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Invited

Selective Oxidation of AlGaAs/GaAs Structure and Its Application to Vertical Cavity Lasers

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1. Introduction

The oxide-confined vertical-cavity surface-emitting lasers (VCSELs) have received attention over the past few years, due in part to their low threshold power consumption [1-4]. This achievement is attributed to the reduced diffraction loss through an index-guide mechanism and an efficient current confinement. However, since the AlGaAs is chemically unstable, an exposed Al(Ga)As layer without sealing is degraded rapidly and can be decomposed. In addition, AlAs layers within a top distributed Bragg reflector (DBR) could be unintentionally oxidized during the selective oxidation to form a buried oxide current aperture. We report on VCSELs fabricated by selective oxidation and sealing of AlAs through the use of the surface oxide barrier as a mask against wet oxidation.

2. Selective Oxidation of AlGaAs/GaAs Structures

An oxidized AlGaAs has been used as a current aperture under a top DBR. Recently thin oxide layer becomes important in determining the characteristics of VCSELs since a thinner oxide layer was suggested to significantly reduce the optical scattering losses[5]. Figure 1 (a) shows the lateral oxidation length depending on the thickness of AlAs layer sandwiched between GaAs layers. The oxidation is performed at 400 °C in H_2O-vapor-saturated N_2. Lateral wet oxidation has a very strong dependence on AlAs thickness for values of thinner than 80 nm and oxidation nearly stops at a thickness of ~11 nm[6]. Also, as shown in Fig. 1 (b), the AlGaAs layers on both sides of AlAs layer reduce the lateral oxidation rate which is enhanced by the stress induced by oxidized AlAs.

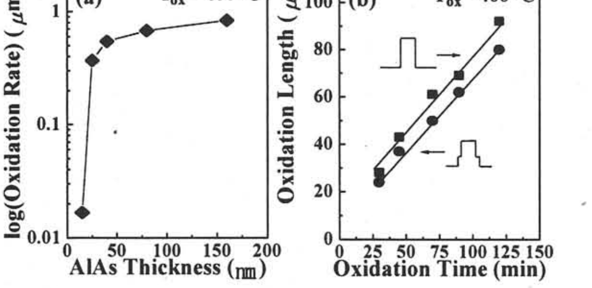

Fig. 1 Lateral wet oxidation of AlAs layers depending on (a) AlAs thickness and (b) AlGaAs interface layer.

3. VCSELs Fabricated by Selective Oxidation

Figure 2 shows a schematic cross section of the oxide-confined VCSELs. The structure has an AlAs native oxide layer directly over the active region within which the laser aperture is defined. The surface oxide barrier formed at the sidewall of the top DBR mesa can be used to selectively block diffusing oxygen species and achieve a deep lateral oxidation in only the AlAs layer closest to the active region. The MOCVD grown wafer has a bottom 24-pair AlAs/GaAs DBR, 3 InGaAs quantum wells (QWs), p-contact layers, and a top 18-pair undoped AlAs/GaAs DBR. The p-contact layers are formed from a λ/4 AlAs current aperture layer and a 3λ/4 GaAs intracavity contact layer. After top DBR square mesas are defined by selective wet etching to the GaAs p-contact layer, the exposed AlAs layers at the top mesa sidewall are sealed by the first wet oxidation at 408 °C for 15 s. This surface oxide blocks diffusing oxygen species not to oxidize against the second wet oxidation for over 1 hr. The 50 μm- square mesas centered on the sealed mesas are then formed to expose the AlAs current aperture layer. AlAs current aperture layer is oxidized to form a current aperture by the second wet oxidation at 400 °C for 22-24 min. An intracavity p-contact is made to the p-type GaAs using AuZn metallization.

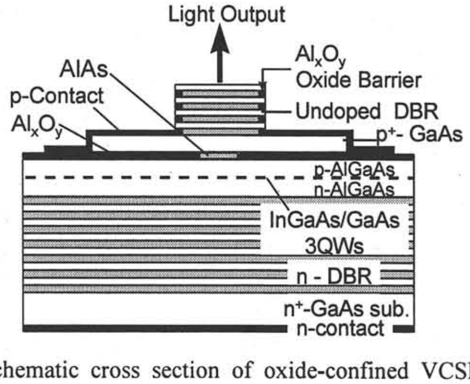

Fig. 2 Schematic cross section of oxide-confined VCSELs with surface oxide barriers at the top DBR sidewall.

Figure 3 shows the SEM micrographs of the simplified VCSEL structure demonstrating the sealing of AlAs layers in the top DBR against the wet oxidation. The unsealed AlAs current aperture layer is oxidized into a distance of 14 μm from the edge of 35 μm-wide stripe mesa while the 10-pair top DBR remains sealed. The surface oxide barrier formed at the mesa sidewall has a thickness of 1.1 μm (Fig. 3 (b)).

A threshold current of 400 μA and a lasing wavelength of 984 nm at $5\times I_{th}$ are measured in 8×8 μm^2 VCSELs fabricated using a combination of the surface oxide barrier

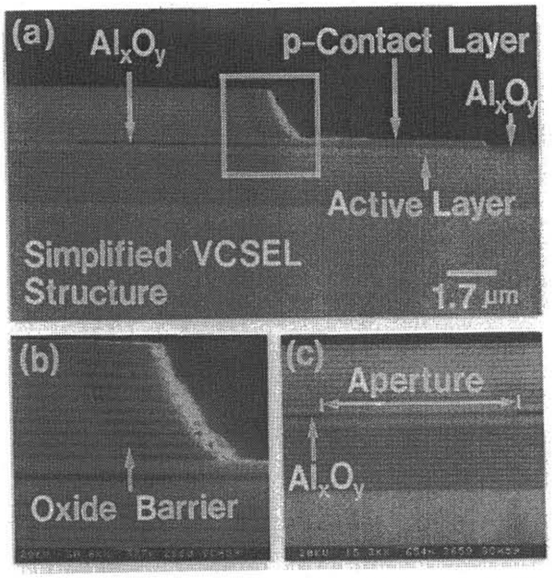

Fig. 3 SEM micrographs showing the sealing of the exposed AlAs against wet oxidation.

and selective oxidation (Fig. 4). It is expected that the output power could be increased if the number of top DBR pairs is optimized[7]. To reduce threshold current, we have fabricated a smaller size VCSEL with a single QW active region and increased numbers of pairs of 30 and 22 in bottom and top DBRs, respectively. A thick SiN_x was used to protect the top mesa sidewall instead of oxide barrier. Fig. 5 shows a very low threshold of 85 μA in a 4×4 μm^2 oxide-confined VCSEL.

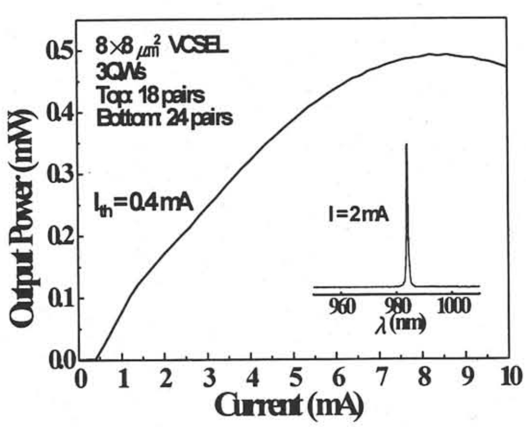

Fig. 4 Light-current curve of 8 × 8 μm^2 VCSELs fabricated using a combination of the surface oxide barrier and selective oxidation. Inset shows the lasing spectrum when operated at 2 mA.

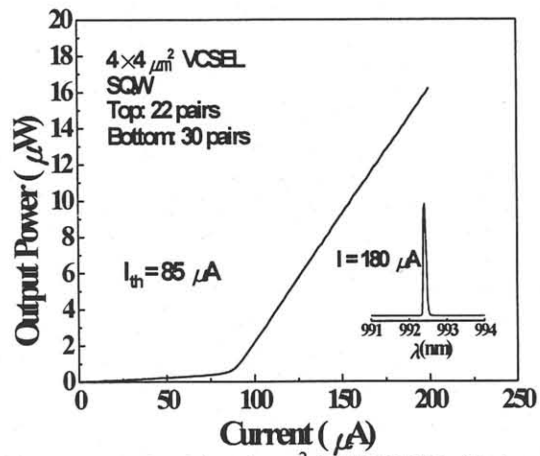

Fig. 5 Light-current curve of 4 × 4 μm^2 SQW VCSELs fabricated by selective oxidation. Inset shows the lasing spectrum when operated at 180 μA.

4. Conclusions

The lateral wet oxidation of AlAs layer is strongly influenced by its thicknesses and heterointerface structures as well as Al compositions. The surface oxide barrier with a thickness of 1.1 μm is formed by a brief wet oxidation at 408 °C, which blocks diffusing oxygen species. The effectiveness of the sealing is demonstrated through using the oxide barrier as a mask against wet oxidation in the fabrication of oxide-confined VCSELs.

Acknowledgments

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