High Speed Polarization Modulation of Oxide Confined Asymmetric VCSELs in Multimode Regime

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Abstract: Polarization resolved optical spectral analysis of multimode, oxide-confined asymmetric VCSELs is presented. High-extinction-ratio polarization switching has been observed even in the multimode regime of these VCSELs. Furthermore, high-frequency polarization modulation of over a GHz with gated RF electrical modulation has been achieved.

Due to the symmetric nature of vertical-cavity surface-emitting lasers (VCSELs), the output polarization is hard to control. In a symmetric VCSEL, each transverse mode is typically associated with two non-degenerate linearly polarized modes. These linear polarization modes are usually bistable and exhibit thermally driven polarization switching at certain bias currents. Mode competition between different transverse polarization modes gives rise to complex mode selection dynamics in the multimode regime. In a symmetric VCSEL, although very high extinction ratio for the polarization switching is possible in the single-mode regime, the polarization extinction-ratio is typically very low (<2) in the multimode regime, due to simultaneous lasing in several different modes with different polarization characteristics. In this paper, we present the polarization resolved optical spectrum for asymmetric oxide confined VCSELs in multimode regime. We also demonstrate the electrically driven, RF frequency induced ultrafast polarization modulation in multimode regime of the VCSEL, for the first time, and achieve high speed modulation of over 1GHz. This is more than two orders of magnitude faster than previously achieved electrically controlled polarization modulation frequency for multimode VCSELs.

Highly-strained VCSEL material with a InGaAs/GaAs quantum-well active region, operating at 1060nm was chosen for this study. The VCSEL under test has an elliptical mesa with major radius of 28μm and minor radius of 16 μm. The axes of ellipse are oriented along crystallographic <110> and<1-10> axes. A tapered-oxide aperture, with oxidation length of 7 μm was used to confine the carriers and provide index guiding. The eccentricity of the oxide aperture is much larger than that of the mesa. The substrate of the bottom-emitting VCSEL was antireflection coated to minimize optical feedback. We have previously demonstrated [1,2] that ultrafast polarization modulation of a VCSEL is possible by applying gated electrical RF signals to the VCSEL in the single-mode regime.

Figure 1 shows the polarization resolved LI curve for constant stage temperature of 20°C for DC conditions and with a 3GHz RF signal of 5dBm nominal power overlaying on top of the DC bias current. Here, the major axis of the VCSEL is along Y-direction. Some interesting features of this LI curve are: (a) even in this highly asymmetric device, both the polarization outputs are still present; (b) very high polarization extinction ratios are observed even in the multimode regime; and (c) both X and Y modes emit similar power in the multimode regime, below 2mA, for the measurements with 3GHz RF signal, which is similar to that observed before in the single mode regime [1-2].

To get insights into the mode structure of this VCSEL, polarization resolved optical spectral measurements were carried out. Figure 2 shows two dimensional contour plots obtained by plotting optical spectral measurements for different bias currents on a same plot for (a) X polarization and (b) Y polarization. Individual optical spectra are also shown at two different bias currents, in Figure 2(c) and (d), to get an idea about the exact nature of the curves and powers in each mode. It can be seen from Figure 2(a) and (b) that the fundamental mode (TEM00) switches between X and Y polarization components, while the first excited state has only a dominant Y component, due to the asymmetric nature of the VCSEL. This leads to high extinction ratio switching even in multimode regime.

Polarization resolved time domain measurements, similar to those described in Barve et al [1] were performed to estimate the speed of the polarization modulation. The VCSEL was subjected to periodic bursts of RF currents. The VCSEL output was passed through a polarizer, then focused onto a multimode optical fiber, detected and amplified. A low pass filter was used after the amplifier to block the carrier RF signal. Fig. 3 shows the time-domain response for X and Y polarized outputs at modulation frequency of 1.05GHz (DC component of the signal was blocked). The frequency of the RF source was kept constant at 2.5 GHz, and the modulation power was 5dBm. 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. This was measured at 2mA of DC bias applied to the VCSEL, which corresponds to the multimode regime, as seen from Fig. 2. This is, by far, the fastest reported polarization modulation using electrical injection in multimode regime.
In conclusion, we present insights into high extinction ratio polarization switching in highly asymmetric VCSELs. We also demonstrate ultrafast polarization modulation in multimode regime, which is attractive for increasing the output power of the VCSEL while maintaining high speed polarization modulation.

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