Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 722-724

First Fabrication of a Reliable AlGaAs/GaAs LED on Si with Self-Assembled GaAs Islands Active Region

Yoshiaki HASEGAWA [1], Takashi EGAWA [2], Takashi JIMBO [2] and Masayoshi UMENO [1, 2]

[1] *Department of Electrical and Computer Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466, Japan*
[2] *Research Center for Micro-Structure Devices, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466, Japan*

We report first fabrication of a reliable AlGaAs/GaAs light emitting diode (LED) on Si with self-assembled GaAs islands active region. Using droplet epitaxy, self-assembled GaAs islands with diameters of ~250 nm and heights of ~100 nm were successfully formed on GaAs/Si substrate by metalorganic chemical vapor deposition (MOCVD). The output power of this LED decreased very slowly and reached to a half of the initial value after ~14 hours at a constant current of 60 mA.

1. Introduction

Light emitting devices grown by heteroepitaxy such as GaN/Al_2O_3, ZnSe/GaAs and GaAs/Si have a serious problem of reliability because of their high dislocation density.[1-4] For example, GaAs-based light emitting diode (LED) and laser grown on Si substrates suffer from rapid degradation because of a high dislocation density ($>10^6$ cm^{-2}) and a large residual thermal stress ($\sim10^9$ dyn/cm^2), which are introduced by the ~4% lattice mismatch and the ~250% difference in the thermal expansion coefficients between GaAs and Si.[4]

If the sizes of active regions in these devices are drastically reduced, the reliability can be remarkably improved due to low dislocation numbers in the active regions. From this point of view, we have previously fabricated an extremely low-threshold quantum wire-like laser on a V-grooved GaAs/Si instead of a conventional quantum well laser.[5] The dislocation number in the active region of this quantum wire-like laser was estimated to be ~1/100 of that of the quantum well laser on Si with 10-μm-wide stripe contact window. On the other hand, high-quality self-assembled nanometer scale GaAs and InGaAs islands (quantum dots) on GaAs substrates have been recently realized using several direct growth techniques such as droplet epitaxy, Stranski-Krastanow growth mode and so on.[6-8] Furthermore, continuous-wave (cw) operation of lasers with these islands active regions has been also demonstrated.[9, 10] In this paper, we report first fabrication of self-assembled GaAs islands on Si and demonstration of a reliable AlGaAs/GaAs LED on Si with the islands active region using droplet epitaxy by metalorganic chemical vapor deposition (MOCVD).

2. Experimental and Results

2. 1 Self-assembled GaAs islands on Si

The samples used in this study were grown on n^+-Si substrates oriented 2° off (100) towards the [011] direction by MOCVD, which is operated at atmospheric pressure. Trimethylgallium (TMG), trimethylaluminum (TMA) and arsine in hydrogen (AsH_3) were used as group-III and group-V sources, respectively. Hydrogen selenide (H_2Se) and diethylzinc (DEZ) were used as n-dopant and p-dopant, respectively. A 2.5-μm-thick n^+-GaAs buffer layer was grown on the Si substrate by two step growth technique. The growth temperature was 750 °C except for the initial GaAs nucleation layer which was grown on Si at 400 °C. The GaAs islands were grown on the GaAs/Si substrate at 700 °C by the supply of TMG and successive AsH_3 supply. TMG flow rate and time were 10 cc/min and 6 s, respectively. This growth condition corresponds to 5-nm-thick GaAs layer by the simultaneous supply of TMG and AsH_3. Figure 1 shows an atomic force microscope (AFM) image of the self-assembled GaAs islands. We found that the GaAs islands on Si are randomly formed as well as the islands on a GaAs substrate in spite of the roughness (~20 nm) of the GaAs buffer layer on Si. The islands exhibit pyramid-like shape with diameters of ~250 nm and heights of ~100 nm. Furthermore, the island density was $1\text{-}2\times10^7$ cm^{-2}, which is similar to the dislocation density of GaAs/Si. Therefore, compared with an LED on Si with a quantum well active region, it is expected that an LED on Si with the islands active region has a potential of high reliability, because dislocation

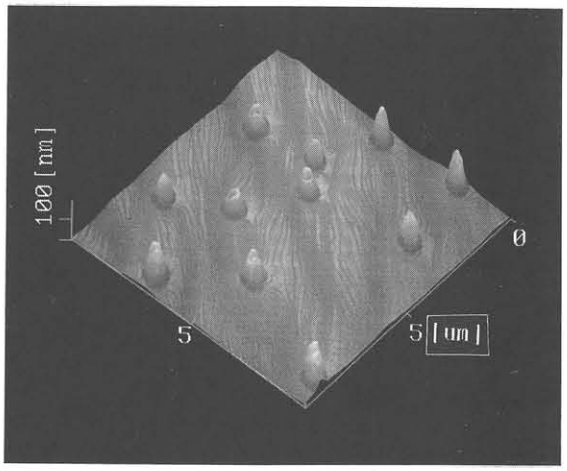

Fig. 1 AFM image of self-assembled GaAs islands on GaAs/Si substrate.

numbers in the active region are successfully reduced. Varying the growth condition such as growth rate and time, the heights of islands were changed between 7 and 180 nm, but the diameters were not markedly changed. In addition, the density was slightly varied between 3×10^6 and 4×10^7 cm^{-2}.

2. 2 AlGaAs/GaAs LED on Si with islands active region

For the application to an LED on Si, the self-assembled GaAs islands active region shown in Fig. 1 were sandwiched by 70-nm-thick lower, upper $Al_{0.3}Ga_{0.7}As$ confining layers grown at 700 °C and 0.74-μm-thick p, n-$Al_{0.7}Ga_{0.3}As$ cladding layers at 750 °C. An 80-nm-thick p^+-GaAs contact layer was finally grown at 750 °C. Surface emitting LED was fabricated from this wafer by depositing Ti/Au contact ring as the p-side electrode. AuSb/Au were evaporated on the n^+-Si substrate as the n-side electrode. Figures 2 and 3 show cross-sectional high-resolution scanning electron microscope (SEM) images of the overall LED on Si and the magnified GaAs island active region, respectively. Two bright areas in $Al_{0.3}Ga_{0.7}As$/GaAs region, as observed in Fig. 2, are GaAs islands. As shown in Fig. 3, the island is connected with a very thin GaAs layer at the interface of the $Al_{0.3}Ga_{0.7}As$ layers. Figure 4 shows a typical light versus current characteristic of this LED under room-temperature direct-current (dc) condition and the inset shows a top-viewed electroluminescence (EL) topograph. It is found that the light is emitted from the each GaAs islands, because the density of bright spots is $1\text{-}2\times10^7$ cm^{-2} as same as that of GaAs islands. Up to 21 μW at 130 mA, the light output power increased linearly with increasing current. At higher current, it was thermally saturated. This was confirmed by the fact that the output power increased linearly up to high current without saturation under pulsed operation. The peak wavelength at 80 mA was 868 nm and the full width at half maximum (FWHM) was 49 nm. The automatic current control (ACC) aging tests for this LED on Si and an AlGaAs/GaAs LED on Si with a 9-nm-thick quantum well active region were carried out at a constant current of 60 mA (0.5 kA/cm^2) as shown in Fig. 5. The LED with a quantum well showed a rapid degradation in which the output power decreased rapidly to a half of the initial value only in a few minutes. In contrast, the output power of LED with the islands decreased very slowly and reached to a half of the initial value after ~14 hours. In order to study in detail the differences of degradation in these LEDs, we were carried out EL observations on 10-μm-wide stripe contact laser structures fabricated from the each LED wafers. Figures 6(a) and 6(b) are top-viewed EL topographs showing the progressive stage of degradation of laser structures with a quantum well and with the islands active region, respectively. The current density during this test was 0.5 kA/cm^2. In the laser with a quantum well, a few <100> dark-line defects (DLDs) originated from threading dislocations were observed. The rapid degradation due to the growth of these DLDs seems to be caused by both increased absorption of emitted light and decreased gain.[4] On the other hand, we observed that the DLD growth was suppressed and only a few bright spots

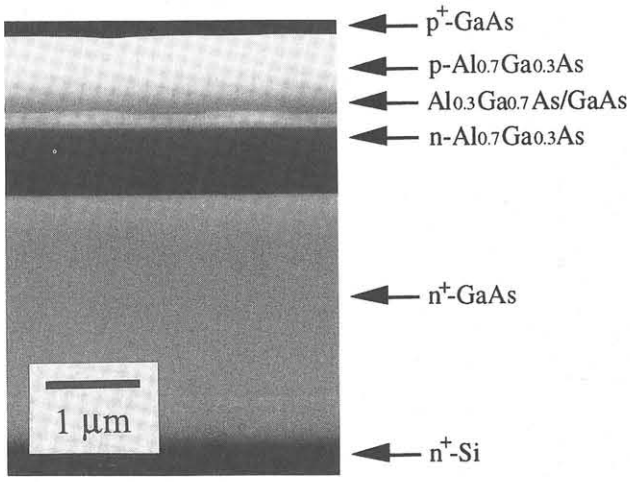

Fig. 2 Cross-sectional SEM image of the overall LED on Si with the GaAs islands active region.

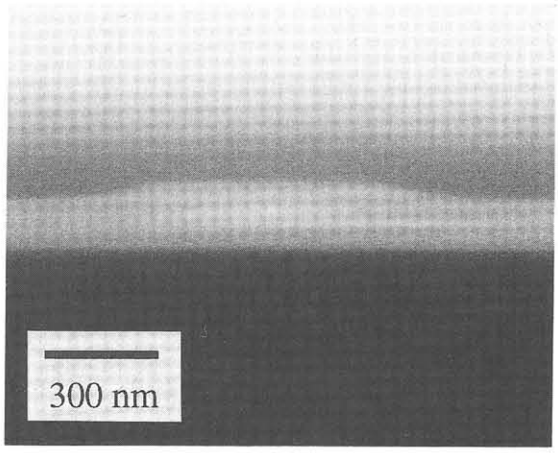

Fig. 3 Cross-sectional SEM image of the magnified GaAs island active region.

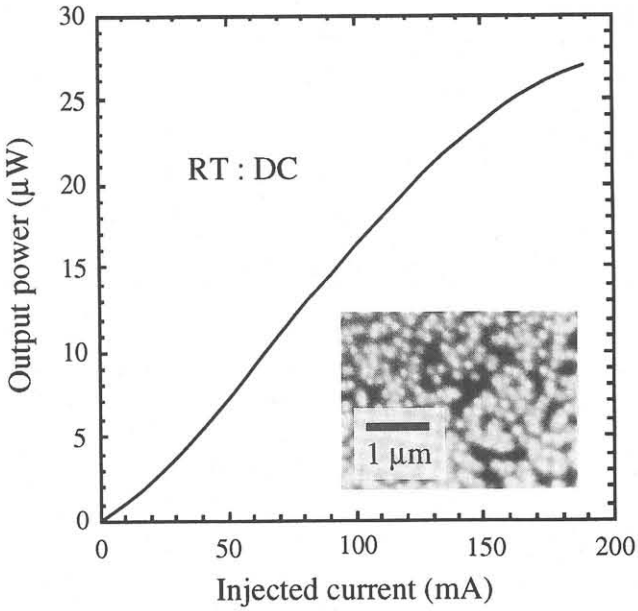

Fig. 4 Typical light versus current characteristic under room-temperature dc condition and top-viewed EL topograph.

(arrows shown in Fig. 6(b)) emitted from the islands were vanished in the laser with the islands. Therefore, it is thought that most of the islands are free of dislocations and nonradiative recombination at dislocations was remarkably reduced by the confinement of the injected carriers in the islands. This effect can be seen in Fig. 5 where the LED with the islands is prevented from rapid degradation.

3. Conclusion

An AlGaAs/GaAs LED on Si with self-assembled GaAs islands active region was fabricated using droplet epitaxy by MOCVD for the first time. Compared with an LED on Si with a quantum well active region, this LED had a high reliability due to reduction of active region by use of GaAs island structure. This novel technique is very promising for the improvement of reliability of light emitting devices with high dislocation density grown by heteroepitaxy.

Acknowledgements

We would like to thank Mr. Y. Niwano, Mr. A. Tanaka and Mr. A. Ogawa for technical support. This work was partially supported by a Grant-in-Aid for Developmental Scientific Research (No. 06555013) from the Ministry of Education, Science and Culture. One of us (Y. Hasegawa) was financially supported by the Japan Society for the Promotion of Science (JSPS) Research Fellowships for Young Scientists.

References

1) S. D. Lester, F. A. Ponce, M. G. Craford and D. A. Steigerwalt, Appl. Phys. Lett., **66**, 1249 (1995).
2) S. Itoh, N. Nakayama, S. Matsumoto, M. Nagai, K. Nakano, M. Ozawa, H. Okuyama, S. Tomiya, T. Ohata, M. Ikeda, A. Ishibashi and Y. Mori, Jpn. J. Appl. Phys., **33**, L938 (1994).
3) S. Guha, J. M. DePuydt, M. A. Haase, J. Qiu and H. Cheng, Appl. Phys. Lett., **63**, 3107 (1993).
4) Y. Hasegawa, T. Egawa, T. Jimbo and M. Umeno, Jpn. J. Appl. Phys., **34**, 2994 (1995).
5) Y. Hasegawa, T. Egawa, T. Jimbo and M. Umeno, J. Cryst. Growth, **145**, 728 (1994).
6) D. Leonard, M. Krishnamurthy, C. M. Reaves, S. P. Denbaars and P. M. Petroff, Appl. Phys. Lett., **63**, 3203 (1993).
7) T. Ueda, Q. Z. Gao, E. Yamaichi, C. Yamagishi and M. Akiyama, J. Cryst. Growth, **145**, 707 (1994).
8) R. Nötzel, T. Fukui, H. Hasegawa, J. Temmyo and T. Tamamura, Appl. Phys. Lett., **65**, 2854 (1994).
9) N. Kirstaedter, N. N. Ledentsov, M. Grundmann, D. Bimberg, V. M. Ustinov, S. S. Ruvimov, M. V. Maximov, P. S. Kop'ev, Zh. I. Alferov, U. Richter, P. Werner, U. Gosele and J. Heydenreich, Electron. Lett., **30**, 1416 (1994).
10) J. Temmyo, E. Kuramochi, M. Sugo, T. Nishiya, R. Nötzel and T. Tamamura, Electron. Lett., **31**, 209 (1995).

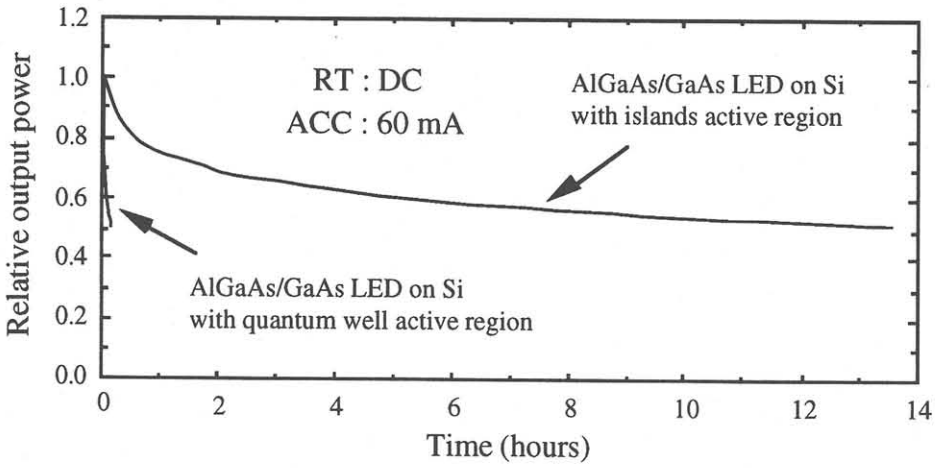

Fig. 5
Results of ACC aging tests for AlGaAs/GaAs LEDs on Si with the GaAs islands active region and a quantum well active region.

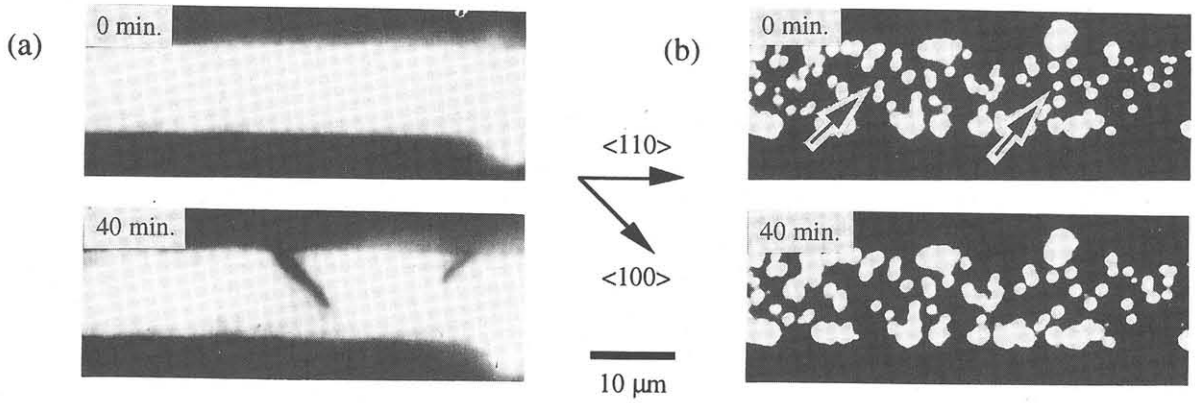

Fig. 6 Top-viewed EL topographs showing the progressive stage of degradation of (a) laser structure with a quantum well active region and (b) laser structure with the GaAs islands active region.