Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 673-675

Characteristics of AlGaAs/AlGaAs Interface after In-Situ Low-Temperature H_2 Annealing and MOVPE Regrowth

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Characteristics of AlGaAs/AlGaAs regrown interface using *in-situ* low temperature H_2 annealing (LTHA) are studied by photoluminescence (PL), secondary ion mass spectroscopy, and cross-sectional transmission electron microscopy. LTHA, which is a recently developed thermal treatment method for air-exposed AlGaAs surfaces by our group, markedly restores the PL spectrum from AlGaAs/GaAs/AlGaAs quantum wells near the regrown interface, indicating that initial air-exposed AlGaAs surface states are reduced. This result can be explained by the surface cleaning effects during LTHA.

1. INTRODUCTION

Although epitaxial regrowth techniques are strongly desired for present and future optoelectronic device fabrication, high-quality regrown AlGaAs interface cannot be obtained because of difficulty in removing Al oxides from air-exposed AlGaAs surfaces using conventional thermal treatments. Attempts to improve interface quality have been made such as electron cyclotron resonance plasma cleaning[1,2] and radical irradiation.[3] However, since all of these processes involve an ultra-high-vacuum system, they are difficult to integrate with metal-organic vapor phase epitaxial (MOVPE) systems. *In-situ* HCl gas etching in the reactor has been reported to be effective on AlGaAs with a GaAs cap layer in MOVPE, but it does not seem to be applicable to native-oxide-covered AlGaAs surfaces.[4]

The purpose of this paper is to study interface characteristics of AlGaAs using *in-situ* low-temperature H_2 annealing (LTHA) recently developed by our group,[5] a new type of thermal treatment for air-exposed AlGaAs applicable to MOVPE.

2. EXPERIMENTAL

The growth system used in the present work was a low pressure MOVPE system with a horizontal reactor. The source materials were trimethylgallium, trimethylaluminum and 100% AsH_3. Hydrogen was used as a carrier gas and the total flow rate was kept to 7.0 standard litters per minute.

The structure of the samples after regrowth with and without LTHA is shown in Fig. 1. The samples were prepared as follows: First, $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ quantum well (QW) samples, which consisted of two QWs: QW1 (near-surface QW: 70 Å) and QW2 (reference QW: 140 Å), were grown at 700°C on semi-insulating GaAs (001) substrates. The well-to-surface distance, *i.e.*, the thickness of the top AlGaAs barrier of QW1 was made 70 Å to observe the interaction between confined QW states and surface states most effectively. Subsequently, the QW samples were exposed to air for at least one day and transferred into the MOVPE reactor after standard surface treatment, *i.e.*, samples were dipped into concentrated H_2SO_4 for 5 minutes, rinsed in deionized water for 10 minutes. Finally, $Al_{0.3}Ga_{0.7}As$ layers were regrown at 700°C with or without LTHA. The regrown AlGaAs layer thickness was maintained at 430 Å.

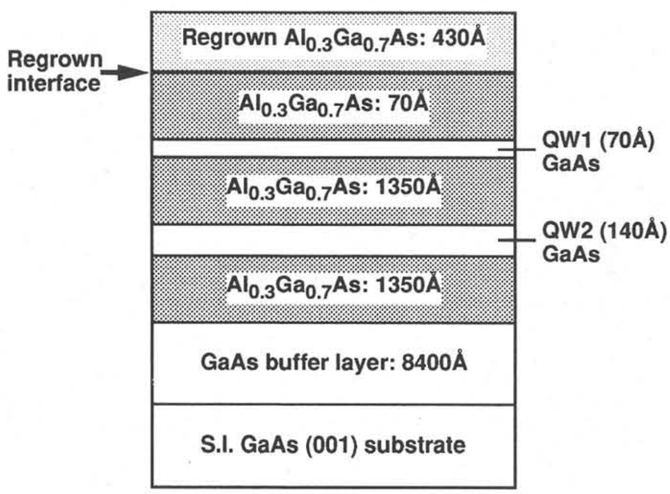

Fig. 1. The sample structure after regrowth with and without LTHA.

Figure 2 shows the thermal treatment sequence of LTHA. LTHA temperature T was varied from 250 to 380°C. LTHA duration t was 10 and 30 minutes. After LTHA, we raised the temperature to the regrowth temperature, maintaining it for 5 minutes. Arsine was introduced into the MOVPE reactor above 400°C. In conventional thermal cleaning, we raised the temperature to the regrowth temperature within about 10 minutes by introducing AsH_3 above 400°C, maintaining it for 5 minutes.

The idea for investigating regrown interface quality using photoluminescence (PL) is based on that used in evaluating surface states by PL intensity from near-surface QWs.[6-9] PL was measured at 77 K using Ar^+ laser (514.5 nm) with power density of about 1 W/cm^2 as an excitation source. Regrown interfaces were also characterized by secondary ion mass spectroscopy (SIMS) and cross-sectional transmission electron microscopy (TEM).

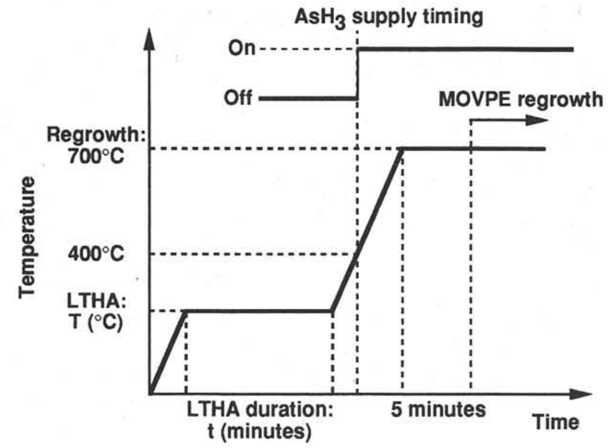

Fig. 2. The thermal treatment sequence of LTHA. LTHA temperature T was varied from 250 to 380℃, and LTHA duration t was 10 and 30 minutes.

3. RESULTS AND DISCUSSION

Figure 3(a) shows PL spectra obtained from the samples after regrowth. In Fig. 3(a), the PL spectra from two types of samples are shown: one is regrown after conventional thermal cleaning without LTHA, and the other is regrown with LTHA under the condition of T=300℃, t=10, and 30 minutes. The typical PL spectrum obtained from the samples before regrowth is shown in Fig. 3(b). The schematic band structures of QW1 are also shown in Figs. 3(a) and 3(b), respectively. PL response from QW1 of non-LTHA samples remains unobservable before and after regrowth. On the other hand, both QWs, QW1 and QW2, of LTHA samples show clear PL responses after regrowth. PL intensity from QW1 increases with the increase of LTHA duration, indicating that initial air-exposed AlGaAs surfaces gradually improve during LTHA. The same PL intensity recovery from QW1 is observed in all samples regrown with LTHA. The mechanism behind this behavior lies in the interaction between confined QW states and non-radiative recombination centers such as interface states and residual impurities at the interface. Since the regrown AlGaAs layer does not change the tunneling distance for carriers, PL recovery through LTHA indicates that surface states of an initial air-exposed AlGaAs surface are reduced.

In order to clarify the differences in PL behavior in samples with and without LTHA, we used SIMS to analyze impurities at the regrown interface. The sample with LTHA under the condition of T=300℃ and t=30 minutes was used. SIMS results showed that oxygen impurity at the interface for the LTHA sample was reduced to two-third (4.9×10^{14} cm^{-2}) and carbon impurity to half (1.1×10^{12} cm^{-2}) of those for the non-LTHA sample. This result means that the oxygen and carbon impurities are removed from the initial air-exposed AlGaAs surface during LTHA.

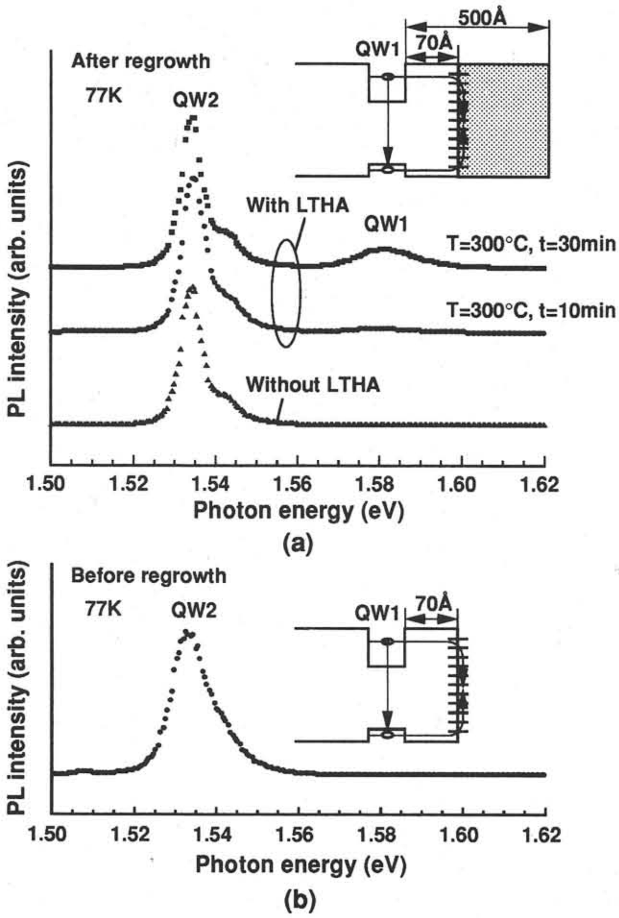

Fig. 3. The PL spectra obtained from the samples (a) after regrowth and (b) before regrowth with the schematic band structure of QW1.

Then, we studied the microstructural aspects of the same interfaces using cross-sectional TEM. Figures 4(a) and 4(b) show the TEM images and the schematic views of the regrown interfaces with and without LTHA, respectively. It is seen in Figs. 4(a) and 4(b) that amorphous interlayer is formed along the interfaces for both samples, but the structures of the amorphous interlayer are extremely different. In case of the LTHA sample, amorphous islands are formed along the interface, and the distance between the islands is estimated to be 30-70 Å, as seen in Fig. 4(a). It should be noted that no lattice disorder can be observed in the region between the islands, indicating that clean AlGaAs surfaces partially appear during LTHA. On the other hand, in case of the non-LTHA sample, amorphous layer with almost uniform thickness is formed along the interface, as seen in Fig. 4(b). Since high density of oxygen impurity, magnitude of 10^{14} cm^{-2}, was observed by the SIMS analysis, the amorphous interlayer seen in Figs. 4(a) and 4(b) is likely to be oxides. Since the thickness of the amorphous islands in Fig. 4(a) is lager than that of the amorphous layer in Fig. 4(b), we speculate that one part of the oxides desorb from the initial air-exposed AlGaAs surface, and the other part of oxides gather to form the islands by the deoxidization process of hydrogen during LTHA. As a result, clean AlGaAs region partially appears on the surface.

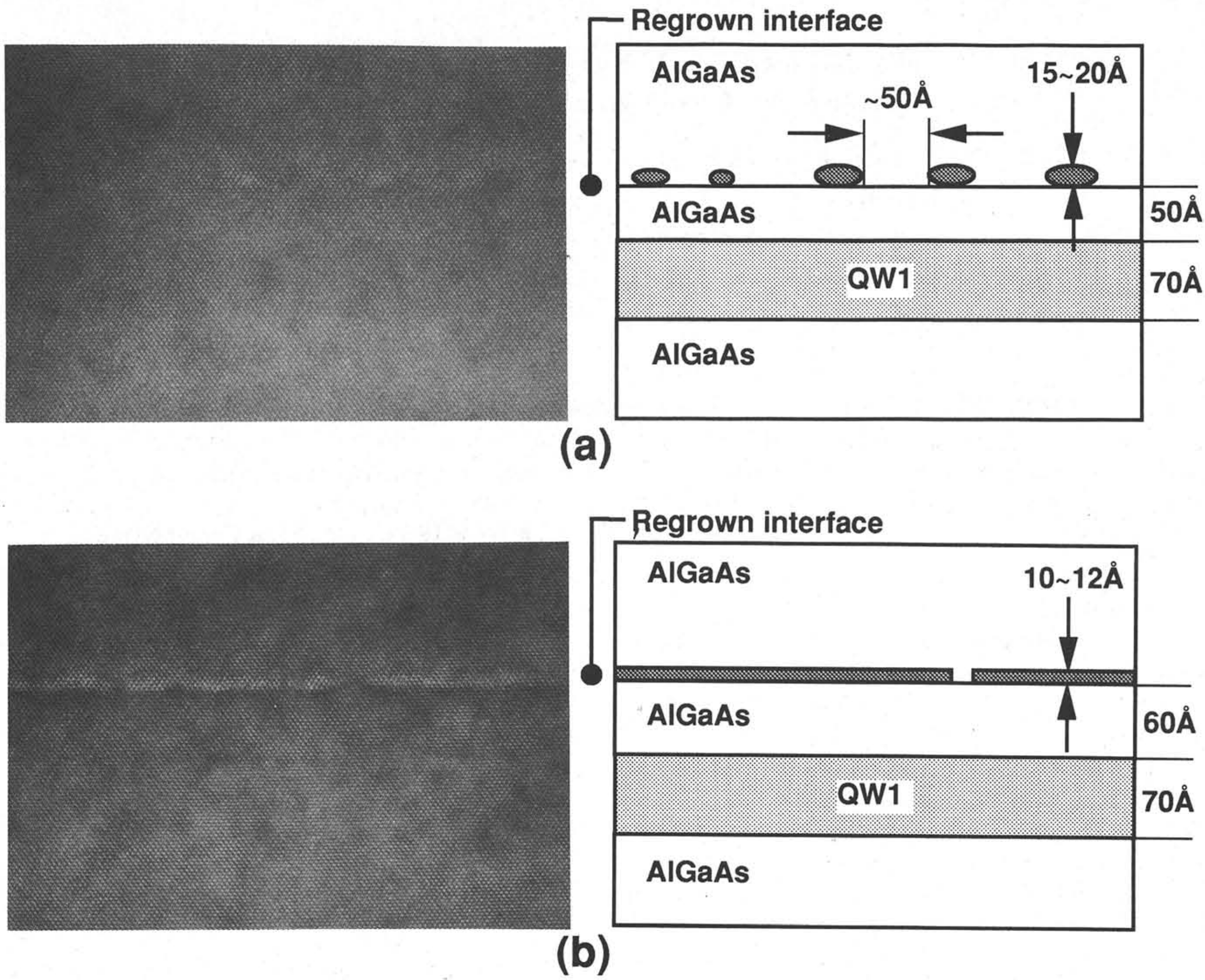

Fig. 4. The cross-sectional TEM images and the schematic views of the regrown interfaces (a) with LTHA and (b) without LTHA.

4. SUMMARY

Interface characteristics of $Al_{0.3}Ga_{0.7}As$ using *in-situ* low-temperature H_2 annealing were studied by PL, SIMS, and cross-sectional TEM. LTHA markedly restored the PL spectrum from $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ QWs near the regrown interface, indicating that initial air-exposed AlGaAs surface states were reduced. This result can be explained by the cleaning effects during LTHA.

Acknowledgments

The authors would like to thank Professor T. Fukui of the Research Center for Interface Quantum Electronics, Hokkaido University, for fruitful discussions.

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