Fast Polarization Modulation in Vertical Cavity Lasers with Electrical RF Injection

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Abstract—We report on a new method for fast electrical modulation of the polarization state of a simple, two terminal VCSEL. By biasing the VCSEL with a gated RF signal, polarization can be modulated at more than a GHz rate, which is fastest for electrical modulation of polarization.

It is well known that VCSEL modes are transverse electromagnetic (TEM) in nature due to the vertical structure. 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. Understanding and controlling the polarization properties of VCSEL is of critical importance for applications in communication networks with polarization sensitive elements, medical imaging, environmental monitoring and military. Various techniques have been previously used to control the polarization state of a VCSEL, such as, asymmetric current injection [1], controlled stress, electro-optic birefringence etc. Fast polarization modulation has been previously achieved by optically injection locking to polarized laser pulses. However, for the ease of control and scaling, being able to modulate the polarization with electrical injection is particularly attractive. So far, the polarization modulation of VCSEL with electrical injection has been limited to less than 5MHz, due to thermal nature of switching mechanisms [2].

We have previously reported [3] on the complex high frequency polarization dynamics occurring near the polarization switching point by injecting a RF frequency electrical current into the VCSEL. In this paper we report, for the first time, on a controlled polarization modulation at 1.35GHz, which is, by far, the fastest reported for electrically injected VCSELs. We demonstrate that the polarization state of a VCSEL can be altered by changing only the frequency of modulation, while keeping all other parameters fixed. This method does not require any special fabrication steps or packaging and thus is suitable for commercially available two terminal VCSELs.

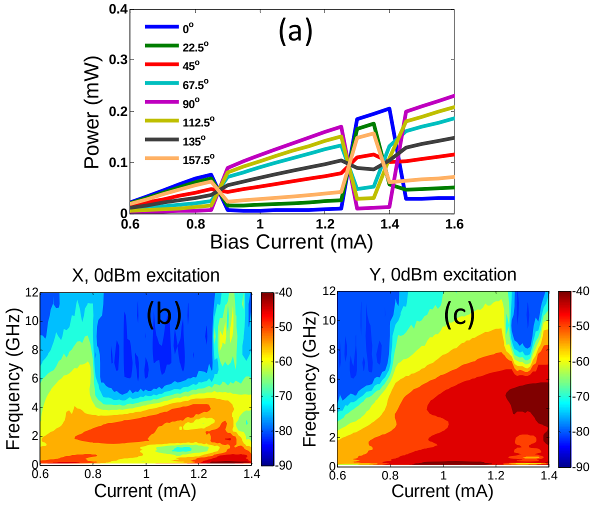

Fig. 1. (a) VCSEL L-I curve at different polarizer angles. (b,c) Polarized S_{21} measurements as a function of bias current, showing frequency dependent polarization switching for X (0^o) and Y (90^o) polarizations

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 angle dependent light-current (LI) curve of this VCSEL is shown in Fig. 1 (a). Transitions after 1.4mA are due to the higher order lateral mode. Polarized frequency response curves (S_{21}) of this VCSEL, subjected to 0dBm nominal modulation power are shown in Fig. 1(b)-(c). For this measurement, the light emitted from the bottom of the VCSEL 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

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transfer function was measured at several different DC biases, and the resulting responses were plotted in two dimensional contour plots, shown in Fig. 1.

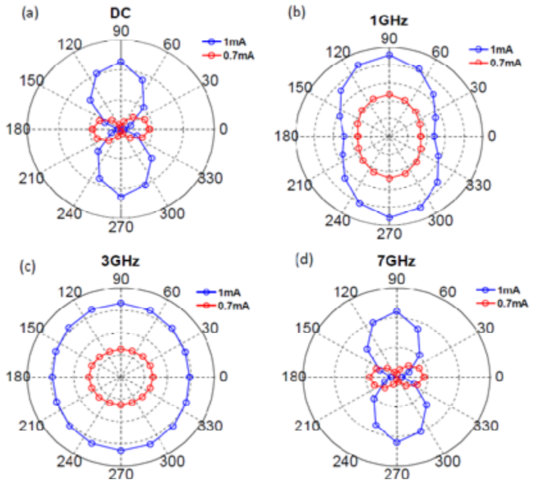

Fig. 2. Polarization angle dependent power measurements at two different bias currents in (a) DC conditions and with RF injection of frequency (b) 1GHz (b) 3GHz and (d) 7GHz.

Interestingly, even though at DC conditions high extinction ratio polarization switching is observed, a rich frequency dependence of this extinction ratio is obtained as the RF signal is applied to the VCSEL. For RF frequencies below 4GHz, the S_{21} parameter is significant in both the polarizations, which is in sharp contrast to DC measurements. This can be visualized with polar plots of output power at different polarization angles, for the same DC bias current, as shown in Fig. 2. VCSEL was subjected to RF injection of various frequencies and at 0dBm nominal modulation power for this measurement. Plots obtained at no RF injection, and with RF injection at 1GHz, 3GHz and 7GHz frequencies are shown in Fig. 2(a), (b), (c) and (d), respectively. It can be clearly seen that, without any RF injection, X (0^o) and Y (90^o) modes are dominant at 0.7mA and 1.0mA current, respectively. As RF modulation is applied, below 4GHz, the VCSEL polarization selection is drastically altered and it emits nearly equal power in all the polarization directions. At higher RF frequencies, response becomes similar to that in DC conditions.

In order to estimate the speed of the polarization modulation, the VCSEL was subjected to periodic burst of RF currents with the nominal modulation power of 0dBm. These periodically gated RF bursts were generated by passing a constant frequency RF signal and a square wave through a double-balanced mixer circuit. The VCSEL output was passed through a polarizer, then focused onto a multimode optical fiber, detected with a high frequency detector, amplified and fed to an oscilloscope. A low pass filter was used after the amplifier to reduce the carrier RF signal by approximately 10dB. Fig. 3 shows the time-domain response for X and Y polarized outputs at different modulation frequencies. The frequency of the RF source was kept constant at 4 GHz, and the modulation power of was 5dBm. Fig. 3 (a) shows the time averaged response for a modulation frequency of 50MHz. It is clear that the polarization mode changes from dominant X mode to dominant Y mode as we go from 'on' to 'off' state of the RF burst. Fig. 3 (b) shows the response at 1.35GHz square wave frequency at 1.05mA of DC bias applied to the VCSEL. Output of X and Y channels are nearly 180^o out of phase, indicating the dominant polarization changing between the two modes, in less than 350ps. This is, by far, the fastest reported polarization modulation using electrical injection.

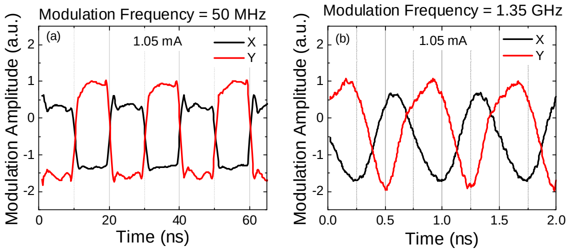

Fig. 3. Polarization modulation response for VCSEL in X and Y polarizations for modulation frequency of (a) 50 MHz (b) 1.35 GHz at 1.05 mA bias.

In conclusion, a new way of electrically modulating the polarization of VCSELs is reported. By injecting the electrical RF signal into the VCSEL, the state of the polarization can be altered at more than a GHz rate, much beyond the thermally limited modulation speeds.

References:

[1] Augustin et al, IEEE PTL, 16(3), 708, 2004
[2] Verschaffelt et al, IEEE J. Quantum Electron., 39(10), pp 1177, 2003
[3] Barve et al, IEEE Photonics Conference, TuF 3, 2012.