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First Fabrication of AlGaAs/GaAs Double-Heterostructure LED's Grown on GaAs(111)A Substrates Using Only Silicon Dopant

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We have grown an AlGaAs/GaAs double-heterostructure (DH) light emitting diode (LED) on a GaAs(111)A-5°-misoriented substrate using only Si dopant by molecular beam epitaxy. A conduction type and a carrier concentration have been controlled by a flux ratio and a Si cell temperature. The smoother heterointerfaces have been also obtained. The p-n junction showed a turn-on voltage of 1.3 V and a reverse voltage of 2.5 V at 1mA. The AlGaAs/GaAs LED exhibited dc operation at 300 K. The optical output power was 30 nW at 150 mA, and the peak in the spectrum was 875 nm with the full width at half maximum of 28 nm. This technique is very promising for fabrication of AlGaAs/GaAs laser diodes using only Si dopant.

1. INTRODUCTION

Si is widely used as an n-type dopant in growth of GaAs and AlGaAs layers using molecular beam epitaxy (MBE). However, it has been reported that Si atoms incorporate as acceptors in GaAs layer grown on (n11)A plane when $n \leq 3$, while behaving as donors on (n11)A (for $n>4$) and (n11)B (for all n) planes including a conventional (100) plane.[1-3)] This amphoteric characteristic of Si has been mainly used as a current confinement in a fabrication of lateral GaAs p-n junction on a patterned substrate.[4-7)] We reported that fabrications of a GaAs p-n junction and a light emitting diode (LED) using only Si dopant.[8)] We also reported that an off-angle of GaAs(111)A substrate is an important factor for controlling a surface morphology and an impurity concentration of an AlGaAs layer.[9)] Although a growth of AlGaAs/GaAs double-heterostructure (DH) is important for fabrications of LED and laser diode (LD), there are problems in surface morphology, heterointerface, conduction type and carrier concentration. In this study, we demonstrate 300 K dc operation of AlGaAs/GaAs DH LED on GaAs(111)A-5°-misoriented substrate using only Si dopant.

2. EXPERIMENTAL

Silicon-doped n^+-GaAs(111)A misoriented 5° toward the [100] direction was used as the substrate because of the improvement of the surface morphology and the control of the impurity concentration.[9)] Before the substrate was introduced into an MBE chamber, it was degreased and etched with an etchant (NH_4OH:H_2O_2:H_2O=2:1:96) for 2 min as described in a previous paper.[10)] The substrate was subjected to thermal etching at a temperature of 700 °C and an As pressure of 2×10^{-3} Pa. Then, a 1.0-μm-thick n^+-GaAs buffer layer was grown at 540 °C with a flux ratio of 7. The growth rate was 1.0 μm/h. After changing the temperature of the Ga cell, a 0.8-μm-thick n-$Al_{0.3}Ga_{0.7}As$ layer, an 8-nm-thick undoped GaAs layer and a 0.8-μm-thick p-$Al_{0.3}Ga_{0.7}As$ layer were grown sequentially. The temperature of the Ga cell was held constant during the growth of the AlGaAs/GaAs DH structure. The growth rates for the AlGaAs and GaAs layers were 1.0 μm/h and 0.7 μm/h, respectively. The flux ratio was 7 for the growth of the n-AlGaAs layer, and was 2 for the growth of the undoped GaAs and p-AlGaAs layers. Two As cells were used to change the As pressure abruptly. One As cell's shutter was closed when the growth of the n-AlGaAs layer was completed. After the growth of the AlGaAs/GaAs DH, a 0.2-μm-thick p^+-GaAs contact layer was grown with a flux ratio of 2 and a growth rate of 1.0 μm/h. In the growth of the AlGaAs/GaAs DH LED, only Si was used for the n-type and p-type dopants. The Si cell temperature was varied to control the carrier concentration of 1×10^{18} cm^{-3} for the n-type and p-type AlGaAs layers, and over 1×10^{18} cm^{-3} for the n-type and p-type GaAs layers.

Following the growth, a 0.1 μm-thick SiO_2 film was sputtered, and a 10-μm-wide stripe window was opened by chemical etching. The Si substrates were lapped off down to about 100 μm thick, Ti/Au and AuSn/Au ohmic electrodes were formed by vacuum evaporation on the p^+-GaAs layer and the n-GaAs(111)A substrate, respectively. The evaporated ohmic electrodes were annealed at 380 °C for 30 sec in N_2 ambient. Then, the sample were cleaved into 100 μm x 300 μm chips. The chips were mounted on a Cu heat sink with a p-side-up configuration. The LED characteristics were measured under dc-biased condition at 300 K.

The AlGaAs/GaAs heterointerfaces were investigated by means of cross-sectional scanning electron microscopy (SEM). The carrier concentration and the conduction type were obtained by electrochemical capacitance-voltage (C-V) measurement.

3. RESULTS AND DISCUSSION

Figure 1 shows a cross-sectional SEM micrograph, obtained with backscattered electrons, for the AlGaAs/GaAs DH LED grown on n^+-GaAs(111)A-5°-misoriented substrate by MBE. The smoother AlGaAs/GaAs heterointerfaces can be obtained as shown in Fig. 1. In a previous report, we showed that the surface morphology of the AlGaAs layer on the GaAs (111)A substrate was strongly affected by the off-angle of the substrate.[9] These results indicate that the use of GaAs(111)A-5°-misoriented substrate is effective in growing the smooth AlGaAs/GaAs quantum well structure. The electrochemical C-V profile of the AlGaAs/GaAs LED is shown in Fig. 2. Note that the conduction type and the carrier concentration can be controlled, and the p-n junction is successfully formed using only Si dopant. The use of GaAs(111)A-5°-misoriented substrate is one of the key parameters in obtaining the mirror surface morphology and the smoother heterointerfaces. Another important factors are that the conduction type and the carrier concentration can be controlled by the flux ratio and the Si cell temperature, respectively .

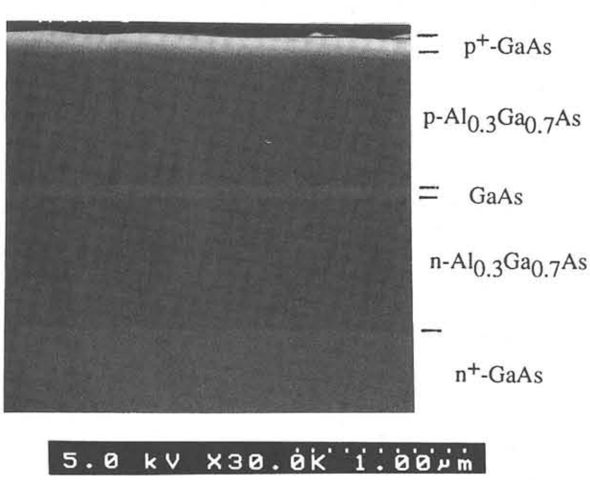

Fig. 1. Cross-sectional SEM micrograph, obtained with backscattered electrons, for the AlGaAs/GaAs DH LED grown on n^+-GaAs(111)A substrate using only Si dopant.

Figure 3 shows the current-voltage (I-V) characteristic of the LED. The LED showed the turn-on voltage of 1.3 V and the reverse voltage of 2.5 V at 1 mA. The ideality factor is calculated by the equation of $J=[\exp(qV/nkT)-1]$, where J is the current density, q is the elementary charge of the electron, k is Boltzmann's constant, and T is the absolute temperature.[11] The ideality factor is approximately 2 for the sample in the forward bias region around 1.0 V, which means that the carrier recombination is dominant at the junction. In spite of the AlGaAs/GaAs interfacial smoothness and the formation of the p-n junction, the reverse characteristic is not as good as the conventional LED because of the growth interruption.

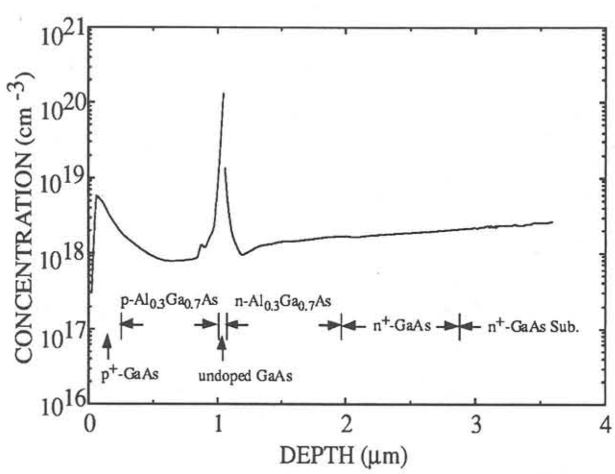

Fig. 2. Electrochemical C-V profile of the AlGaAs/GaAs DH LED grown on n^+-GaAs(111)A substrate using only Si dopant.

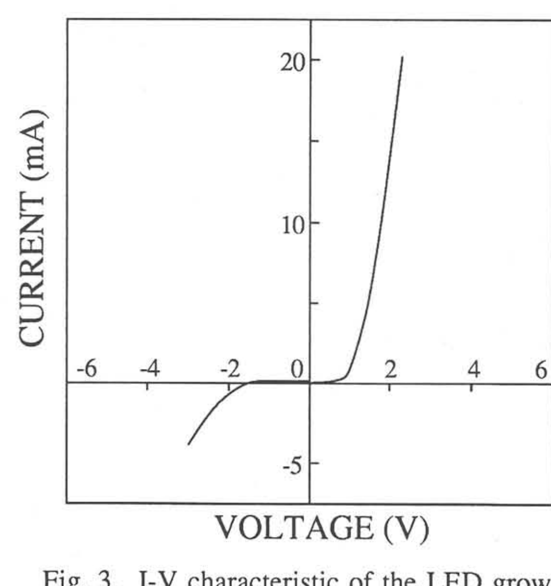

Fig. 3. I-V characteristic of the LED grown on n^+-GaAs(111)A substrate using only Si dopant.

The light output power versus dc current (L-I) characteristic and the emitting spectrum of the LED at 300 K are shown in Figs. 4 and 5, respectively. The optical output power was 30 nW at 150 mA. At higher drive currents, the optical gain can produce a superlinear increase, which is evidence for the stimulated as well as spontaneous emissions in this sample.[12] The peak in the spectrum of emitted light at 875 nm has a full width at half maximum (FWHM) of about 28 nm at 300 K. The origin of the peak can be ascribed to the emission in the undoped GaAs layer. The profile for the emission spectrum is broad and the peak intensity is weak. The weak intensity may be due to the insufficient carrier confinement at room temperature because of low Al content in the AlGaAs layers. No lasing operation was observed at a low temperature of 14 K, which is probably due to the lack of AlGaAs cladding layers and the difficulty of the formation of Fabry-Perot cavities by cleaving two parallel facets.

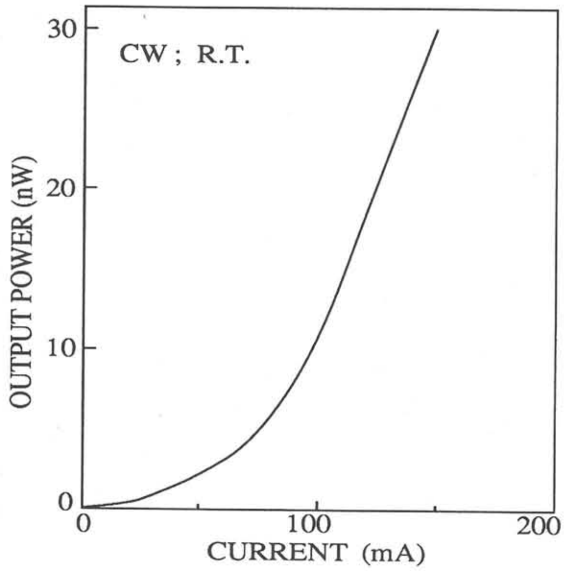

Fig. 4. Room-temperature L-I characteristic of the AlGaAs/GaAs DH LED grown on n^+-GaAs(111)A substrate using only Si dopant.

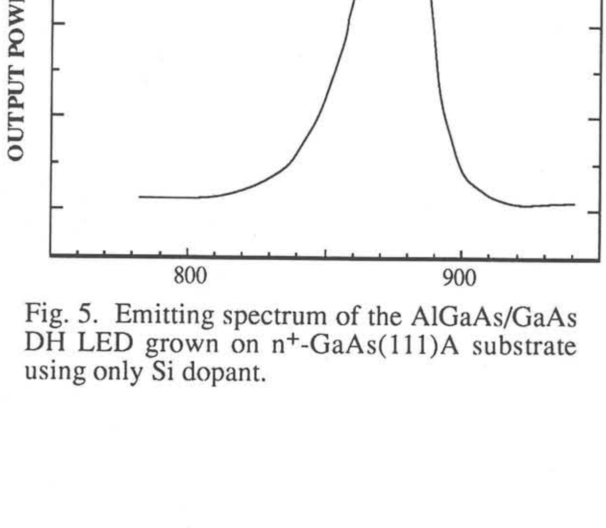

Fig. 5. Emitting spectrum of the AlGaAs/GaAs DH LED grown on n^+-GaAs(111)A substrate using only Si dopant.

4. CONCLUSIONS

We have grown the AlGaAs/GaAs DH LED on GaAs(111)A-5°-misoriented substrate using only Si dopant. The conduction type and the carrier concentration have been controlled by the flux ratio and the Si cell temperature. The smoother heterointerfaces have been also obtained. The AlGaAs/GaAs DH LED exhibited the dc operation at 300 K. This technique is very promising for the fabrication of AlGaAs/GaAs laser diodes using only Si dopant.

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