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Point Defects of GaAs Films on Fluoride/Si Structures and Its Reduction by 2-Step Growth Method

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The reason why electrical properties of GaAs films grown on CaF_2/Si(111) structures at high (600℃) substrate temperature are degraded is studied. RBS measurements and SIMS observations revealed that the degradation was due to point defects which were originated from mutual diffusion at GaAs/fluoride interface. It was found that 2-step growth method was effective to reduce the point defects so as to give electron mobility as high as 2250 cm^2/Vs.

Introduction

Semiconductor-on-insulator(SOI) structures using fluorides as insulator materials have been investigated for application to high-speed ICs, OEICs and three-dimensional ICs. Especially, EBE (electron beam exposure)-epitaxy method have made it possible to obtain GaAs films with good crystallinity and surface morphology.[1)] However electron mobility of GaAs film grown by EBE-epitaxy had not been satisfactory in comparison with that of bulk crystal. In this paper, we showed that the point defects were origin of the degrading the mobility in GaAs film, by RBS measurements, SIMS observations and measurements of electron mobility. And we proposed 2-step growth (TSG) method to show its effectiveness for suppressing the point defects and for getting higher electron mobility.

Experiments

Experimental procedure is shown in Fig. 1. First, 200-300nm-thick CaF_2 films were grown on the clean Si(111) substrates at 600℃ by MBE. Then, the surfaces of CaF_2 films were exposed to an electron beam under As_4 impingement, to modify the CaF_2 surfaces. Electron dose was 150 $\mu C/cm^2$ and beam energy was 3keV. Finally, 1 μm-thick GaAs films were grown on the CaF_2 surfaces varying the GaAs growth temperature. The 0.5 μm surface layers were doped by Si:2×10^{17} cm^{-3}. Defect types in the GaAs

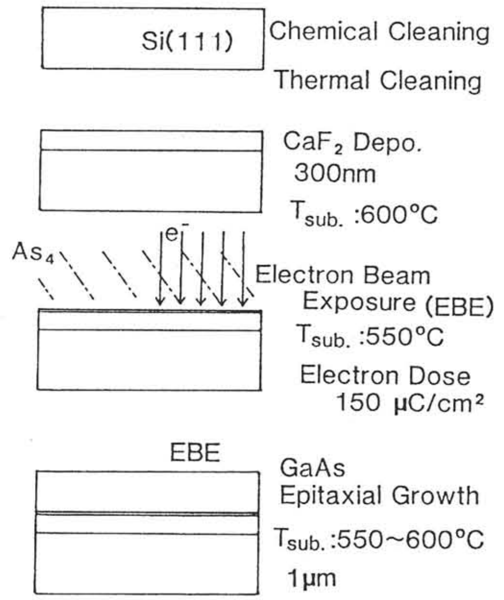

Fig. 1 Experimental procedure.

films were analized from the dependences of incident ion energy in the RBS measurement, and Hall mobilities were measured by van der Pauw method. SIMS profiles were also observed for 20-30nm GaAs films grown on the CaF_2 films.

The types of defects were determined by estimating the dechanneling factor, σ_D derived from the RBS measurements. It is reported that the σ_D has different dependence of incident energy, depending on the type of defect. It is reported[2] that, σ_D is proportional to E^{-1} (E: energy of probe ions at the analizing region in the sample) if point defects are dominant, σ_D is independent on E if line defects are dominant, and σ_D is proportional to $E^{0.5}$ if plane defects are dominant.

The dechanneling factor σ_D is described by

$$\sigma_D = \frac{1}{n_D}\cdot\frac{d}{dz}\left[-\ln\left\{\frac{(1-\chi(z))}{(1-\chi_v(z))}\right\}\right] \qquad (1)$$

where $n_D(z)$ is defect density at depth z, $\chi(z)$ is normalized channeling yield of the sample at depth z, $\chi_v(z)$ is normalized channeling yield of virgin crystal at depth z. We can obtain $n_D\sigma_D$ by RBS measurement of $\chi(z)$ and $\chi_v(z)$. Since n_D is independent on E, the energy dependence of σ_D can be derived.

Results and Discussion

Figure 2 shows the relation between growth temperature and Hall mobility of GaAs films. It is shown in this figure that Hall mobilities degrade in the temperature region higer than 575℃ in the case of single temperature growth method (●). Figure 3 shows the incident energy dependence of dechanneling factors σ_D at the surface region of GaAs films by RBS measurements. Closed circles and open circles indicate $n_D\sigma_D$ of samples grown at low-temperature (550℃) and at high-temperature (600℃), respectively. It is clear that, the energy dependences of σ_D are different, though the amounts of $n_D\sigma_D$ of the two samples are nearly equal. The σ_D for a sample grown at 550℃ is independent on incident energy, to show that plane defects are dominant in this GaAs film. On the other hand,

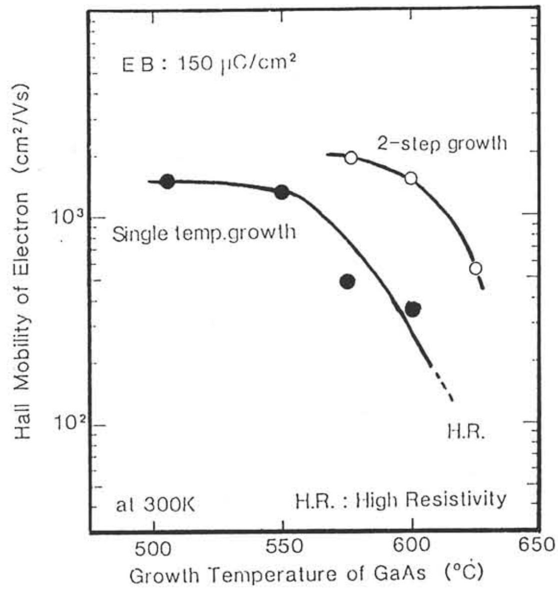

Fig. 2 GaAs growth temperature v.s. Hall mobility of surface regions of GaAs films by using single temperature growth method (●) and TSG(○) method.

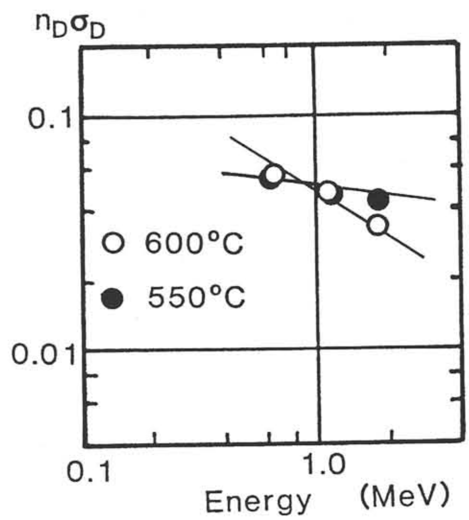

Fig. 3 Dependence of incident energy of probe ions on $n_D\sigma_D$ of surface region of GaAs films (Growth tempetarure is 550℃ for ●, 600℃ for ○.).

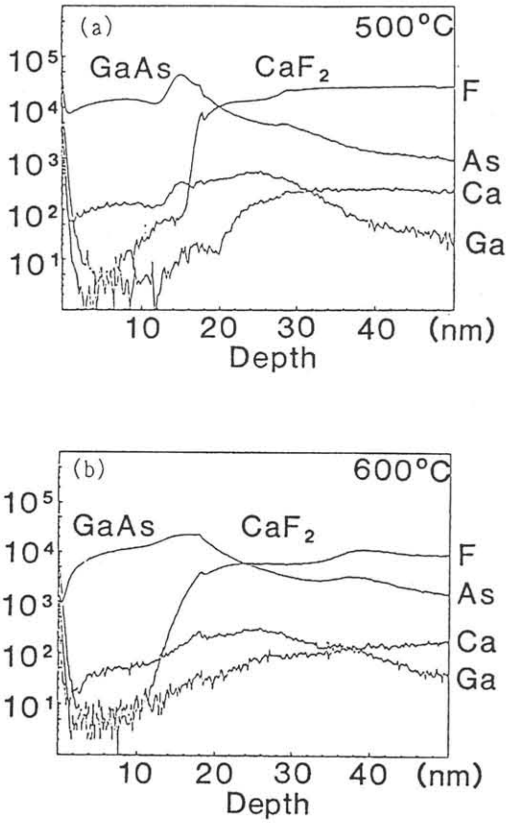

Fig. 4 SIMS observation of $GaAs/CaF_2$ interface. Growth temperature is (a)500℃, and (b)600℃.

the σ_D for that grown at 600℃ is proportional to E^{-1}, to show that point defects are dominant in this film. From these results, it can be concluded that degradation of Hall mobility in the GaAs film grown at higher temperature was (● in Fig. 2) due to the increase of the point defects.

Then, in order to find the origin of the point defects, we observed SIMS profiles of near interface of $GaAs/CaF_2$. As shown in Fig. 4, mutual diffusion between GaAs film and CaF_2 film was observed more apparently in a sample grown at 600℃ than those at 500℃. From these results, it is interpreted that the point defects were caused by the impurity atoms diffused from $GaAs/CaF_2$ interface and/or by some kinds of vacancy induced by mutual diffusion at the interface.

These experimental results shows that high-temperature growth is not desirable. However, it has been reported that rather high-temperature is desirable for homo-epitaxial GaAs(111) growth to obtain good electrical properties.[3] So, high-temperature growth must be necessary to obtain good electrical properties even in the EBE-epitaxy method. In order to solve this problem concerning the growth temperature, we developed a novel method, 2-step growth (TSG) method, that is, first GaAs layer is grown at low-temperature (500℃) followed by higher-temperature (600℃) growth. Results of the TSG method are shown in Fig. 2 (○). It can be seen that apparent improvement in mobilities has been achieved even in the higher growth temperature region, compared with the single temperature growth case (●). The maximum value of 2250 cm^2/Vs (N_D:2×10^{17} cm^{-3}) has been obtained.

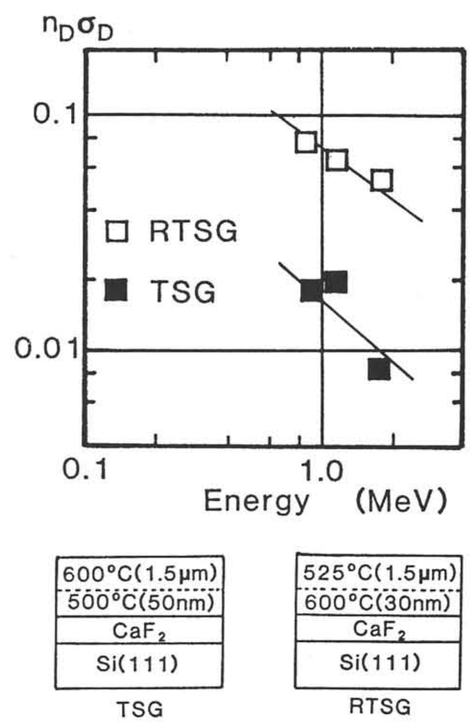

Fig. 5 Dependence of incident energy of probe ions on $n_D\sigma_D$. ■ is for TSG method, □ is for RTSG method. And schematics of sample structures grown by TSG method and RTSG method.

As a cross-check of such story, we carried out reverse 2-step growth (RTSG) method, that is, initial high temperature growth was followed by low temperature growth. We have measured the energy dependence of σ_D of near surface region of GaAs grown by the TSG method and the RTSG method. Dominant defect types in GaAs films grown by the TSG method (■) and the RTSG method (□) are found to be both point defect ones. However, its density was drastically decreased for the case of the TSG as shown in Fig. 5. On the other hand, there still existed a lot of point defects in the GaAs film grown by the RTSG method. The resistivity of GaAs film grown by the RTSG method was high due to many carrier traps. These results indicate that, the mutual diffusion at the GaAs/CaF_2 interface can be suppressed even at high-temperature growth as long as the initial growth is carried out at low-temperature. It is interesting that plane defects observed in single step growth (● Fig. 3) is not so clear in the sample of TSG method. The plane defects which observed in the 550℃ grown sample must be decreased in the near surface region of TSG sample, because growth of the near surface region has been done at high temperature.

Conclusion

We analized the type of defects in the surface region of SOI-GaAs films grown by EBE-epitaxy with RBS measurements and SIMS observations. From these analyses, point defects increased in GaAs films grown at high-temperature. The origin of the point defects which cause degradation of mobility is speculated from mutual diffusion at the CaAs/CaF_2 interface. In conclusion, the TSG(2-step growth) method is effective to suppress point defects in GaAs films, and to obtain good electrical properties of GaAs films.

Acknoledgement

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