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Polarization switching behavior of VCSEL arrays

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We present an experimental study of the opto-electronic and polarization behavior of arrays of VCSELs. Although the individual elements of the studied air-post and oxide-confined VCSEL arrays show a uniform threshold current, slope efficiency and emission wavelength, their polarization behavior can be quite non-uniform. We furthermore investigate the cross-talk between different VCSELs in an array. The spectral analysis of these VCSEL arrays, with a pitch of 250μm, shows the cross-talk is mainly of a thermal nature. However, this thermal cross-talk between neighboring devices is more than one order of magnitude smaller than the self-heating of the VCSELs and will therefore only marginally influence their polarization behavior.

1. Introduction

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a new type of semiconductor lasers that have attracted a lot of attention during the past years [1] due to the possibility of manufacturing these devices in 2D arrays [2], their superior beam quality, low power consumption [3] and high modulation bandwidth [4] compared to traditional edge-emitting semiconductor lasers or light emitting diodes. As two dimensional arrays of VCSELs are very suitable sources for parallel optical datacommunication, the uniformity of such 2D arrays has been studied in detail resulting in a high uniformity with respect to threshold current, slope efficiency and emission wavelength [2]. But also the uniformity in polarization behavior and the cross-talk between different devices are important aspects of these 2D arrays of VCSELs.

Indeed, one drawback of these devices is that the polarization of the emitted light is not defined a priori due to their quasi-cylindrical symmetry and direction of lasing perpendicular to the active region. However, real VCSELs do emit linearly polarized light. Sometimes the direction of the polarization in the transverse plane is randomly distributed from VCSEL to VCSEL, but usually there is a preference for a polarization direction along the [110] and [1-10] crystallographic axes for VCSELs grown on a (001) oriented substrate. This has been attributed to birefringence introduced by unintentional stress during manufacturing and by the electro-optic effect in the cavity and the mirrors [5]. But even VCSELs grown on the same wafer do not necessarily all have the same polarization direction preference. What's more, polarization switching (PS) from one state to the orthogonal one is often observed as the current is changed.

Therefore, we have studied the polarization behavior of air-post and oxide-confined VCSELs arrays. For both types of devices, which have been fabricated at CSEM, the pitch between the individual VCSELs in the array is 250μm. The air-post VCSEL array consists of 8 by 8 devices of which 9 elements have been bonded, while all 4 devices of the 2 by 2 oxide-confined VCSEL array are connected to the VCSEL package. The arrays were selected such that all devices show PS, which is not a general feature of these arrays.

2. Uniformity

In Fig.1 we show a typical DC polarization resolved optical output power versus current characteristics of the studied devices. In case of the air-post devices, the PS happens through a region of mode-hopping, while for the oxide-confined devices there is no mode-hopping at the PS point due to the appearance of a large region of hysteresis in the PS characteristics. For both types of VCSELs the observed PS is from the higher to the lower frequency mode, which has been denoted type I PS in [6].

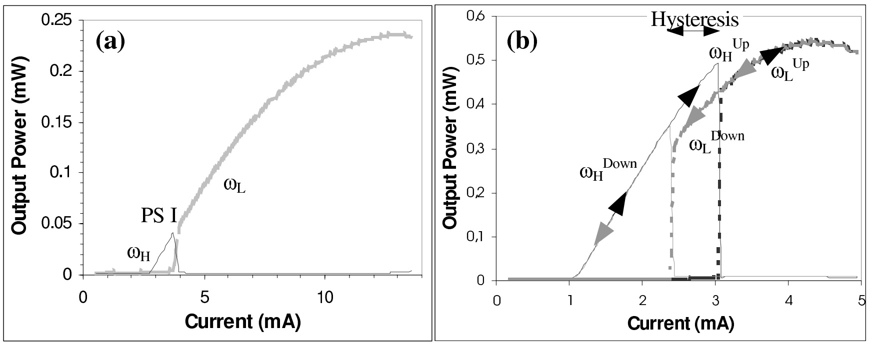

Fig.1: Polarization resolved PI-curve of (a) the air-post and (b) the oxide-confined VCSELs for the upward (indicated with "Up") and downward (indicated with "Down") current scan. Here ω_H (ω_L) is the high (low) frequency mode. The difference in the optical power level before and after the PS in (b) is due to the alignment of the optical setup.

In Table 1 an overview is given of the threshold current I_{th}, the PS current I_{sw} and the switching current relative to threshold I_{sw}-I_{th} for various devices within our arrays. In case of the oxide-confined devices, the switching current I_{sw} is taken as the middle of the hysteresis region. Also shown in this table is the standard deviation and the ratio of the standard deviation to the mean value of these various parameters. From the value of the standard deviations in Table 1 it can be seen that for both arrays the PS behavior is less uniform than the threshold current.

Air-post VCSELs	I_{th}	I_{sw}	I_{sw}-I_{th}	Oxide-confined VCSELs	I_{th}	I_{sw}	I_{sw}-I_{th}
1	3,15	4,02	0,87	1	1,15	2,59	1,44
2	3,35	3,95	0,6	2	1,3	3,11	1,81
3	3,5	4,2	0,7	3	1,25	2,69	1,44
4	3,4	4,46	1,06	4	1,15	2,63	1,48
5	2,95	4,22	1,27				
6	3,25	4,32	1,07				
7	3,2	3,85	0,65				
8	3,15	4,55	1,4				
9	NA	NA	NA				
Standard deviation	0,172	0,246	0,296	Standard deviation	0,075	0,240	0,179
Standard deviation / Mean value	0,053	0,059	0,312	Standard deviation / Mean value	0,062	0,087	0,116

Table 1: Uniformity of the PS behavior of an array of VCSELs. All currents and standard deviations are expressed in mA. The device indicated by NA was not working.

3. Cross-talk

Due to the large pitch of 250µm between the devices in the arrays, we have observed no direct influence of one VCSEL on the polarization resolved PI-curve of the neighboring device. However, as the current injected into a VCSEL will lead to an increase of its temperature, we expect some thermal cross-talk between different elements of an array. To measure this effect, we have performed a spectral analysis using a high resolution scanning Fabry-Perot spectrum analyzer. First, the temperature change in the active region of the VCSELs is calibrated by measuring the spectral shift Δf of the emission wavelength with increasing substrate temperature. For the air-post devices, this calibration gives

$$\frac{\Delta f}{\Delta T_{substrate}} = 13{,}8\,GHz/mA$$

In this setup, the substrate temperature of the VCSEL array is actively controlled by means of a peltier element and a thermistor temperature sensor. After this calibration procedure, the thermal resistance of the VCSELs can be determined via a measurement of the wavelength shift with increasing injection current. As the thermal resistance describes the proportionality between the temperature increase in the VCSEL and the dissipated power, we calculate the dissipated power $P_{dissipated}$ corresponding to a particular injection current I using

$$P_{dissipated} = (I\,V_{th} + R_d\,I^2)\,(1-\eta_{wp})$$

where the voltage V across the VCSEL is approximated by the linear expression $V=(V_{th}+R_d\,I)$ and η_{wp} is the wall-plug efficiency. The thermal resistance R_{self} of the air-post VCSELs determined in this way is

$$R_{self} = \frac{\Delta T^{self}}{\Delta P^{self}_{dissipated}} = 2{,}53\,K/mW$$

Finally, the thermal cross-talk is determined by measuring the spectral shift of a particular device caused by a change in the current injected into an adjacent VCSEL, resulting for the air-post devices in a value of

$$R_{cross} = \frac{\Delta T^{self}}{\Delta P^{cross}_{dissipated}} = 0{,}13\,K/mW$$

When comparing this thermal cross-talk R_{cross} with the thermal resistance R_{self}, we can see that the heating in an adjacent device of the air-post VCSEL array is almost 20 times smaller than the self-heating. Furthermore, we have observed that the heating in a particular device, when several neighboring VCSELs are switched-on, is a superposition of the temperature increase due to each neighboring VCSEL separately.

The same set of measurements has been performed on the oxide-confined VCSEL array, yielding a thermal resistance R_{self} of 6,71 K/mW and a thermal cross-talk R_{cross} of 0,07 K/mW. To explain this large difference between R_{self} and R_{cross}, we have calculated the temperature distribution inside the VCSEL wafer assuming a heat source inside the VCSEL with a Gaussian profile in the radial direction corresponding to a Gaussian profile of the injected current. The resulting temperature profile, as shown in Fig.2 for an injection current of 5mA in one of the air-post VCSELs, clearly indicates a large difference between the temperature increase of the electrically driven VCSEL and temperature increase of the neighboring device. The calculated values of the thermal resistance and the thermal cross-talk are R_{self} = 2,5 K/mW and R_{cross} = 0,09 K/mW, which are in good agreement with the measured values.

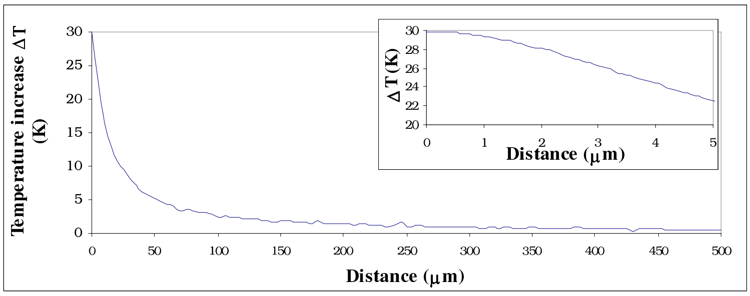

Fig.2: Calculated temperature distribution inside the air-post VCSEL wafer for an injected current of 5mA. The switched-on VCSEL is positioned at 0μm and the adjacent device is situated at 250μm. The inset shows an enlargement of the temperature profile near the switched-on VCSEL.

4. Conclusion

We have experimentally investigated the polarization behavior of arrays of VCSEL, using both air-post and oxide-confined VCSELs. The polarization behavior of the different elements is less uniform than their other opto-electronic characteristics, e.g. the threshold current, indicating that the PS behavior is governed by small anisotropies inside the VCSELs. We did not observe a direct influence of the PS behavior of one VCSEL on that of a neighboring device. Instead, the cross-talk between different VCSELs of an array is of a thermal nature. However, this thermal cross-talk is much smaller than the self-heating of the VCSELs and will therefore only marginally influence the VCSEL's characteristics.

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