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Low Threshold Current Density Surface-Emitting Lasers Buried by Amorphous GaAs

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We examined vertical-cavity surface-emitting lasers buried in low-temperature-grown amorphous GaAs for surface passivation of etched cavity. The amorphous GaAs deposition on ion-beam-etched InGaAs active layers provides a significant improvement, more than 20%, in threshold current density and differential quantum efficiency.

1. Introduction

Vertical-cavity surface-emitting lasers (VC SELs) are promising for the applications in optical parallel processing, optical communications and optical interconnections.[1,2] The most important issues to open the wide application area are improvement of threshold current and light output power. Post type index-guided SELs have advantages in achieving low threshold current performances due to a strong confinement of optical field and current, as compared to gain-guided SELs. However, if the active region is etched to increase the optical and current confinements, surface recombination currents are induced through the etched sidewall. In this work, we demonstrate the effectiveness of highly resistive amorphous GaAs (*a*-GaAs) in burying the active region of VCSEL devices, thus achieving performance improvement by more than 20% both in threshold current and differential quantum efficiency.

2. Experimental

We used a periodic gain InGaAs/GaAs VCSEL structure with a two-wavelength-thick (2λ) cavity and AlAs/GaAs mirror layers grown by metal-organic chemical vapor deposition. The detailed laser structure was described in our previous reports.[3,4] We fabricated bottom-emitting lasers using chemically-assisted ion beam etching with chlorine. The laser posts were etched through the active region to the top layer of the bottom mirror by *in-situ* monitoring of etch depth using laser reflectometry.[5] The etched sample with about 5x5 mm^2 size was divided into two pieces. One piece was entered for measurement without additional surface treatment. Another piece was deposited by *a*-GaAs using molecular beam epitaxy technique at 160 °C for 2.5 h under the As/Ga ratio of 20. The thickness of *a*-GaAs layer was about 2.5 μm. The properties of *a*-GaAs layer was examined for a sample deposited on a semi-insulating GaAs substrate. The amorphous state of the deposited layer was identified from X-ray diffraction measurement and its resistivity was measured to be larger than 900 Ωcm. The *a*-GaAs layer on the p-type metal contact of VCSEL devices was removed by reactive ion etching using chlorine and argon. Figure 1 shows a schematic diagram of *a*-GaAs-buried devices.

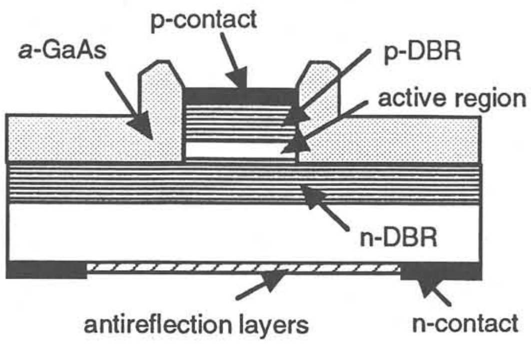

Figure 1. Schematic diagram of amorphous-GaAs-buried surface-emitting lasers.

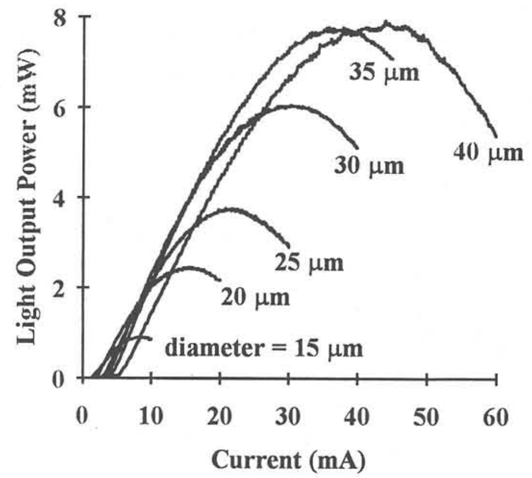

Figure 2. CW light output against current characteristics for amorphous-GaAs-buried lasers.

3. Results and Discussion

The device characteristics were measured at room temperature without a heat sink. The lasing wavelength was around 990 nm at threshold currents and shifted to longer wavelength up to 995 nm with increasing current. Figure 2 shows the light output power against current curves for *a*-GaAs-buried devices. We compared the L-I characteristics of *a*-GaAs-buried devices with those of air-post devices. The threshold currents obtained from air-post circular devices with 15, 20, 25, and 40 μm diameters were 2.5, 4.3, 4.6, and 6.0 mA, respectively. The threshold currents of *a*-GaAs-buried devices with 10, 15, 20, 25, 30, 35 and 40 μm diameters were 0.7, 1.3, 2.1, 2.9, 3.4, 4.1 and 5.1 mA, which are significantly lower than the data for the air-post devices.

Figure 3 shows the data of threshold current densities, J_{th}, for the air-post and *a*-GaAs-buried devices. Even though the data points are somewhat scattered on the same device size, the lowest values of J_{th} for each sizes of the air-post devices are in the range of 480 - 1350 A/cm^2 and those of the *a*-GaAs-buried devices are 380 - 500 A/cm^2. This result indicates that the *a*-GaAs deposition reduced J_{th} by more than 20%. Figure 4 shows the data of external differential quantum efficiencies, η_{ex}, for the same devices. The average values of η_{ex} for each sizes are also significantly increased by the passivation treatment.

The improvement of the threshold current density and differential quantum efficiency by *a*-GaAs

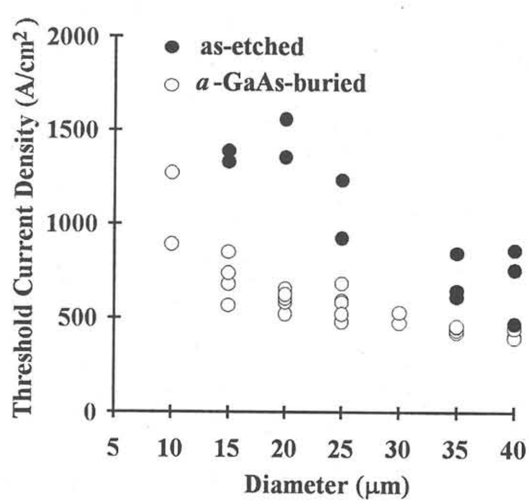

Figure 3. Threshold current densities for air-post and amorphous-GaAs-buried lasers.

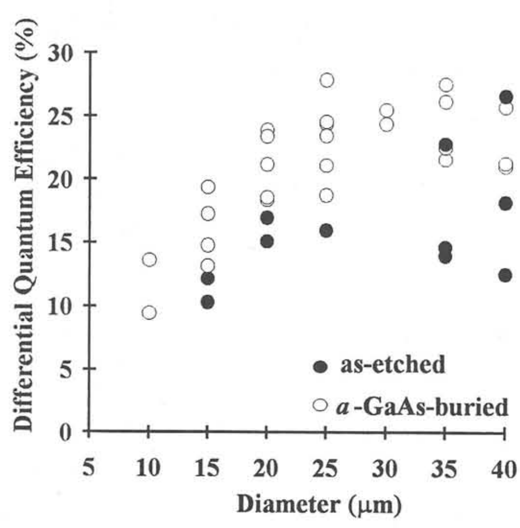

Figure 4. Differential quantum efficiencies for air-post and amorphous-GaAs-buried lasers.

deposition, seen in Figs. 2 and 3, is believed to be originated from a low defect density at the surface of active layers buried in a-GaAs. The reduction of nonradiative surface recombination induces both a decrease of threshold current density and an increase of differential quantum efficiency.[6] The bonding structure of a-GaAs has tetrahedral characters which are close to the structure of crystalline GaAs.[7] Thus, we expect that the surface defects on the InGaAs/GaAs layers buried by a-GaAs must be much low, as compared to the layers buried by other dissimilar passivation materials, such as silicon nitride or polyimide.

The threshold current density seen in Fig. 3 approaches the lowest value[8] among other data obtained for the post type VCSELs of which active region is completely etched. Compared to the output power characteristics of their devices, our passivated devices show much higher values in maximum power and differential quantum efficiency. We note, however, that the whole performances of the passivated devices, seen in Figs. 2-4, are not so good as the as-etched air-post devices reported in our previous work[3]. We used the same epitaxial wafers for these works, but the device performances showed considerable differences depending on run-to-run (or chip-to-chip), due to non-uniform epitaxial quality and/or process control. Thus, the effect of a-GaAs deposition was investigated using the specimens within a small area and following the same process except the a-GaAs deposition. Recently, the threshold characteristic of VCSEL has been dramatically improved to a several μA level by lateral oxidation of a AlAs layer covering active layers.[8] Compared to this device scheme, the amorphous GaAs passivated SEL might still have a disadvantage due to remaining surface recombination, although etching through active region provides effective current confinement.

For the a-GaAs-buried SELs, we also investigated modal behaviors. Because a-GaAs has a higher refractive index and a lower band gap than crystalline GaAs and AlAs layers, a-GaAs layer surrounding SEL devices provide an antiguide region which can suppress high order transverse mode emission. From the measurements of near field profiles for the a-GaAs-buried lasers, we observed a stable single mode emission for a 10 μm diameter device.

4. Summary

We have demonstrated the surface passivation of index-guided surface-emitting lasers by low temperature deposition of a-GaAs. The threshold current density and differential quantum efficiency were improved more than 20% after the a-GaAs deposition. The improvement of these performances might be originated from relatively low defect density at the surface of active layers buried by amorphous GaAs.

Acknowledgments

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