

Controlled Polarisation Switching in VCSELs by means of Asymmetric Current Injection

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We have investigated the potential of asymmetric current injection for polarisation switching in GaAs-based intra-cavity contacted vertical cavity surface emitting lasers using two sets of p- and n-type contacts per device. When using the contacts set along the $[1\bar{1}0]$ axis, the polarisation was set along $[011]$ while using the contacts along $[011]$ the polarisation switches from the direction along $[011]$ to a direction making an angle of 25 to 90° towards $[011]$.

Introduction

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are very interesting for many short-distance fibre-optic communications applications and free-space parallel optical interconnects because of their low manufacturability costs, their circular beam and the possibility of making 2D arrays.

A major handicap in VCSELs is the unknown polarisation of the emitted light; it is hard to predict the emitted polarisation and it even can switch with increasing current [1-3].

An anisotropy in the gain or the losses is needed to fix the polarisation. This can be done by introducing an asymmetry in either the mirrors [4], in the cavity or in the active area.

We have introduced the concept of asymmetric current injection in Intra-cavity contacted VCSELs as a means to avoid the current crowding within the cavity and hence to favour lasing at the fundamental mode [5]. Moreover this asymmetric current injection has been shown to be very effective for stabilising the polarisation [6,7] since it introduces a net x-component for both the k-vector of the electrons and the electrical field. Both effects lead to an anisotropy in the gain. Previous simulations and experimental results [3,6,7] have shown that the polarisation is stably perpendicular to the current.

In this paper we present our results regarding an active polarisation switching in VCSELs when using two perpendicular sets of p- and n-contacts for each device.

Fabrication

The processing of the intra-cavity VCSELs was carried out using an MOVPE grown structure on an n-doped (100) GaAs substrate. The n-type lower mirror consists of 35 pairs of $\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}/\text{Al}_{0.92}\text{Ga}_{0.08}\text{As}$ layers with graded transitions and a doping concentration of $1.5 \times 10^{18} \text{ cm}^{-3}$. The active region has 5 x 8 nm thick GaAs quantum wells and n- and p-type confinement layers consisting of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ with a graded Aluminium content from 0.2 to 0.54. Furthermore there are $\text{Al}_{0.98}\text{Ga}_{0.02}\text{As}$ layers at both sides of the cavity intended to form the current constriction layers after a lateral wet selective oxidation [8]. Finally the top p-type DBR consists of 20 pairs alternating $\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}/\text{Al}_{0.92}\text{Ga}_{0.08}\text{As}$ with graded transitions and a doping concentration of $3 \times 10^{18} \text{ cm}^{-3}$ for the topmost 15 layer pairs and $1 \times 10^{18} \text{ cm}^{-3}$ for the lowest 5 pairs. Processing this air-post VCSEL structure into intra-cavity contacted VCSELs requires extra attention during the two etching steps of the mesas. The top p-contact should be placed on the low Al-containing layer of the top DBR with the high doping i.e. $3 \times 10^{18} \text{ cm}^{-3}$. Similarly, the n-contact is placed on the low Al-containing layer of the bottom DBR. Therefore etching the top and bottom DBRs should stop at the 14th layer of $\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}$ and around the second $\text{Al}_{0.16}\text{Ga}_{0.84}\text{As}$ of the bottom DBR respectively. The etching has to be followed by a wet etch to selectively remove high Al-containing layers. The detailed processing is described elsewhere [9].

Results and Discussion

Polarisation-dependent measurements are performed. Each VCSEL is excited using a DC current source while a beam splitter, two polarisation filters and two power meters allow measuring the transmitted powers of the two polarisations simultaneously.

All symmetric devices (with a p-contact surrounding the device mesa) showed the same polarisation along the [110] axis, stable with increasing current. Because the current flow in the xy-plane is equally spread in every direction, the direction of the current cannot influence the polarisation. This demonstrates that the [110] direction is the preferred polarisation direction for this wafer, fixed by more dominant mechanisms such as the crystal structure and mechanical strain. The same polarisation was found in the case of all measured asymmetric devices whose contacts lie in the $[\bar{1}10]$ direction confirming this preferential direction.

We have also measured VCSELs having four contacts split in two orthogonal sets

of n- and p-contacts (Fig. 1). We found when using the contacts set along the $[\bar{1}10]$ direction the polarisation was along the [110] direction whereas when using the set parallel to the [110] direction the polarisation switched to a direction making a certain angle with [110]. This angle varies between 25 to 90 degrees from VCSEL to VCSEL.

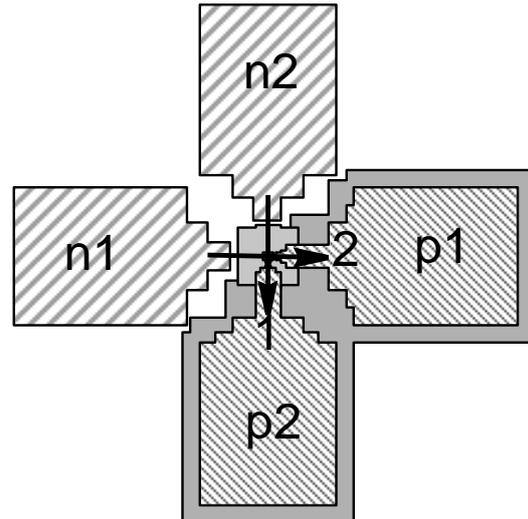


Figure 1- The layout of the four-contact VCSEL.

For each device the polarisation was stable independently of the injection current intensity. Figure 2 shows a schematic of the polarisation schemes.

In order to understand this result we simulate the current paths in the used VCSEL structure using a simple 2D model [10]. This shows that the lateral component of the current in the used structure is small in comparison to an ideal intra-cavity structure (Fig. 3). The same goes

for the electrical field and hence when contacting along the $[110]$ axis the weak lateral component of both the current and the electrical field is not sufficient to impose the polarisation perpendicular to the contacting set i.e. along the $[\bar{1}10]$ direction.

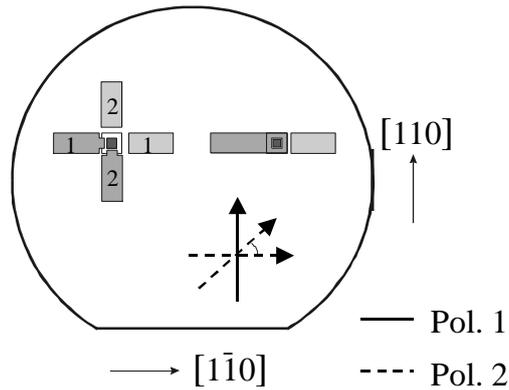


Figure 2- Schemes of polarisation switching

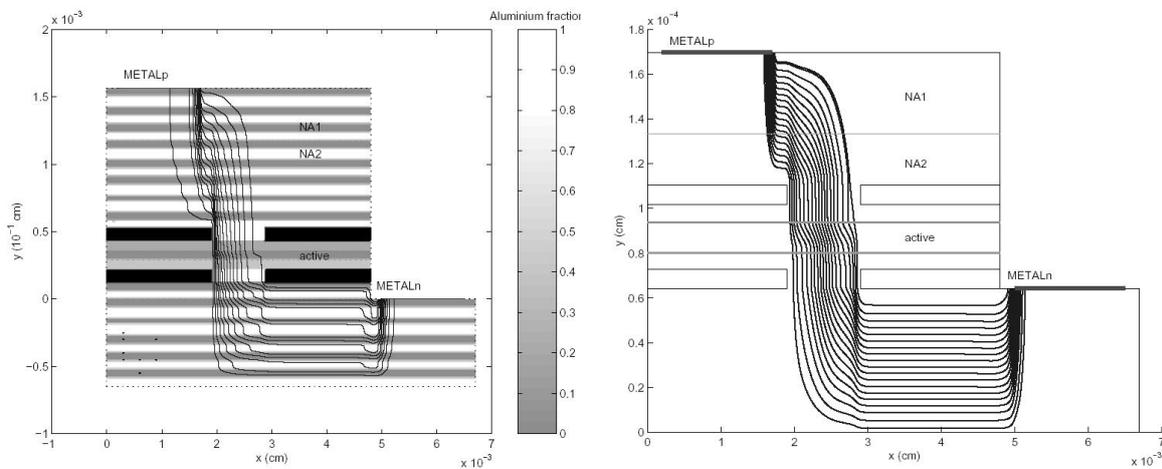


Figure 3- Current paths in the used VCSEL structure (left) and in an ideal intra-cavity VCSEL structure (right).

Conclusions

Intra-cavity VCSELs with asymmetric current injection have been fabricated and characterised. VCSELs with two perpendicular sets of p- and n-contacts show polarisation switching when changing the used contact set. Though the two observed polarisations are not always perpendicular we have demonstrated experimentally the possibility of an active polarisation switching in VCSELs. This additional modulation method can be used for routing purposes in reconfigurable optical interconnects.

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