has a circular mesa of 14µm diameter. A tapered oxide aperture, with oxidation length of 3µm, was used to confine the carriers and provide index guiding. The substrate of the bottom-emitting VCSEL was antireflection coated to minimize the optical feedback. The polarization dependent light-current (LI) curve of this VCSEL is shown in Fig. 1. This VCSEL shows type I polarization switching (switching from high to low wavelength) around 0.78mA of bias.

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In order to study the frequency dependence of its polarization properties, the VCSEL was electrically modulated with a network analyzer, operating at 130MHz to 20GHz frequency range, at a modulation power of 1mW. This corresponds to a current swing of approximately 300µA peak to peak, which is much lower than the bias current. Light emitted from the bottom was focused onto a multimode optical fiber using aspheric lens and mirror assembly, after passing through a polarizer. The signal was detected using a 25GHz infrared photodetector, the output of which was amplified and fed to the network analyzer. The modulation transfer function was measured at several different DC biases, and the resulting responses were plotted in two dimensional contour plots, shown in Fig. 2.

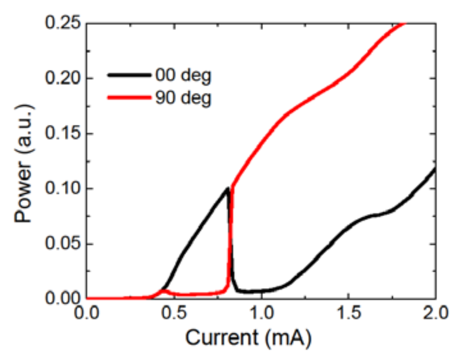

Fig. 1. VCSEL L-I with a polarizer showing polarization switching at 0.78mA.

It is clear from Fig. 2 that even though all other parameters are unchanged, the polarization direction can be controlled by varying the frequency of modulation. For instance, above 0.7mA, the polarization switching to 90° occurs only above 4GHz. Below 4GHz, both the polarization modes are coexisting. The exact nature of this frequency response depends on the modulation amplitude. For example, at the modulation power of -10dBm, the optical power goes from 90° to 0° between 3-4GHz, and goes back into 90° polarization mode above 4GHz. The small increase in modulation response in 0° polarization response shown in Fig. 2(a) is due to a higher order mode. It should be noted that these phenomena are not thermally driven, as the modulation frequencies are much higher than typical thermal cutoff frequencies for polarization switching, which are less than 1MHz [2].

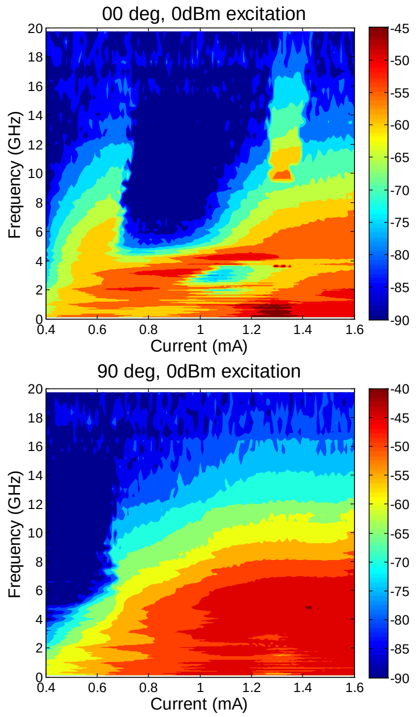

Fig. 2. Frequency response of VCSEL for two different polarization directions as a function of bias current, showing frequency dependent polarization switching.

In order to estimate the polarization switching extinction ratio that can be obtained by changing the frequency, a DC measurement of power was carried out on this VCSEL under high frequency continuous wave (CW) electrical modulation. Results are shown in Fig. 3. It is clear that the ratio of power going into each polarization can be controlled by the frequency of modulation. It should be emphasized that only the averaged DC power was measured in this experiment. High extinction ratio of 18dB was obtained just by changing the CW modulation frequency.

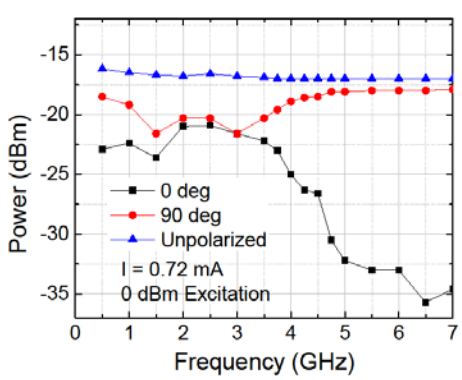

Fig. 3. DC power in different polarization modes of VCSEL under different frequency modulation.

Fig. 4. shows optical spectra at two different frequencies of modulation. VCSEL was biased at 0.72mA, with an RF power of 0dBm superimposed on the DC bias. The optical modes are broadened, probably due to chirping as a result of modulation. It can be seen that at 3GHz modulation, the fundamental mode consists of two orthogonal polarizations with equal intensity. As the frequency of modulation increases to 6GHz, the power shorter wavelength mode decreases as compared to the longer wavelength mode. Unpolarized spectrum is simply the sum of the spectra for two orthogonal polarizations.

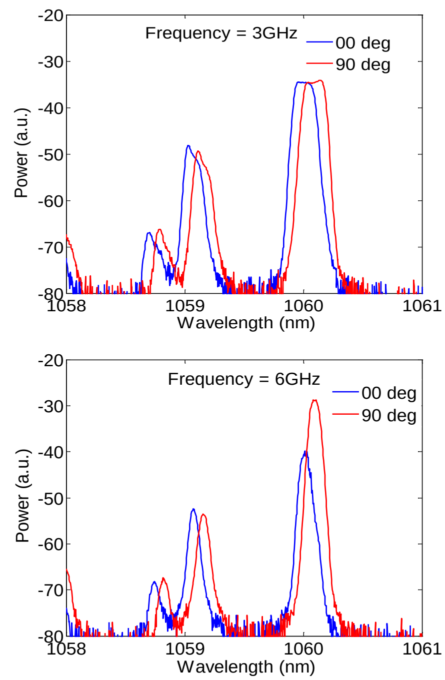

Fig. 4. Optical spectrum obtained from the VCSEL biased at 0.72mA of DC current, with constant frequency modulation of (a) 3GHz and (b) 6GHz..

In conclusion, the polarization state of a VCSEL can be altered purely by changing the modulation frequency of electrical injection. High extinction ratios obtained by this method suggest the potential for this technique for polarization control, possibly at high modulation speeds. Measurements reported here also important towards understanding the complex physics behind the frequency dependent polarization dynamics in VCSELs.

References:

[1] Augustin et al, IEEE Photon. Technol. Lett., 16(3), pp 708, 2004
[2] Verschaffelt et al, IEEE J. Quantum Electron., 39(10), pp 1177, 2003