Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 340-341

B-11-5

AlGaAs/GaAs Laser Diodes with GaAs Islands Active Regions on Si Substrates Grown by Droplet Epitaxy

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1. Introduction

GaAs-based laser diodes and LED's on Si substrates suffer from rapid degradation due to formation of dark-line defects (DLD's), which are caused by the large difference between the material properties of GaAs and Si [1]. Although many attempts to improve the reliability have been aimed until now at a reduction of dislocation density, long-lasting GaAs-based laser diodes on Si have not been achieved by the uses of conventional techniques such as optimized growth sequence, thermal cycle annealing and selective area growth.

Recently, high-quality self-formed nanometer-scale GaAs and InGaAs quantum dot-like islands have grown on GaAs substrate using droplet epitaxy and Stranski-Krastanow (SK) growth mode [2]. Small volume of active region in the laser diode on Si reduces the number of dislocation in the active region, which contributes to the fabrication of reliable laser diode on Si. We reported 300 K pulsed operation for the AlGaAs/GaAs laser diodes with the self-formed GaAs islands active regions on Si [3]. In this study, we demonstrate 100 K CW lasing oscillations of the self-formed GaAs islands active regions on Si. We also show that the self-formed GaAs islands active regions are effective in improving reliability of the laser diode and LED on Si.

2. Experimental

The samples were grown on the n^+-Si substrates oriented 2° off towards the [011] direction in MOCVD reactor at atmospheric pressure. Figure 1 shows a schematic cross-sectional structure of the MOCVD-grown AlGaAs/GaAs laser diode on Si using the droplet epitaxy. The active region consists of an undoped 70-nm-thick $Al_{0.3}Ga_{0.7}As$ lower confining layer, undoped GaAs islands active layers formed by droplet epitaxy, undoped 50-nm-thick $Al_{0.3}Ga_{0.7}As$ barrier layers and an undoped 70-nm-thick $Al_{0.3}Ga_{0.7}As$ upper confining layer. Atomic force microscope image of the self-formed GaAs islands grown on the GaAs/Si is shown in Fig. 2. The size and density of the GaAs island could be controlled by the TMG flow rate. The GaAs islands exhibited a conical shape with heights of 8 nm, effective diameters of 300 nm, and densities of 1~2x10^7 cm^{-2}. For the laser diode on Si with the etch pit density of 10^7 cm^{-2}, the average number of dislocations per device were 300 for the conventional quantum well structure with 300 μm x 10 μm stripe and it was less than one for the laser diode with the self-formed GaAs islands active region. This indicates that the GaAs island in the active region is dislocation free. The similar device structure was also grown on GaAs substrate.

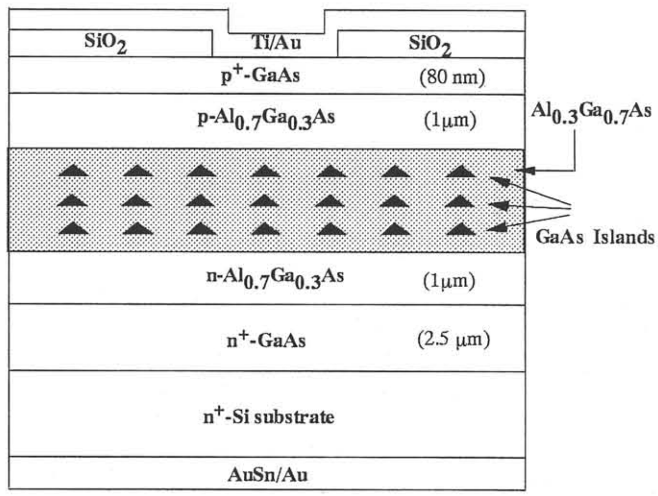

Fig. 1. Cross-sectional structure of the self-formed AlGaAs/GaAs laser diode on the Si substrate grown by the droplet epitaxy.

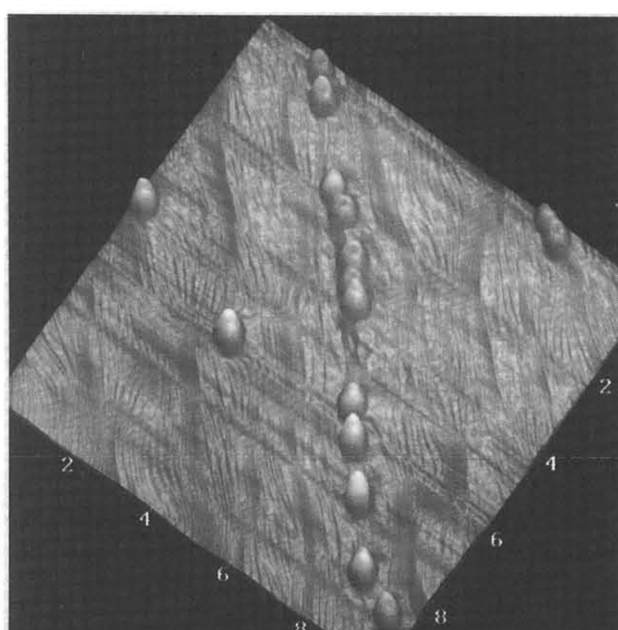

Fig. 2. AFM image of the self-formed GaAs islands on the Si substrate grown by the droplet epitaxy. The area is 10 μm x 10 μm.

3. Results and Discussion

Figure 3 shows the L-I characteristic and emission spectrum of the self-formed laser diode on Si under the CW condition at 100 K. The self-formed laser on Si exhibited the 100 K CW I_{th} of 110 mA, the J_{th} of 3.9 kA/cm^2, the η_d of 7.0 % and the lasing wavelength of 771 nm with the FWHM of 1.8 nm. The device also showed the 300 K pulsed I_{th} of 260 mA, the J_{th} of 5.4 kA/cm^2, the η_d of 4.7 % and the lasing wavelength of 791 nm with the FWHM of 2.8 nm. The AlGaAs/GaAs laser diode on GaAs substrate exhibited the I_{th} of 138 mA, the J_{th} of 3.6 kA/cm^2, the η_d of 35 % and the lasing wavelength of 807 nm with the FWHM of 2.8 nm under CW condition at 300 K. Figure 4 shows the electroluminescence (EL) topograph from the surface of the AlGaAs/GaAs laser diode with the self-formed GaAs islands active regions on the Si substrate. As shown in Fig. 4, the light emission was from the individual GaAs island.

Figure 5 shows the comparison of aging results under the automatic current control (ACC) condition for the AlGaAs/GaAs laser diodes consisting of the GaAs self-formed islands and the quantum wells on Si. The lifetime at 300 K was examined by measuring the output power at a constant current of 60 mA dc. The output power from the the quantum well structure decreased rapidly to a half of the initial value only in a few minutes. This rapid degradation was caused by the formation of DLD's. On the other hand, the output power from the GaAs island active region decreased slowly and reached to a half of the initial value after 14 hours. EL observation indicates the DLD's growth was suppressed and only a few bright spots emitted from the GaAs islands became dark.

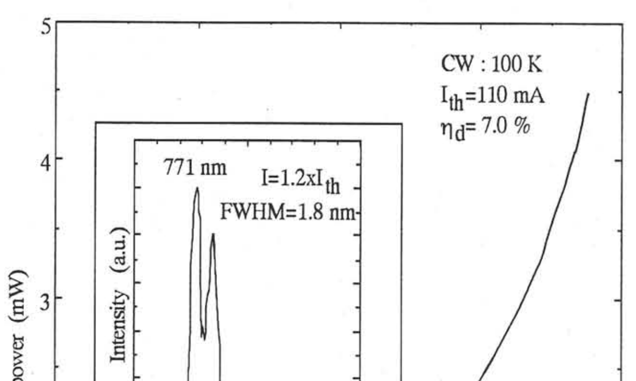

Fig. 3. 100 K CW L-I characteristic and emission spectrum of the AlGaAs/GaAs laser diode with the self-formed GaAs islands active regions on Si substrate.

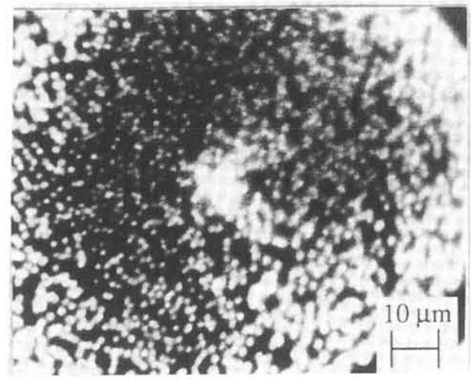

Fig. 4. EL image from the surface of the AlGaAs/GaAs laser diode with the self-formed GaAs islands active regions on Si substrate.

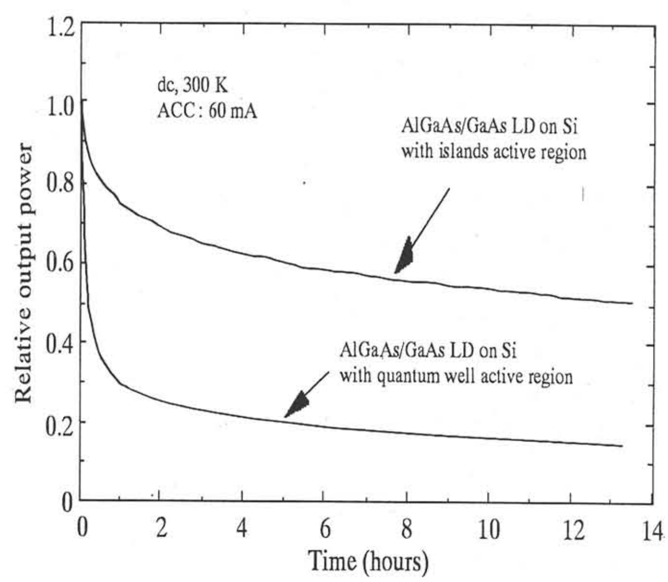

Fig. 5. Comparison of aging results for the AlGaAs/GaAs laser diode structures on Si with the GaAs islands and the quantum wells. The lifetime at 300 K was examined by measuring the output power at a constant current of 60 mA.

4. Conclusions

We have demonstrated CW lasing oscillation of the self-formed AlGaAs/GaAs laser diode on Si for the first time. The AlGaAs/GaAs laser diodes with the self-formed GaAs islands active regions on Si substrates showed the I_{th} of 110 mA, the J_{th} of 3.9 kA/cm^2 and the lasing wavelength of 771 nm with the FWHM of 1.8 nm under CW condition at 100 K. Compared with the conventional quantum well laser diode on Si, the self-formed laser diode on Si exhibited the improved reliability due to the reduction of the dislocation number in the active region.

References

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