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Growth Mechanism of SOI-GaAs Films on CaF_2/Si Structures in the Electron-Beam Exposure and Epitaxy (EBE-Epitaxy) Technique

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We investigate the surface modification effect of CaF_2 surfaces by electron beam (e-beam) exposure in order to clarify the growth mechanism of the EBE-epitaxy (Electron-Beam Exposure and Epitaxy) for GaAs/CaF_2/Si(111) structures. It is found that As atoms of the order of monolayer are adsorbed on the surface of CaF_2 film exposed to an e-beam, but not adsorbed to the unexposed surface even though both of these CaF_2 surfaces were impinged by an As_4 flux under the same condition. It is also found that the amount of As atoms adsorbed on the CaF_2 surface has a strong correlation with the quality of top GaAs films. Thermal stability and distribution of the As atoms on the CaF_2 surface are also examined.

§1. Introduction

A GaAs SOI(semiconductor-on-insulator) structure on Si substrate is attractive for high speed ICs (integrated circuit), opto-electronic ICs and 3-dimensional ICs. For the formation of the SOI structure, a variety of methods have been studied actively. Among them, heteroepitaxy method by which GaAs films can be grown at a relatively low temperature, is one of the best methods to fabricate the GaAs-SOI structure since it can provide stoichiometric good films.

From this viewpoint, we have investigated the GaAs/insulator/Si structure using fluoride.[1-2] However, it was difficult to obtain a thin GaAs film having good quality because the growth of GaAs on CaF_2 was initiated by the three-dimensional growth and the crystalline quality of the film degraded near the interface between GaAs and CaF_2. Recently, we developed a novel heteroepitaxy method, EBE-epitaxy (Electron-Beam Exposure and Epitaxy), which is very useful for growing SOI-GaAs films with excellent crystallinity on CaF_2/Si (111) structure.[3-5] In this method, the surface of CaF_2 films is first modified by electron-beam (e-beam) exposure under arsenic (As) impingement, then excellent GaAs films are grown on the modified CaF_2 surfaces.

In this presentation, in order to clarify the growth mechanism of the EBE-epitaxy, we study how the surface of CaF_2 film is changed by exposure of an e-beam under As impingement, and also investigate the relation between the CaF_2 surface modification and the quality of top GaAs films.

§2. Experimental Procedure

Detailed growth process of the EBE-epitaxy for GaAs/CaF_2/Si(111) structures was described in ref. 3. In brief, single-crystal CaF_2 films were grown on (111) oriented Si substrates at 700°C. Then, the surfaces of the CaF_2 films were exposed to a 3keV e-beam under impingement of As_4 flux. Finally, 320nm thick GaAs films were grown on the CaF_2/Si structures at 550°C.

In order to investigate the surface modification of CaF_2 film in the EBE-epitaxy, we prepared CaF_2/Si(111) structures in which the surface of CaF_2 was exposed to an e-beam at various doses under As impingement. The typical current density of an e-beam was about 1-10μA/cm^2. The temperature of CaF_2/Si structures was brought to 550°C during the e-beam exposure, and then the sample was kept in the As_4 flux down to 300°C. Rutherford backscattering spectroscopy (RBS) measurements were performed using 1.5MeV $^4He^+$ ions to examine the change of the modified CaF_2 surface. The glancing angle method in RBS was also used for acheiving higher depth resolution.

§3. Results and Discussion

Figure 1 shows RBS random and aligned spectra of CaF_2 films grown on the Si(111) substrates. In this figure, both samples were impinged by an As_4 flux at 550°C, but only the sample in the Fig. 1(b) was exposed to an e-beam to a dose of 300μC/cm^2. It is clear that numbers of As atoms are adsorbed on the surface of the e-beam-exposed CaF_2 in Fig. 1(b), while they are not adsorbed on the unexposed CaF_2 surface.

Thermal stability of these As atoms adsorbed on the CaF_2 surface is examined. Figure 2 shows the changes of As signals in the aligned RBS spectra of the As-adsorbed CaF_2/Si(111) structure by annealing at various temperatures in N_2 atmosphere. Almost no channeling effect was observed for the As spectra in this figure, which means that the counts of As signals correspond to the total adsorbed atoms. The amount of As atoms corresponding to about 3 monolayers before annealing decreases largely to be 1.7 monolayers when the sample is annealed at 550°C for 10min. This large desorption of As atoms is speculated, at present, to be due to the removal of As atoms which are located in the interstitial state or arround the Ca clusters. In this speculation, that is, a part of As atoms around the Ca cluster, generated by e-beam exposure with an excess energy[3,5] of 3keV, come off the surface together with the Ca clusters by annealing at 550°C.

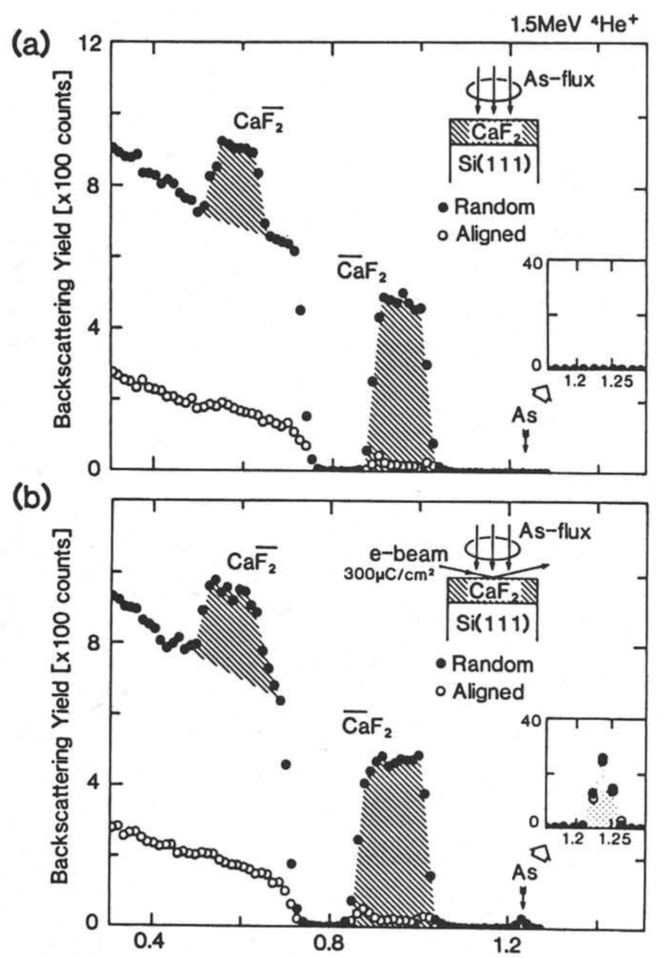

Fig. 1 RBS spectra taken from CaF_2/Si(111) structures, in which (a) is only As-impinged and (b) is As-impinged during e-beam exposure.

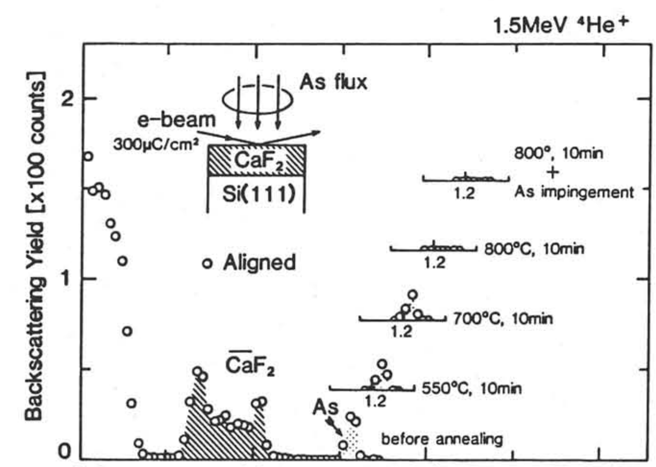

Fig. 2 Change of the aligned As signals of the As-adsorbed CaF_2/Si(111) structure by annealing at various temperatures.

It is noteworthy that no significant change could be observed in the adsorbed As atoms from 550°C to 700°C. Souda and Aono reported[6] that the CaF_2 surface exposed to e-beam under vacuum condition was restored to the initial surface, which had existed before e-beam exposure, by annealing at 500°C. In our experiment, however, the As-adsorbed CaF_2 surface was stable up to 700°C and no more As atoms were desorbed from the surface of CaF_2 film, which suggests that As atoms are strongly sticked on the CaF_2 surface, e.g. As atoms are substituted for fluorine (F) atoms by e-beam exposure under As impingement.

When the sample was further annealed at 800°C for 10min, As atoms disappeared from the surface of CaF_2 film. And once As atoms were desorbed from the surface of CaF_2, we could not observed them even though the sample were impinged again by an As_4 flux. This fact indicates that the surface of the e-beam exposed CaF_2 film is completely restored to the initial state by annealing at 800°C. Annealing in the vacuum condition also gave the similiar results as in the above N_2 atmosphere.

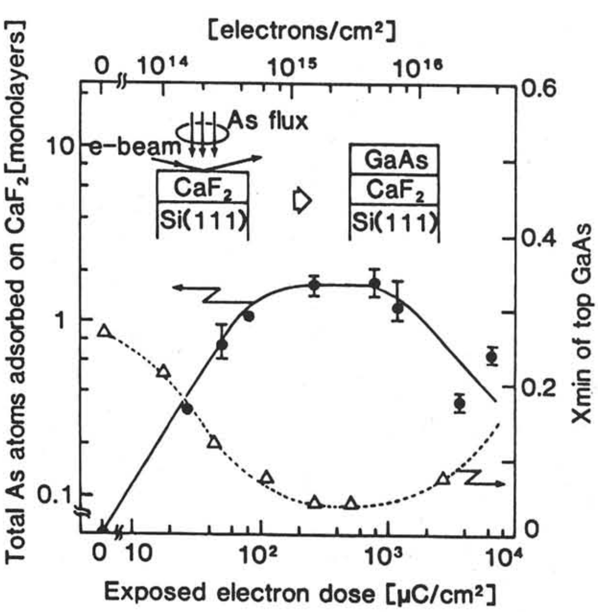

Fig. 3 electron dose vs. the amount of the As atoms adsorbed on the CaF_2 surface, and electron dose vs. χ_{min} of top GaAs films.

Figure 3 shows the electron dose vs. the amount of As atoms adsorbed on the CaF_2 surface which was annealed at 550°C for 10min. This annealing condition was best for the growth of GaAs overlayer.[3] In the low dose region, the amount of As atoms increases almost linearly with increasing the dose to about 100μC/cm^2. As the e-beam exposure further proceeds, the amount shows a saturated tendency in the dose range between 100μC/cm^2 and 1mC/cm^2. Finally, the adsorbed As atoms decrease with the dose in the region higher than 1mC/cm^2. It is interesting to note that the crystalline quality of top GaAs films, grown on the As-adsorbed CaF_2 surface, has a strong correlation with the amount of the adsorbed As atoms on the CaF_2 surface. In the saturation region, the amount of adsorbed As atoms corresponds to about 1.7 monolayer. This value indicates that As atoms do not exist only in the uppermost F sites, but they also exist in bulk CaF_2. Thus, the distribution of the excess As atoms is investigated using a glancing angle RBS method.

Figure 4 shows the random spectrum for As atoms in the e-beam-exposed CaF_2/Si(111) structure. The electron dose to the sample was 300μC/cm^2. As signal from an As-adsorbed Si(111) substrate, which was obtained by impinging an As_4 flux at 700°C to Si(111) (7×7) surface, is also shown as a reference. In the reference sample, it has been reported that As atoms of 1 monolayer are adsorbed uniformly.[7-8] It is found from this figure that As atoms in the CaF_2/Si(111) structure are distributed to about 10nm in depth from the surface by exposure of a 3keV e-beam. It is also found from comparison with a reference sample that the As atom profile is composed of a surface peak and a penetrating tail, and that surface peak area of adsorbed As atoms corresponds to the amount of a monolayer or a little less. Therefore, the excess As atoms beyond 1 monolayer, referred in Fig.

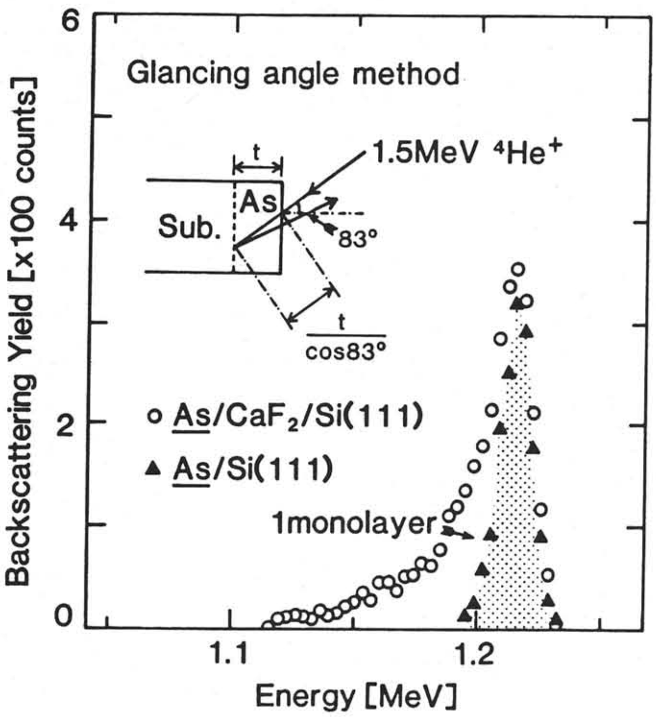

Fig. 4 Random As signal of the As-adsorbed CaF_2/Si(111) structure measured by glancing angle method in RBS. The incidence of 1.5MeV $^4He^+$ ions is tilted by 83° against the <111> normal axis of the sample. As signal of Si (111) substrate, on which As atoms of 1 monolayer are adsorbed, are also shown as a reference.

3, can be explained from the depth distribution of As atoms.

§4. Conclusion

In order to explain the growth mechanism of the EBE-epitaxy, we investigated the CaF_2 surface modified by e-beam exposure under As impingement. Main results obtained are as follows.

1) As atoms are adsorbed on the CaF_2 surface exposed to e-beam under As impingement while they are not adsorbed on the unexposed surface. The As-adsorbed CaF_2 surface is thermally stable up to 700°C.

2) The quality of top GaAs films is strongly dependent on the amount of As atoms adsorbed on CaF_2 films.

3) When e-beam exposure to the CaF_2 surface is carried out with an energy of 3keV, As atoms are penetrated to 10nm in depth from the surface of CaF_2 film. As atoms estimated at nearly 1 monolayer or less are adsorbed on the uppermost layer of CaF_2 film.

According to the above results and the reports[6,9] that the uppermost F atoms of CaF_2 are dissociated by e-beam exposure, we can conclude that uppermost As atoms of modified CaF_2 film, at least, contribute to the improvement of the quality of top GaAs films.

Acknowledgement

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