Light emitting properties of VCSEL chips in liquid crystal cell

Y. Xie,[1] W. Woestenborghs,[1] J. Beeckman,[1] K. Neyts,[1] and K. Panajotov[2]

[1] Ghent University, Dept. of Electronics and Information Systems, 9000 Ghent, Belgium
[2] Vrije Universiteit Brussels, Dept. of Applied Physics and Photonics, 1000 Brussels, Belgium

A VCSEL chip of 250 µm by 250 µm is placed inside a liquid crystal cell with a gap between the emitting area and the upper glass plate of about 30 µm. This allows covering the VCSEL with a thin layer of liquid crystal after filling the cell through capillary forces. The light emitting properties are investigated, including the optical power, divergence and polarization, all in function of the applied current to the VCSEL. It is observed that the polarization states of the laser beam can be changed by using different type of liquid crystal. This technology opens an effective way to fabricate integrated VCSEL chips in optoelectronic devices and different experiments are planned in the future with the fabricated devices.

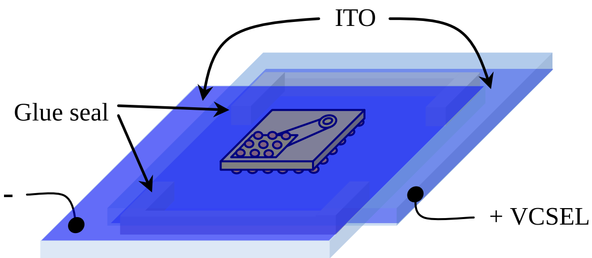
Introduction

The bandwidth of electrical interconnects in traditional silicon based integrated circuits are reaching the physical limitations [1-4]. Optoelectronic devices become an alternative which can provide high-speed, high-capacity and low power consumption optical interconnects [5-9]. Vertical Cavity Surface Emitting Lasers (VCSELs) have been used in optoelectronic devices in the past decade [10-15]. The application of the VCSEL laser in optoelectronic devices benefits of high light emission efficiency and low energy consumption. In addition, it has been demonstrated that the properties of the emitted light can be controlled, in both wavelength [11, 12] and polarization [13], by using a liquid crystal (LC) layer in close contact with the VCSEL chip. The orientation of the liquid crystal in the layer is controlled by an applied voltage. In these articles however, he VCSEL is optically pumped, in order to avoid technological difficulties. In other publications, an external liquid crystal device was used as a computer controlled hologram to achieve reconfigurable optical interconnects [14, 15].

In this work, we fabricated and characterized electrically driven VCSEL cells, in which the emitting area was covered with a thin extra-cavity LC layer. We demonstrate that the lasing properties are not fundamentally changed because the liquid crystal layer is a very weak external cavity which introduces only minor reflections. However, the LC layer affects strongly the polarization state of the VCSEL emission due to its birefringent properties. In a next stage we plan to drive the liquid crystal separately in order to control the polarization state and to incorporate the LC layer in an external cavity with high reflection in order to control other properties of the VCSEL emission.

Technology and experimental setup

A single mode VCSEL (LASER COMPONENTS GmbH) with 850 nm wavelength and 0.5 mW output optical power was used in our cells. The cell structure was demonstrated in Figure 1 (left). Both the top and bottom glass substrates were covered with ITO thin films as electrodes of VCSEL. A single layer of gold coated spacers of 30 µm size were mixed in optical glue, which was cured by UV light. 130 µm spacers were used in the glue seal. One optical microscope picture of VCSEL cell is shown in Figure 1 *right*. Gold coated spacer balls on the anode pad and the bottom of the chip are shown by arrows.



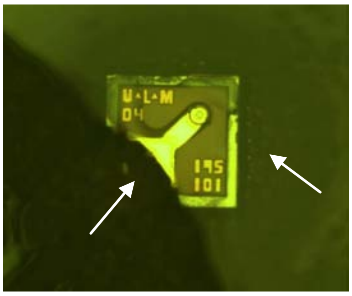


Figure 1. Schematic structure (*left*) and microscopic picture (*right*) of the VCSEL cell. The bottom and the anode pad of VCSEL were conductively connected to the bottom and top ITO electrodes, respectively, through micro-sized gold balls embedded in cured optical glue (white arrows).

The optical setup, shown in Figure 2, was designed to characterize the optical properties of the light emitted from the VCSEL cell. Two convex lenses were used to produce parallel light beam and focused it, respectively. The divergence θ can be calculated by measuring the size of the spot (D) in between the two convex lenses.

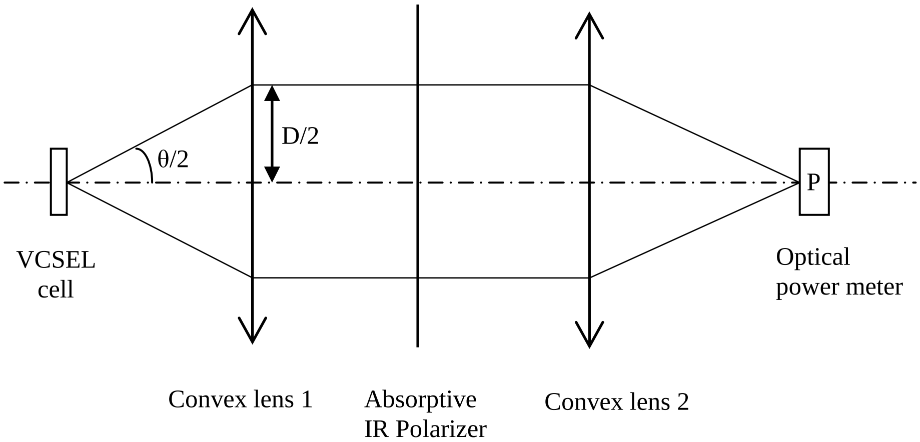


Figure 2. Optical setup for VCSEL cell measurement. The divergence θ can be calculated by measuring the size of the spot (D) in between the two convex lenses.

Results and Discussions

Electro-optical characteristics were investigated by I-P curve before LC was filled in. The maximum operating current is 1.8 mA. We observed that the threshold current was 0.5 mA, and the output optical power linearly increased with the driving current.
In order to test the polarization state of the emitted beam, one rotatable absorptive infra-red (IR) polarizer was set in between the two lenses. The dependence of optical power on the current at different polarization directions was measured. I-P curves were taken at

0°, 45° and 90° for cells filled with 5CB and E7 LC, respectively (Figure 3, top left and bottom left).

The polarization state can be described by Stokes parameters S1, S2 and S3 [16]. S1 describes the linear polarization along 0° or 90°; S2 describes the linear polarization along ±45°; S3 describes the degree of circular polarization. These parameters were calculated from above data and shown in the right column in Figure 3. It is observed that the polarization states of the light from two cells were different. For the 5CB cell, Stokes parameters S1 and S2 changed with driving current when it was higher than the threshold (top right in Figure 3). In contrast, they stayed stable in the working range (from 0.5 to 1.8 mA) for the E7 cell (bottom right in Figure 3). This can be explained by the different temperature sensitivity of LC 5CB and E7. Compared with broad nematic phase temperature range of E7 (from -10 to 60.5°C), it is only from 24 to 35.3°C for 5CB. That means 5CB is much more temperature sensitive than E7. When VCSEL is working, its temperature increased with the driving current, in the result, the birefringence of 5CB, consequently the phase retardation of the transmitted laser beam, changed with the current.

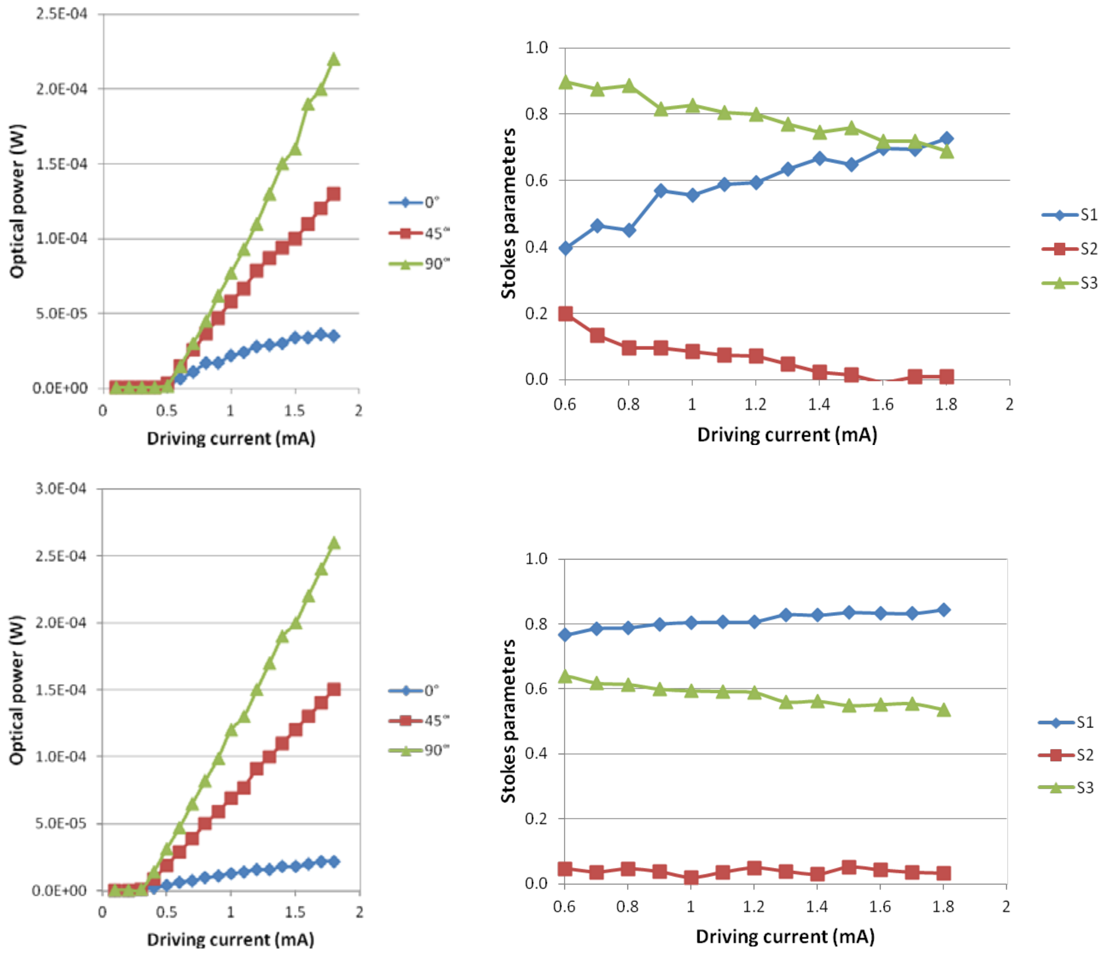


Figure 3. Electro-optical characteristics of VCSEL cells filled with 5CB (top) and E7 (bottom). *Left*: I-P curves in polarization direction 0°, 45° and 90°. *Right*: Stokes parameters.

Conclusions and outlook

We have designed and fabricated a novel LC cell for optoelectronic devices. A VCSEL laser was located in the cell and covered by extra-cavity LC layer. The optical properties, including the optical power and polarization state of the laser beam were investigated. It is observed that the polarization state of the laser beam can be changed by using different types of liquid crystal. We have shown that the polarization state changes when changing the driving current when we use a LC with a low isotropic transition temperature. This is an indication that the VCSEL chip is heated during its operation. Our technology opens an effective way to fabricate integrated VCSEL chips in optoelectronic devices and in further work we plan to demonstrate the control of the polarization state by applying a voltage to the LC layer, independent of the VCSEL current.

References

[1] B.E. Lemoff, M.E. Ali, G. Panotopoulos, G.M. Flower, B. Madhavan, A.F.J. Levi, and D.W. Dolfi, J. Lightwave Technol., vol. 22, 2043, 2004.

[2] D. Fey, W. Erhard, M. Gruber, J. Jahns, H. Bartelt, G. Grimm, L. Hoppe, and S. Sinzinger, Proc. IEEE. Vol. 88 (2000), p. 838.

[3] J. Shin, C. Seo, A. Chellapa, M. Brooke, A. Chatterjee and N.M. Jokerst: Proc. IEEE Electronic Components and Technology Conf., 1067, 2003.

[4] D.A.B. Miller, IEEE J. Select. Top. Quant. Elect., vol. 6, 1312, 2000.

[5] C. Hoyeol, P. Kapur, and K.C. Saraswat, J. Lightwave Technol., vol. 22, 2021, 2004.

[6] F.C.F. Tsai, C.J. O'Brien, N.S. Petrovic, and A.D. Rakic, Appl. Opt., vol. 44, 6380, 2005.

[7] X. Wang, F. Kiamilev, G.C. Papen, J. Ekman, P. Gui, M.J. McFadden, J.C. Deroba, M.W. Haney, and C. Kuznia: Appl. Opt., vol. 44, 6240, 2005.

[8] R. Bockstaele, T. Coosemans, C. Sys, L. Vanwassenhove, A. Van Hove, B. Dhoedt, I. Moerman, P. Van Daele, R. Baets, R. Annen, H. Melchior, J. Hall, P.L. Heremans, M. Brunfaut, and J. Van Campenhout, IEEE J. Sel. Top. Quant. Elect., vol. 5, 224, 1999.

[9] V. Baukens, G. Verschaffelt, P. Tuteleers, P. Vynck, H. Ottevaere, M. Kufner, S. Kufner, I. Veretennicoff, R. Bockstaele, A. Van Hove, B. Dhoedt, R. Baets, and H. Thienpont, J. Optic. Pure Appl. Optic., vol. 1, 255, 1999.

[10] T. Sakamoto, H. Tsuda, M. Hikita, T. Kagawa, K. Tateno, and C. Amano, J. Lightwave Technol., vol. 18, 1487, 2000.

[11] C. Levallois, B. Caillaud, J.L. de Bougrenet de la Tocnaye, L. Dupont, A. Le Corre, H. Folliot, O. Dehaese, and S. Loualiche, Appl. Phy. L., vol. 89, 011102, 2006.

[12] O. Castany and L. Dupont, J. Micromech. Microeng., vol. 20, 065019, 2000.

[13] C.I. Wilkinson, J. Woodhead, J.E.F. Frost, J.S. Roberts, R. Wilson, and M.F. Lewis, IEEE Photon. Technol. L., vol. 11, 155, 1999.

[14] S. Tang, Y. Tang, J. Colegrove, and D.M. Craig, IEEE Photon. Technol. L., vol. 16, 1385, 2004.

[15] M. Aljada, K.E. Alameh, Y.-T. Lee, and I.-S. Chung, Opt. Express, vol.14, 6823, 2006.

[16] T. Scharf, Polarized Light in Liquid Crystals and Polymers, John Wiley & Sons, 2007