In Situ Fabrication of Oxide Apertures in Vertical-Cavity Surface-Emitting Lasers

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Abstract:

One way to define the spatial mode of a vertical-cavity surface-emitting laser (VCSEL) is by incorporating an oxide aperture above its active region. The oxide aperture can be grown in a conventional oxidation furnace, but this can take hours of preparation time and often yields inconsistent results. An alternative is to grow the oxide aperture *in situ*, allowing for precise definition of the size of the aperture.

The goal of this project was to configure an existing furnace designed for *in situ* oxidation monitoring to produce consistent and even oxidation on arrays of VCSELs.

Introduction:

The spatial mode of a VCSEL is often defined by the size and shape of its air-post mesa. However this results in photon scattering losses at the edges of the mesa. By defining the mode with an oxide aperture instead, these losses can be greatly reduced, thereby increasing the efficiency and beam quality of the laser. In addition, this technique allows the mesa to be made larger, which makes fabrication of the VCSEL easier.

One way to create the oxide aperture is to grow it laterally in an oxidation furnace. However, standard oxidation furnaces do not allow monitoring of the reaction, and therefore require long setup times and often produce unpredictable results. A more promising alternative is *in situ* oxidation in a furnace that allows real-time monitoring. By watching the oxidation progress, the reaction can be stopped precisely when the correct aperture size has been achieved.

Experimental Setup:

In this project, we created apertures in VCSELs by oxidizing AlGaAs layers just above the active region, as seen in Figure 1. Each sample consisted of an array of such structures with varying sizes on a GaAs substrate.

We used an oxidation furnace configured for optical monitoring. Nitrogen gas was available from a wall source and was pumped in through two separate flowmeters equipped with valves. One flowmeter led directly into the furnace chamber, while the other led to a heated bubbler, then into the furnace chamber.

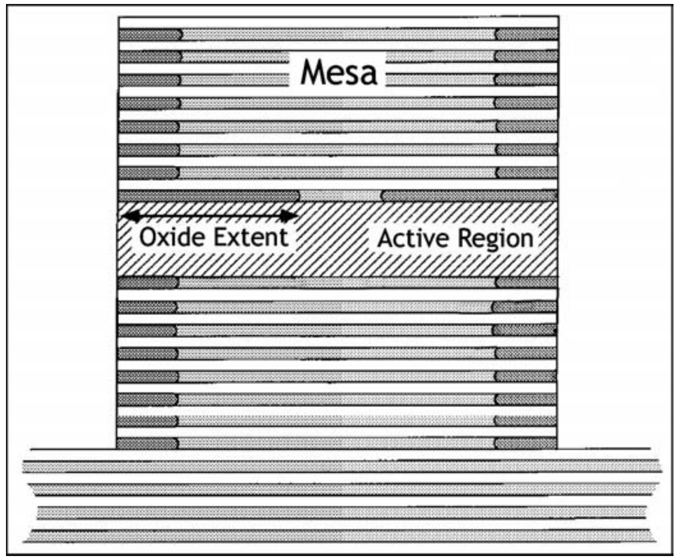

Figure 1: VCSEL with oxide aperture.

The furnace was equipped with a quartz viewport through which the oxidation could be monitored. The chamber was kept under a slight vacuum, which kept this viewport in place. Samples could be placed in the furnace by disconnecting the vacuum and removing the viewport.

The monitoring was achieved using a near-infrared sensitive silicon CCD camera with a high magnification lens system, which was mounted over the viewport. The camera connected to a video capture card on a computer, which allowed real-time viewing of the oxidation progress.

Experimental Procedure:

The wet oxidation of AlGaAs requires a moist, heated environment devoid of oxygen gas. To provide this environment, samples being oxidized were heated on a graphite hot plate with a steady stream of water-vapor-saturated nitrogen gas flowing into the furnace chamber. Samples were typically oxidized at

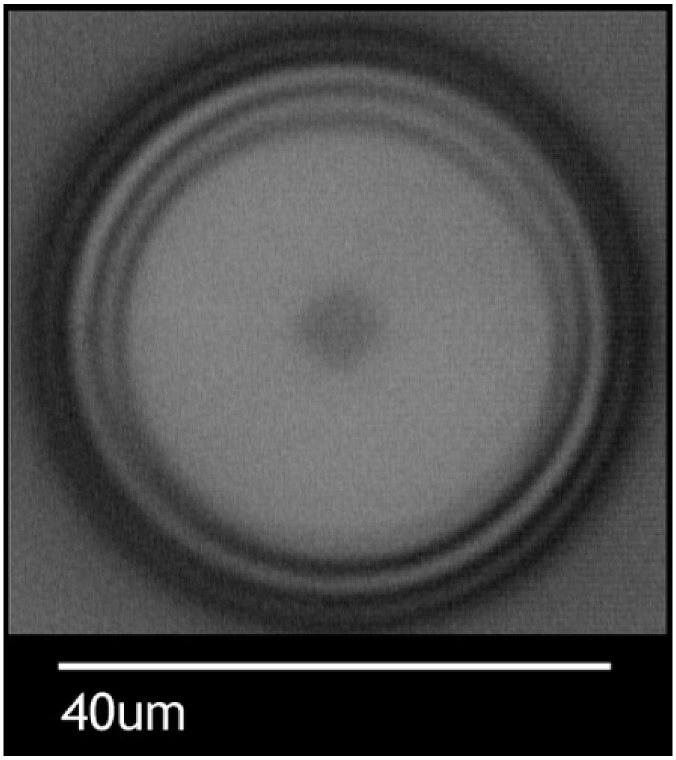

Figure 2: Top view of an oxide aperture.

a temperature of 430°C, with saturated nitrogen gas flowing in at a rate of 2 SCFH.

Results and Conclusions:

Many samples were oxidized over the course of the project. This helped uncover several problems with the furnace setup that needed to be solved for it to be functional. These problems included vibration, poor image contrast, and non-uniform oxidation rates.

The first problem addressed was vibration. Vibrations from the floor of the lab were traveling up the legs of the furnace table and causing poor image quality. This was alleviated by adding air-filled supports under each table leg, though due to the long lens structure, it was impossible to remove all vibration.

Once we achieved a stable image, the next task was to maximize the contrast in the image between the oxidized and unoxidized regions. Computer simulations showed that maximum contrast would occur between 850 and 950 nm. For this reason an 850 nm long-pass filter was used. Figure 2 shows a top view image of a VCSEL oxidized in our furnace; in it, the dark dot in the middle is the unoxidized region and the light ring is the oxidized region.

The final problem addressed was non-uniform oxidation rates in different structures on a single sample. The oxidation rates on structures only 200 μm away from each other varied by approximately 0.1 μm/min. The oxidation rate of AlGaAs in similar systems has been shown to be highly dependant on both temperature and flow rate of water vapor. Therefore the two possible explanations for this non-uniformity were uneven temperature on the hot plate or uneven water vapor dispersion in the chamber.

Future Work:

Unfortunately there was insufficient time for the final problem of non-uniform oxidation rates to be solved. One possible solution currently being pursued is to try an alternate material for the hot plate. The current hot plate is composed of graphite, which is a planar material. It typically has very good in-plane thermal conductivity, but very poor out-of-plane thermal conductivity. A material with a higher omnidirectional thermal conductivity (such as copper) could alleviate thermal non-uniformity.

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