Selective oxidation of AlGaAs aperture layers of a Vertical-cavity surface-emitting laser with a generation wavelength of 850 nm

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Abstract. A study of the technology of selective oxidation of the buried AlGaAs layer used as an aperture layer in the structure of a Vertical-cavity surface-emitting laser has been carried out. Oxidation process was made as thermal oxidating in a humidified nitrogen atmosphere. The conditions of the oxidation process are described, images of the oxidation results and the dependence of the growth rate of the oxidized layer on the process temperature are presented. A technology for the formation of an oxide current aperture has been developed for vertical cavity surface emitting lasers with a generation wavelength of 850 nm, which makes it possible to accurately control the size and shape of the resulting aperture.

1. Introduction
Currently, Vertical-cavity surface-emitting laser (VCSELs) are optoelectronic devices with very attractive characteristics, including low power consumption and high effective modulation frequency. VCSELs are widely used in a variety of devices: optical sensors, information processing devices, high-speed fiber-optic communication systems, and much more [1]. To achieve high performance of VCSELs, it is necessary to manufacture devices with a low threshold current, low voltage drop, and high optical power [2]. VCSELs of 850 nm spectral range are the key components in modern optical networks for data transmission. For the fabrication of 850 nm VCSELs, an epitaxial AlGaAs / GaAs heterostructures are typically used, which include an upper and lower distributed Bragg reflectors, a microcavity with an active region, and aperture layers.

The VCSEL fabrication process includes the epitaxial growth of a heterostructure of the required design and subsequent processing [3]. One of the significant stages of VCSEL fabrication is the formation of the aperture. For its creating, you can use ion implantation or oxidation. The process of aperture formation using wet thermal oxidation consists in lateral oxiditing of epitaxial AlGaAs layers with a high Al content (more than 95%) in a humid environment. Plasma-chemical etching (PCE) is typically used to open access to the aperture layer. An oxide aperture VCSEL has several advantages over an VCSEL with implanted aperture. The oxide aperture provides: low resistance of the upper distributed Bragg reflector (DBR), excludes recombination on the sidewalls near the optical cavity, minimizes lateral current spreading outside the cavity, a lower refractive index of the aluminum oxide layer provides better optical confinement than in the case of an ion-implanted aperture. In addition, ion implantation introduces many radiation defects; nonradiative recombination...
at these defects leads to a sharp increase in the threshold current and significantly reduces the quantum efficiency. VCSEL with oxide aperture have a low threshold current, low voltage drop and high power conversion efficiency [4].

2. Experimental technique

The aim of this work is to develop a technology and analyze of various conditions of wet thermal oxidation of the buried aperture layer of the AlGaAs / GaAs heterostructure, during fabrication of the 850 nm VCSELs.

The experiments were carried out on epitaxial heterostructures grown by the metal-organic chemical vapor deposition (MOCVD) method. The heterostructure has 21 alternating pairs of carbon-doped upper DBR layers, an aperture layer, an active region consisting of 4 quantum wells, and a lower DBR consisting of 35 pairs of silicon-doped layers. The concentration of aluminum in the aperture layer reaches 98%. A detailed description of the heterostructure is given in Table 1. A SiO₂ mask was formed on the wafer, then the mesa structures were formed using plasma-chemical etching in an inductively coupled plasma with a mixture of Cl₂ and BCl₃ gases on a Sentech SI 500 setup. Diameter of mesa-structure was 22 µm, the mesa height was 3 µm. This opened access to the aperture layer for subsequent oxidation. Then the wafer with the formed mesa structures was divided into samples (15×15 mm) for subsequent experiments. A schematic drawing of the experimental structure is shown in Figure 1.

![Figure 1. Schematic drawing of the experimental structure.](image)

For a series of experimental oxidations, a PEO-601 furnace for electronic component processing was used. An important process of thermal oxidation was carried out with nitrogen as a carrier gas, which was bubbled through water heated to 90 degrees. The carrier gas began to be supplied only after the furnace reached the operating temperature, therefore, oxidation did not occur during heating. The process parameters such as the heating time to the operating temperature, the operating temperature, and the carrier gas flow rate varied within wide limits. The process took 60 minutes. After each experimental process, the aperture diameter was measured with an optical micrometer. Further, the parameters of the oxidation process were corrected, and the next sample was oxidized. After several experimental processes, the aperture diameter was measured on the samples using a microscope with a software micrometer with an accuracy of 10 nm.
Table 1. Design of the heterostructure.

| №  | Purpose       | Material                                      | Thickness, nm |
|----|---------------|-----------------------------------------------|---------------|
| 1  | protective cap-layer | GaAs                                         | 20            |
| 2  | p-DBR         | \( Al_{0.12}Ga_{0.88}As/Al_{0.9}Ga_{0.1}As \) | 2936          |
| 3  | aperture layer | \( Al_{0.96}Ga_{0.02}As \)                   | 59            |
| 4  | active region  | \( In_xGa_{(1-x)}As/Al_xGa_{(1-x)}As \)       | 233           |
| 5  | n-DBR         | \( Al_{0.12}Ga_{0.88}As/Al_{0.9}Ga_{0.1}As \) | 4636          |
| 6  | substrate     | GaAs                                         | 650 μm        |

3. Experimental results

From the obtained results, it was found that the rate of heating to the operating temperature strongly affects the shape of the aperture; the longer it reaches the operating temperature, the more correct the shape of the aperture. If the time to reach the operating temperature was less than 60 minutes, then the shape of the aperture was corrugated. Therefore, the time to reach the operating temperature was chosen equal to 80 minutes. The influence of the carrier gas flow rate was found to be extremely insignificant. The process temperature has the greatest influence on the rate of oxidation. This is due to an increase in the diffusion rate of oxidant particles through a film of aluminum oxide, which is formed on the surface, and an increase in the rate of the chemical reaction between the oxidant and the material to be oxidized [5]. The insignificant effect of the flow rate of the carrier gas is due to the fact that the oxidation rate is limited by the rate of diffusion of the oxidant through the oxide film, and an increase in the concentration of the oxidant in the chamber does not give a result.

After carrying out a series of experimental oxidation processes, the dependence of the oxidizing rate on temperature was plotted for a fixed process time of 60 minutes. The resulting dependence is shown in Figure 2. Based on this dependence, the optimal oxidation regime was selected with the following parameters: \( t_{proc} = 60\text{min} \), \( V_{gas} = 2l/min \). With these parameters, a sufficiently high oxidation rate was ensured and the aperture had the shape of a regular circle with a diameter of 7.2 - 8 μm (Figure 3).

Figure 2. Dependence of the rate of oxidation of the aperture layer on the temperature of the process.

The next stage of the experiment was to study the cross-section of a sample with an oxidized aperture using the scanning electron microscopy (Figure 4). The image clearly shows the most oxidized aperture layer with the formed aperture. The layers of the upper DBR were also partially oxidized, this is due to the presence of aluminum in aluminum-contained layers. The lower oxidation is due to the low concentration of aluminum, which affects the rate of the layer oxidation.

**Figure 3.** Images of mesa structures with oxide apertures.

**Figure 4.** SEM image of cross-section of the mesa structure.

**4. Conclusion**

As a result of the study, the parameters influencing the rate of oxidation of the buried aperture layer of the AlGaAs / GaAs heterostructure were determined in relation to the 850 nm VCSEL. The main influence on the oxidation rate is exerted by the process temperature, since the diffusion of the oxidant through the oxide film to the oxidized material is accelerated and the rate of the chemical reaction increases with temperature rise. The flow rate of the carrier gas does not significantly affect the oxidizing rate due to the fact that the oxidation rate is mainly limited by the diffusion rate of the oxidant. The heating rate to operating temperature affects the shape of the aperture. The dependence of the oxidation rate on the process temperature has been obtained, and a technology for the selective oxidation of buried AlGaAs layers in a PEO-601 furnace has been developed.
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