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GaInAs/AlGaInAs Semiconductor Lasers on InP Substrate with AlAs Oxide Current Confinement

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An AlAs oxide current confinement structure based on InP substrate has been demonstrated for the first time to realize a low threshold long wavelength laser. The oxidized width is confirmed to be well controllable by properly choosing oxidation time and temperature. We fabricated a MOCVD grown 1.65μm wavelength GaInAs/AlGaInAs MQW laser with the AlAs-oxide confinement structure of 3μm-wide and 15μm-wide windows. A 3μm-wide window oxidized laser having uncoated facets shows a threshold of 51mA for 800μm of cavity length. The window width dependence of threshold current densities is also presented.

1. Introduction

Recently, the drastic threshold reduction of 0.98μm InGaAs/AlGaAs vertical-cavity surface-emitting lasers (VCSEL) has been achieved[1),2),3)]. This is mainly due to the introduction of AlAs-oxide for current confinement. The active region diameter is well controllable by oxidation time and temperature, and the oxide interface provides a low surface recombination rate in a small device size. For long-wavelength VCSELs, AlAs-oxide confined GaInAsP/InP VCSELs were reported by using a wafer fusion technique[4)]. On the other hand, the long wavelength AlGaInAs/InP system is also attractive, because of its strong electron confinement with its large conduction band offset($\Delta Ec=0.72\Delta Eg$). A tensile-strained AlAs on an InP substrate has a very large hetero-barrier and may work effectively as an electron stopper in a p-type region.

In this paper, we propose a novel current confinement structure with an oxidized AlAs layer for long-wavelength lasers which is grown on an InP substrate. We expect the proposed structure will provide a threshold reduction and a high temperature operation of long wavelength lasers, in particular, this technique can be applied for long-wavelength VCSELs effectively, resulting in low threshold operation without fusion techniques. We present some preliminary characteristics of AlAs oxidation on InP substrates and demonstrate edge emitting GaInAs/AlGaInAs compressive strain 3QW lasers with the AlAs oxide confinement for the first time (Fig. 1). Also, the oxide-window width dependence of threshold current densities has been examined.

2. Experiment

The critical thickness of an AlAs layer on an InP substrate is ~100Å. However, in order to confirm easily and investigate the oxidation of AlAs in this study, we grew a 200Å thick non-doped AlAs layer sandwiched by lattice-matched 1000Å non-doped $Al_{0.48}In_{0.52}As$ layers on a n-InP substrate by using MOCVD.

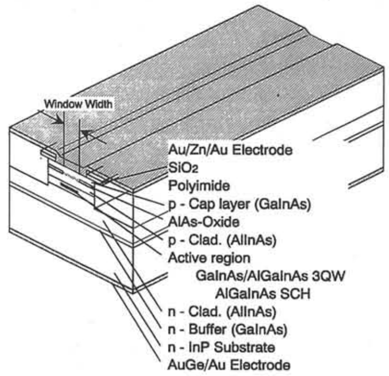

Fig. 1: GaInAs/AlGaInAs laser with AlAs-oxide confinement structure

After sputtering SiO_2 over the wafer, 50μm-wide and 7μm-wide stripe mesas were formed by a wet-etch. 50μm masas were annealed at 450°C~500°C in a nitrogen gas ambient bubbled through 85°C water. Figure 2 shows the top view and cross-section of the oxidized AlAs which indicates a smooth interface. The oxidation width versus the oxidation time at 450°C is shown Fig. 3.

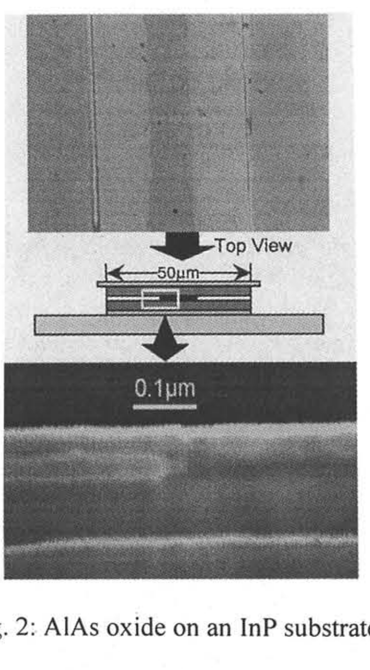

Fig. 2: AlAs oxide on an InP substrate

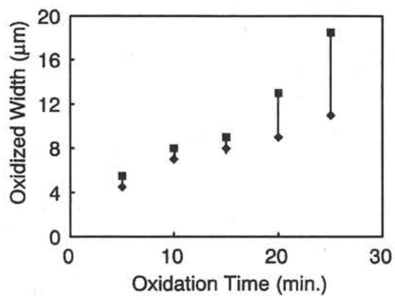

Fig. 3: Oxidized width vs oxidation time at 450°C

The oxidation rate dependent on an oxidation temperature is shown in Fig. 4. We understand that the oxidation rate drastically increased by an oxidation temperature and to a better uniformity of oxidation is obtained at lower temperature. However, Fig. 3 shows fluctuations of oxide-interfaces for longer oxidation time. Thus, a suitable oxidation condition of about 10 minutes at 400°C~450°C is obtained for forming a micro active region. 7μm-wide mesas are oxidized at 415°C for 10 minutes and results is shown in Fig. 5. We got a very smooth oxide-interface.

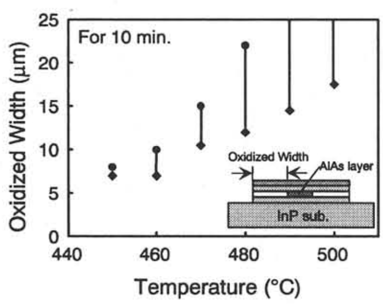

Fig. 4: Oxidation rate at various temperatures

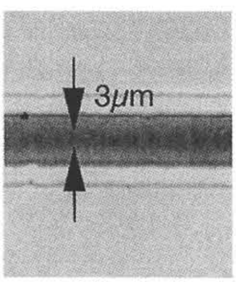

Fig. 5: Top view of an 7μm-wide stripe mesa with a 3μm-wide window

The 50μm-wide stripe mesa buried by polyimide including an entirely oxidized AlAs layer (oxidation condition: 480°C, 30 minute) was fabricated and metallized (contact area : 30 μm×250μm) for testing the isolation characteristic. The I-V characteristic in comparison with a non-oxidized structure was measured as shown in Fig. 6. 200Å-thick AlAs-oxide provides a good insulation characteristic for a bias voltage of 8V, which is enough for current confinement structure of semiconductor lasers. If a higher controllability of an oxidized width is achieved, forming a sub-μm wide oxide-window is possible.

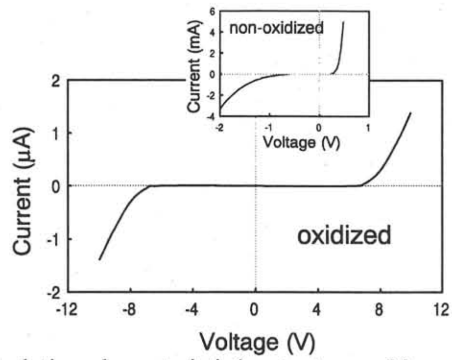

Fig. 6: Isolation characteristic(contact area: 30μm×250μm)

3. Laser Fabrication

The band diagram of the MOCVD grown laser wafer is shown in Fig. 7. The active layer consists of compressive strain three quantum wells and SCH layers of 1.15μm wavelength quaternary. The emission wavelength is 1.65μm. An AlAs layer locates 1.2μm away from the active layer in order to reduce a influence of large strain. Using the laser wafer, we have fabricated a polyimide-buried stripe GaInAs/AlGaInAs laser with an oxide current confinement by a selective oxidation technique, which has a 50μm-wide or 7μm-wide mesas by a wet-etching. The followed selective oxidation process provides 15μm-wide and 7μm-apertures, respectively.

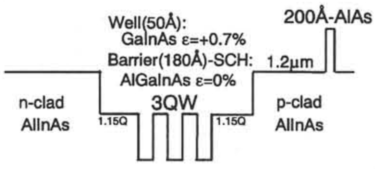

Fig. 7: Laser structure

4. Results and Discussion

The performance of a AlAs-inserted laser wafer has been examined, comparing without the oxide. Figure 8 shows the threshold current density of broad lasers (50μm-wide-stripe contact) from both wafers. There are no noticeable difference in laser wafer qualities for light emission.

The I-L characteristic of a 15μm-wide window oxidized laser is shown in the Fig. 9. The threshold current density is 2.0kA/cm^2, where the active region width is assumed to be the aperture width of the oxide. The NFP is shown in Fig. 10. The length of current spreading was measured to be ~1μm with I=0.5Ith. The temperature characteristic (T_0) is 63K (@25°C~35°C). The interval currently of 1.2μm between the active layer and the AlAs layer must be decreased for reducing the effect of current spreading.

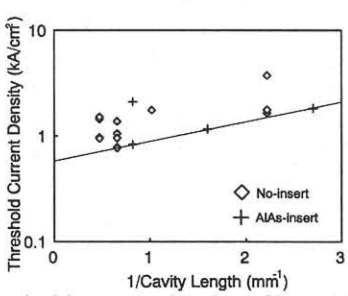

Fig. 8: Threshold current density of broad lasers from AlAs-inserted and non-inserted laser wafers

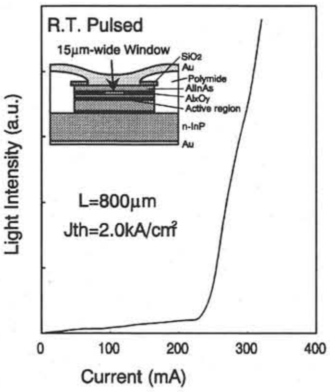

Fig. 9: I-L characteristics of oxidized lasers with 15μm-wide window

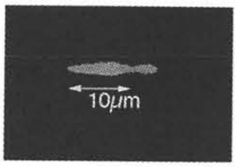

Fig. 10: NFP at I/Ith =0.5 of 15μm-wide window laser

Figure 11 shows the I-L characteristic of a 3μm-wide window oxidized laser with cleaved facets, which shows a threshold of 51mA. The threshold current density of a 800 μm-long laser with a 3μm-wide window is 2.1~3.0kA/cm^2 without considering current spreading. The threshold current density depends on the oxide-window width, as shown in Fig. 12. The reason of deteriorating J_{th} for narrower oxide-window lasers is current spreading in a lateral direction, caused by a fairly large separation between the AlAs layer and the active layer. In order to arrange the AlAs-oxide layer near the active layer for current confinement with maintaining the thickness of AlAs below the critical thickness, a strain-compensation super-lattice structure of AlAs/AlInAs is now under investigation. We expect an additional effect of multi-quantum barrier (MQB) in the super-lattice structure, which may result in reducing a carrier leakage.

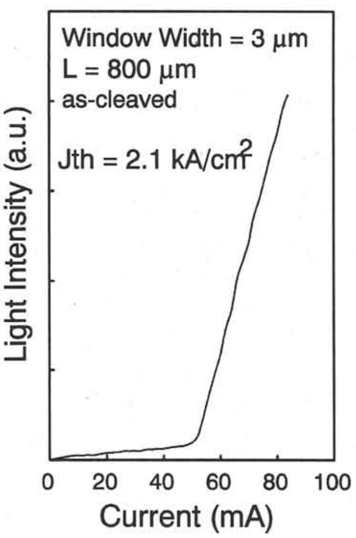

Fig. 11: I-L characteristic of a 3μm-wide window laser under pulsed operation at room temperature

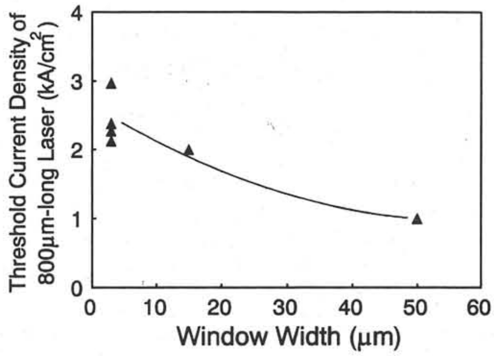

Fig. 12: Threshold current density versus the window width

5. Conclusion

In conclusion, a possibility of an novel AlAs oxide confinement structure for low threshold and high temperature operation of long wavelength lasers has been presented. A good isolation characteristic was obtained even for a very thin 200Å thick AlAs. Edge emitting lasers with the AlAs-oxide confinement structure was demonstrated with Ith=51mA. The proposed structure will be helpful for low threshold and high temperature operation of long wavelength lasers and finally long-wavelength VCSELs.

6. References

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