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Planarized Growth of Ge Overlayers on CaF_2/Si Structures by Electron Beam Exposure to Predeposited Layers

Seigo KANEMARU, Hiroshi ISHIWARA, and Seijiro FURUKAWA

Graduate School of Science and Engineering, Tokyo Institute of Technology,

4259 Nagatsuda, Midoriku, Yokohama 227, Japan

The effect of electron beam exposure to thin Ge layers predeposited at room temperature on CaF_2/Si(111) structures was investigated. It was found that electron beam exposure prevented island growth of the predeposited Ge layers and improves the surface morphology and the crystalline quality of Ge films which were grown on the electron beam exposed regions subsequently. The exposure effect was varied with the electron dose but it hardly depended on the electron dose rate.

1. Introduction

Heteroepitaxial growth of GaAs or Ge films on Group IIa fluorides/Si structures have potential applications to three dimensional devices such as very high speed LSI's optoelectronic IC's, and intelligent infrared sensors. In applications to high speed LSI's, it is particularly important to make semiconductor films thinner and to make the crystalline quality near the interface between the semiconductor and fluoride films better for reducing the parasitic capacitance and obtaining good electrical transport properties. However, it is generally known in the heteroepitaxial systems with lattice mismatch between the film and the substrate that the growth in the layer-by-layer manner is difficult to occur and the crystalline quality of semiconductor films degrades near the hetero-interface, as shown in the cases of GaAs and Ge growth on fluorides.[1),2)] We have reported in a Ge/CaF_2/Si structure that a thin Ge layer deposited at room temperature prior to deposition of thick Ge at high temperature (a predeposited Ge layer) is useful to improve the surface morphology and the crystalline quality of Ge films[3)]. However, optimum thickness of the predeposited Ge layer is very thin (1 nm) and thicker predeposited layers do not improve the crystalline quality of Ge films, but they degrade the quality. Reproducibility of this effect was also not so excellent. So, in order to analyze these phenomena precisely, we investigated the early stage of the growth of Ge films by in-situ reflection medium energy electron diffraction (RMEED) technique. In this experiment, we found that RMEED pattern of a predeposited Ge layer on a CaF_2/Si structure changed during observation and the surface of Ge films grown on this electron beam(e-beam) exposed area was reproducibly very smooth, while the unexposed area was rugged. In this presentation, we discuss the e-beam exposure effect to predeposited Ge layers on CaF_2/Si(111) structures.

2. Experimental Procedure

Deposition of CaF_2 and Ge films was carried out in a molecular beam epitaxy system with a base pressure in the 10^{-8} Pa range. This system is equipped with a reflection medium energy electron diffraction apparatus with 3keV primary energy, which is also used to expose electrons on predeposited layers in this experiment. The e-beam was incident to the sample with a glancing angle of 3° and it was scanned electrostatically on the sample surface with a frequency of 160 Hz. Before exposing the beam to the samples, the beam current was measured using a Faraday cup. The e-beam exposure system is schematically shown in Fig. 1.

Si(111) substrates were chemically cleaned and heated in a vacuum to evaporate contaminants from the surface. CaF_2 films were first deposited

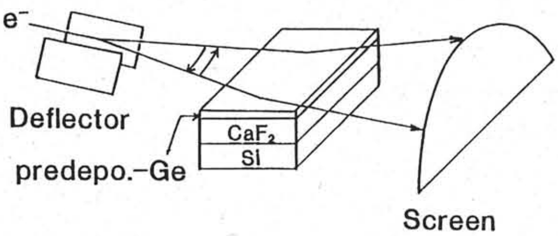

Fig.1. Schematic diagram of electron beam exposure. An electron beam is able to be scanned along the sample plane. Typical incident angle is 3°.

on the Si substrate kept at 700°C. The thickness of CaF_2 films ranged from 230nm to 400nm. Under these growth conditions, CaF_2 films are known to have a good crystalline quality.[4] After deposition of CaF_2, the samples were cooled down near to room temperature and thin Ge films were deposited on top of the CaF_2/Si structures by evaporation of 10N purity Ge from effusion cell. Thickness of predeposited Ge layers was measured by a quartz crystal thickness monitor. After the predeposition, the substrate temperature was elevated again to 400-600°C and the predeposited Ge layers on CaF_2 films were exposed to an e-beam. RMEED patterns were monitored during the e-beam exposure. Finally, thick Ge films were grown on the e-beam exposed thin Ge layers at 600°C.

The surface morphology of the samples was examined by scanning electron microscopy and Nomarski interference microscopy. The crystal orientation of Ge films was measured by electron channeling pattern method. The crystalline quality of Ge films on CaF_2/Si structures was characterized by Rutherford backscattering and channeling measurements (RBS) with 1.5 MeV $^4He^+$ ions.

3. Results and Discussion

Figures 2 (a) and (b) show the RMEED patterns obtained from 4nm thick predeposited Ge layers which were exposed to an e-beam for 2 and 10 seconds at 400°C, respectively. In this experiment the incident e-beam was not scanned in order to observe the diffraction pattern. The beam current density was estimated to be about $10^{-4}A/cm^2$. Since the pattern in Fig. 2(a) is halo, we can see that the predeposited Ge layer was amorphous at this stage. However, it gradually changed to a streak pattern as the sample was exposed to an e-beam. An example of the streak pattern at the total exposure time of about 10 seconds is shown in Fig. 2 (b). This change of the pattern was concluded to result from the e-beam exposure effect, since the RMEED pattern in the unexposed area still showed a halo pattern when the beam was moved to a new position. Figure 2 (c) shows the RMEED pattern of a predeposited Ge layer which was annealed at 600°C.(This area was not exposed to an e-beam before this observation.) The spotty pattern indicates that the predeposited Ge layer grew in island shapes by annealing at 600°C. However, it was found that the spotty pattern changed to a streak pattern better than that of Fig. 2 (b) after exposure of electrons. We speculate from these results that e-beam exposure prevents the island growth of predeposited Ge layers on CaF_2 surfaces and it is useful to obtain flat, epitaxial layers.

The e-beam exposure effect became more pronounced when thick Ge films were grown on the predeposited Ge layers at 600°C. Figure 3 shows the scanning electron micrographs, electron channeling patterns and Rutherford backscattering

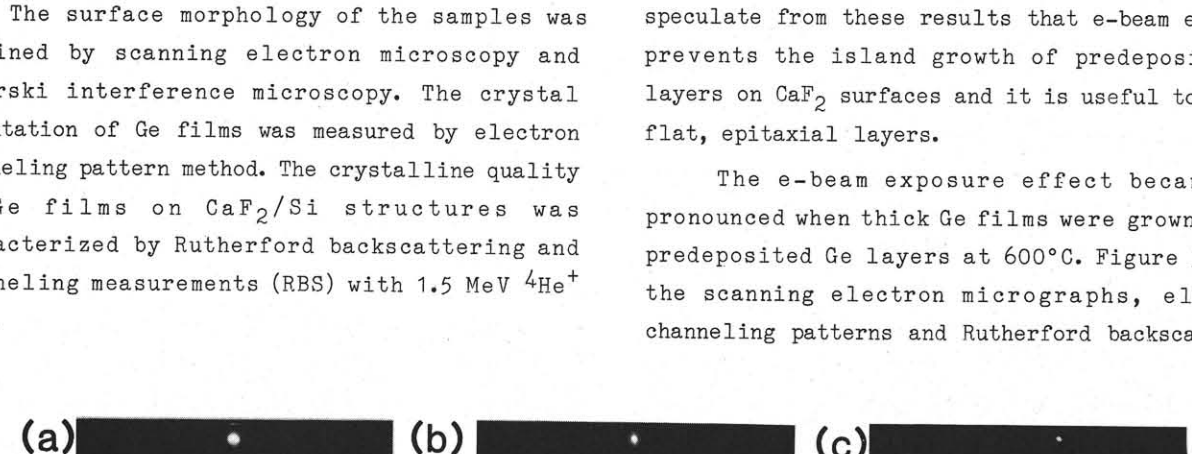

Fig.2. RMEED patterns of predeposited Ge layers: (a) a predeposited Ge layer exposed to an electron beam for 2 seconds at 400°C, (b) for 10 seconds at 400°C, (c) a predeposited Ge layer annealed at 600°C but not exposed to an electron beam.

and channeling spectra for a sample with exposed and unexposed regions. That is, Fig.3(a) corresponds to a region where the predeposited Ge layer was exposed to an e-beam, and Fig.3(b) corresponds to the other unexposed region. Thickness of the predeposited layer was 3nm. It is evident from these micrographs that the surface of the Ge film on the exposed region is very smooth, though the film on the unexposed region is very rough. Electron channeling patterns show that Ge films on both exposed and unexposed regions grow epitaxially as (111) crystals, however, they also show that the Ge film on the unexposed region is not single crystal, but it is composed of crystallites with orientations both identical to those of the underlying CaF_2 film (type A) and rotated 180° about the surface normal <111> axis of the CaF_2 (type B). The Ge film grown on the e-beam exposed region has dominantly type A orientation to the CaF_2 film. RBS aligned spectra show that the crystalline quality of the Ge film on the exposed layer is better than that of the Ge film on the unexposed region. We conclude from these results that Ge films grown on e-beam exposed thin Ge layers have better crystalline quality than those on unexposed layers, as well as the former have flatter surfaces.

In order to further investigate the e-beam exposure effect to predeposited Ge layers, dependences on the electron dose and the dose rate were measured. Figure 4 shows the variation of the channeling minimum yield of Ge films grown on e-beam exposed Ge layer with the electron dose. The electron dose rate was kept constant at 8 μA/cm^2. The thicknesses of predeposited Ge and post-grown Ge films were 6nm and 250nm, respectively. The

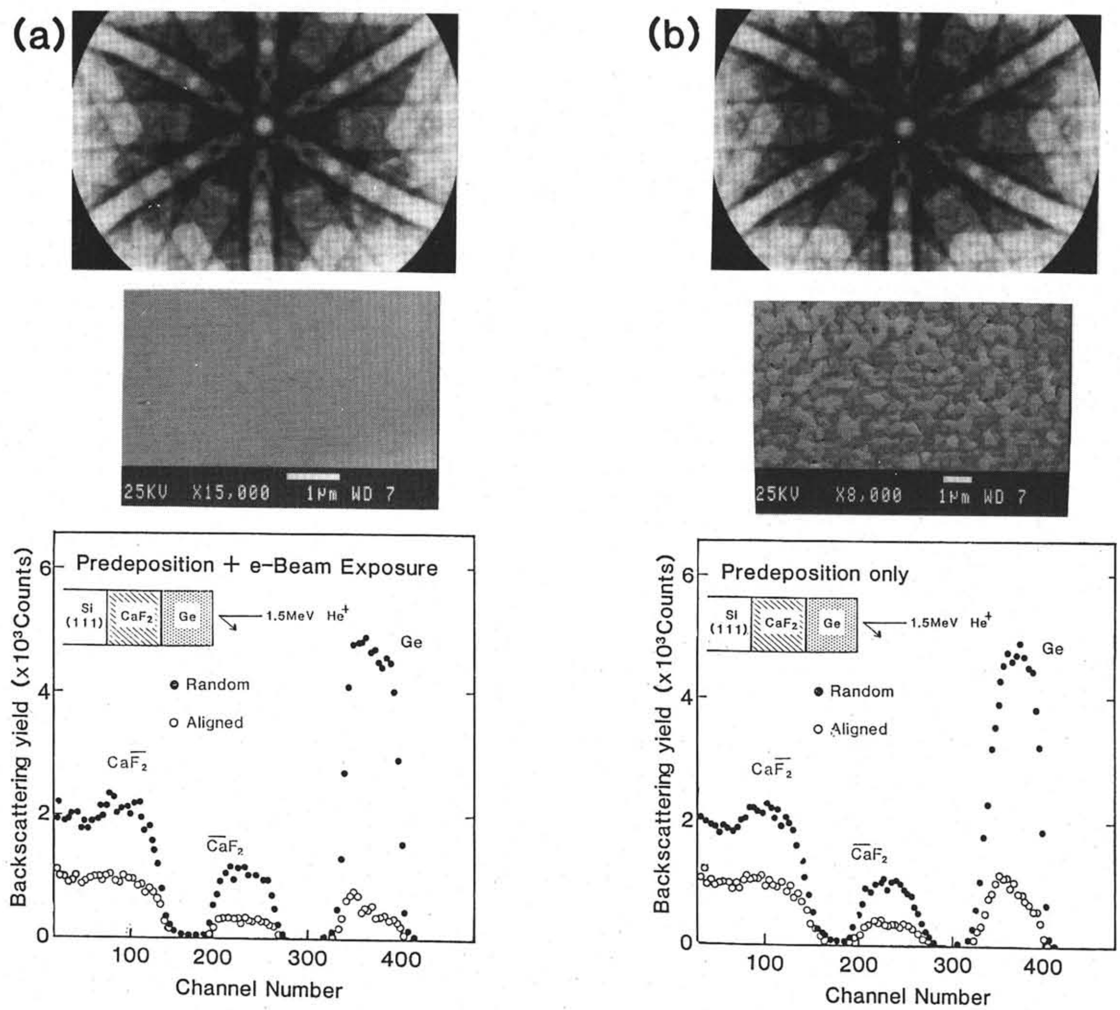

Fig.3. Scanning electron micrographs, electron channeling patterns and Rutherford backscattring spectra for $Ge/CaF_2/Si(111)$ structures: (a) a predeposited Ge layer is exposed to an electron beam, (b) a predeposited Ge layer is not exposed.

crystalline quality of the Ge film on the unexposed region is inferior to that in Fig. 2 (b) because of the thicker predeposited layer. Whereas, it was found that the exposure of electrons with doses of 160-640 $\mu C/cm^2$ improved the film quality to the same level as that of Fig.2(c). Further increase of the electron dose, however, degraded the crystalline quality and this variation well coincides with that of the surface morphology, as shown in Fig. 4. The degradation of the Ge film was found to be caused by that of the underlying CaF_2 film, since the CaF_2 surface observed after etching of the top Ge film was also very rough. The dependence on the electron dose rate of the channeling minimum yield of Ge films grown on the e-beam exposed Ge layers is shown in Fig. 5, where the total electron dose was kept at 160 $\mu C/cm^2$. We can see that dependence on the dose rate does not affect the crystalline quality under this experimental conditions. These results suggest that the e-beam exposure effect to predeposited Ge layers is not simple thermal heating effect but it is a kind of total dose effect, which may contain such phenomena as knock-on displacement of atoms or chemical bond dissociation[5]. Detailed studies on the effect of an e-beam in this system is now in progress.

4. Conclusion

We investigated the effect of electron beam exposure to predeposited Ge layers on CaF_2/Si(111) structures. It was found that the electron beam improves the crystalline quality and surface flatness of predeposited Ge layers. The effect strongly depended on the electron dose but it hardly depended on the electron dose rate. In the growth experiment of thick Ge overlayers on the electron beam exposed thin Ge layers, the surface morphology and crystalline quality of overgrown Ge films were found to be improved drastically in a proper dose range. Similar e-beam effects are also expected in the predeposition technique for GaAs or Si films on CaF_2/Si structures.

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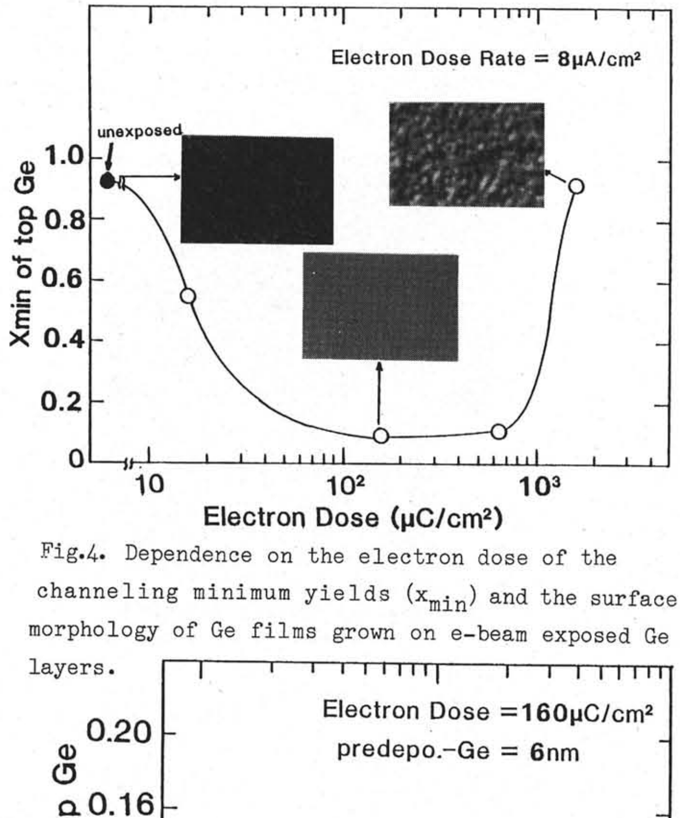

Fig.4. Dependence on the electron dose of the channeling minimum yields (x_{min}) and the surface morphology of Ge films grown on e-beam exposed Ge layers.

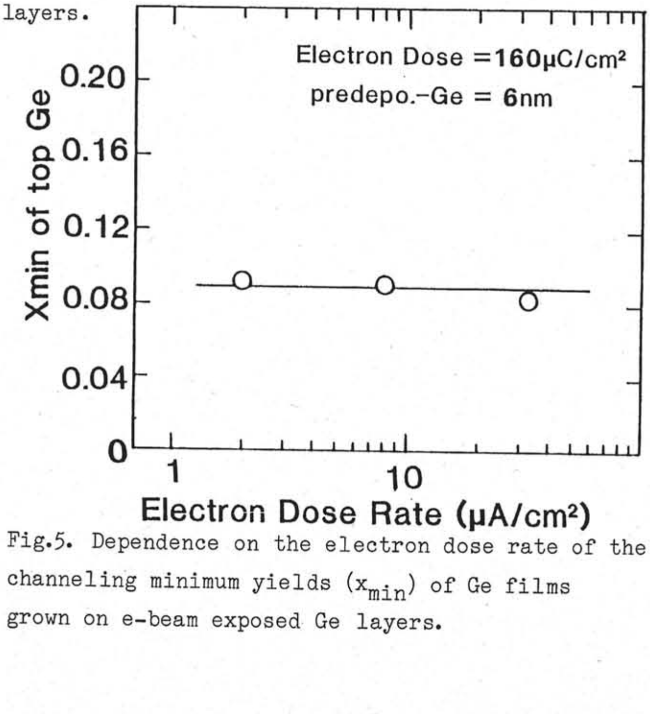

Fig.5. Dependence on the electron dose rate of the channeling minimum yields (x_{min}) of Ge films grown on e-beam exposed Ge layers.