Processing of Intra-cavity VCSELs in Structures with Doped DBRs

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Standard GaAs-based VCSEL structures with doped DBR mirrors are processed into intra-cavity contacted VCSELs with asymmetric current injection to investigate their polarisation behaviour. The processing requires reflectometry measurements during etching of the first and second mesa. The p- and n-contacts are deposited on an AlGaAs layer with the lowest Al-content of the upper and bottom DBR respectively. A dichromate solution was used to etch selectively the higher Al-content layer of the DBRs before depositing the contacts.

Introduction

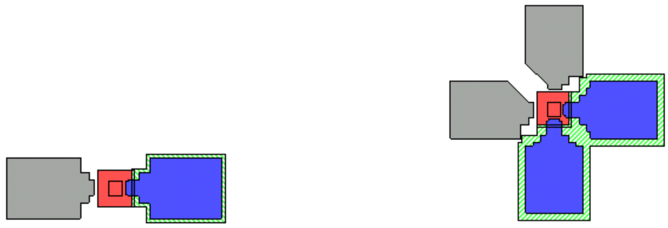
Vertical-Cavity Surface-Emitting Lasers (VCSELs) have become the source of choice for many short-distance fiber-optic communications applications and free-space parallel optical interconnects because of their many advantages as compared to edge emitting lasers: for example low manufacturability costs, superior operation conditions, and the possibility to create 2D arrays. A drawback of VCSELs is that the polarisation of the emitted light is not defined a priori, because of the symmetric structure, and can switch with increasing current.

Asymmetric current injection in intra-cavity contacted VCSELs has been demonstrated to be an effective way to stabilize the polarisation perpendicular to the lateral current [1, 2]. To achieve this lateral current component, the p- and n-contacts are no longer circumventing the mesa, but are restricted to opposite sides of the top and bottom mesa, respectively (see Fig. 1(a)). This concept allows not only to stabilize the polarisation, but also to switch the polarisation actively between two orthogonal directions. This adds an additional degree of freedom in the modulation of the laser light and can be used for routing purposes, for example in a reconfigurable optical interconnect.

To implement this idea, a new mask set has been developed. The layout for the VCSEL has 2 contact pairs as can be seen in figure 1(b). With this layout it will be possible to actively switch the polarisation with the choice of contacts.

Layer structure

To investigate the polarisation switching behaviour, four-contact intra-cavity VCSELs are processed from a standard 850 nm VCSEL wafer with doped mirrors. (See Fig. 2 for



(a) (b)

Figure 1: Mask layout of (a) two-contact VCSEL for polarisation stabilisation and (b) four-contact device for polarisation switching.

the Aluminium percentage profile of this wafer). This layer structure is in fact designed for standard airpost oxide-confined VCSELs, without a specific intracavity structure, so special measures have to be taken to assure good devices. The main problem is that no contact layers in between the mirrors and the cavity are implemented in the design. Therefore, we have to use several pairs of both the top and bottom DBR as contact layers and deposit the metal on the low Al-content layers to get lower contact resistance.

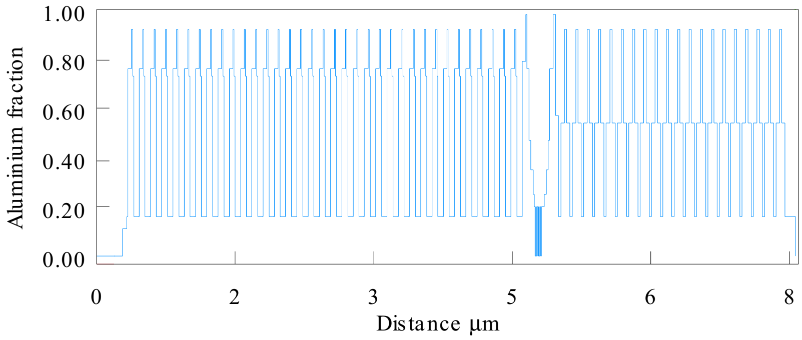
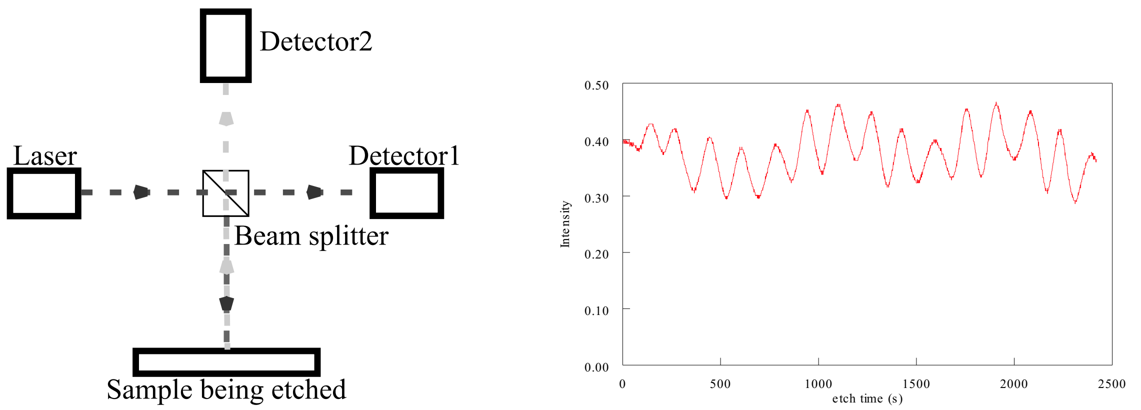


Figure 2: Aluminium content profile of the VCSEL layer structure

Process overview

During processing of the VCSEL, several critical steps occur. The first step is the etching of the top-mesa. A silicon-nitride mask is made by deposition, and subsequent photolithography and dry-etching of the SiN_x with SF_6 and Ar. Finally it has to be checked whether the SiN_x has been opened.
With this mask the first top mesa can be etched by the use of Reactive Ion Etching (RIE). The critical point in this processing step is to stop exactly on the right p-layer. In the case of the used structure one of the lowest $Al_{0.16}Ga_{0.82}As$ layers of the top mirror is the preferred one to stop in. To be able to stop in this layer an accurate measurement is required. This is done by making use of in-situ reflectometry at 650 nm, and is based on the difference in absorption for the layers with low- and high Al-content [3]. The setup for this measurement is shown in Fig. 3(a). A typical result is shown in Fig. 3(b). On the

basis of this strongly oscillating signal good reproducibility in etching can be obtained.



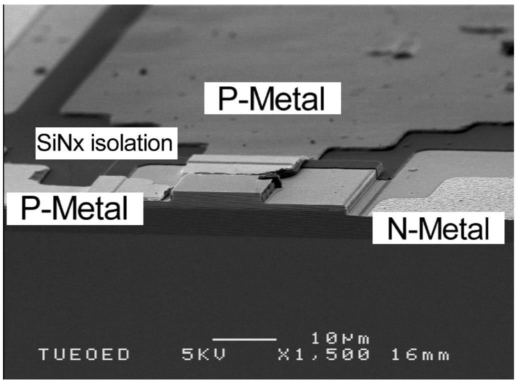
(a) (b)

Figure 3: Reflectometry: (a) Setup for in-situ reflectometry and (b) Measured reflection while etching top-mesa.

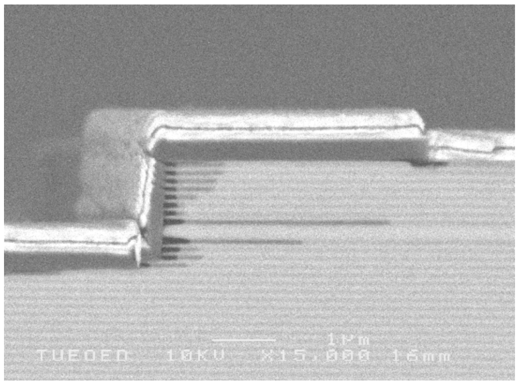
Because of this layer thickness being only about 360 Å, high Al-content layers surrounding it, and a non-uniform etch, the etch will not stop at the right material all over the sample. To overcome this, after the dry etch, $Al_{0.92}Ga_{0.08}As$ is wet etched selectively using a $K_2Cr_2O_7$ solution. This etch stops at an Al fraction of 0.2. The result is a more uniform, low Al-content P-contact layer at the mesa top surface, at which the metal contact is sputtered.
The second mesa is etched in a similar way.
Next, oxide current constrictions are formed by wet selective oxidation of the high (x=0.98) aluminium containing layers, to make sure the current will flow through the middle of the device. To protect the n-contact layers at the surface, a silicon-nitride mask is deposited using an image reversal process with the N-metal mask, so there is no need for an extra mask. The P-contact layers are still covered with SiN_x, so no special measures have to be taken there.
According to [4] the oxidation rate for $Al_{0.98}Ga_{0.02}As$ is about 10 times higher than for $Al_{0.92}Ga_{0.08}As$, at the conditions: an oven temperature of 420°C, N_2 flow of 2 l/min, and a water bubbler temperature of 95°C.
Because the P-contact extends to the bottom mesa, isolation from the N-contact is required. This is achieved by depositing a silicon-nitride isolation layer which is subsequently annealed to avoid bubbling. For the deposition of the P- and N-contacts a lift-off process is used. After this the contacts have to be annealed. Since the P-metallisation has to bridge the mesa-step, the P-metallisation is evaporated at an angle to ensure that the sidewalls are covered.

Processed devices

In Fig. 4(a) a SEM image of a cleave through a processed device is shown. The raised edges of the P-contacts due to the evaporation at an angle are visible. Figure 4(b) is



(a)



(b)

Figure 4: SEM photos of processed devices, (a) a cleaved device, (b) zoomed in on 2nd mesa

zoomed in on the second mesa to have a closer look at the oxidation fronts in the layers with differing Al-content. It is clear from the figure that the oxidation of $Al_{0.98}Ga_{0.02}As$ only extends for 3 to 4 μm, i.e. far less than the desired 15 μm to provide a good current flow in the middle of the device.

Results and Conclusions

First characterization of processed devices shows laser operation, although the four-contact VCSELs lase only for one set of contacts. This is attributed to orientation-dependence in the processing, possibly in depositing the P-contact at an angle. Therefore, we have not yet been able to test the polarisation switching. Nevertheless, our results show that by using in-situ reflectometry and selective wet etching, the etch-depth is much better controlled, allowing us to fabricate an intra-cavity VCSEL from a standard VCSEL-structure with doped DBRs.

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