Electron-Beam Exposure Epitaxy (EBE-Epitaxy) for the Formation of SOI-GaAs Films on CaF$_2$/Si(111) Structures

Hee Chul LEE, Tanemasa ASANO, Hiroshi ISHIWARA, Seigo KANEMARU* and Seijiro FURUKAWA
Graduate School of Science and Engineering, Tokyo Institute of Technology,
4259 Nagatsuda, Midoriku, Yokohama 227

A novel heteroepitaxy technique, which we call as an electron-beam exposure epitaxy (EBE epitaxy), has been employed in growing GaAs films on CaF$_2$/Si(111) structures. In this method, prior to the growth of GaAs films, the surfaces of CaF$_2$ are exposed to an electron-beam under impingement of arsenic fluxes. Consequently, thin GaAs films with excellent crystallinity and smooth surfaces could be obtained on the CaF$_2$/Si(111) structures. The electron beam exposure effect strongly depended upon the electron dose. It has been also found that the GaAs films grown by this method have preferentially and dominantly type A orientation which is identical to that of the CaF$_2$. Cross-sectional transmission electron microscopy has shown that the defect density in the GaAs films is remarkably reduced by employing the EBE epitaxy.

1. Introduction

GaAs on insulator structure is one promising candidate of ideal structures for fabrication of high speed LSI's, optoelectronic IC's and 3-dimensional IC's for the future. Moreover, if GaAs-SOI (semiconductor-on-insulator) structure is formed on Si substrates, it will bring further advantages such as the reliability and the high thermal conductivity of Si. In order to realize this GaAs-SOI structure, we have used alkaline earth fluoride of CaF$_2$ as an insulating material, and shown the feasibility of this structure. However, it was difficult to obtain a thin GaAs film having good quality because the growth of GaAs on CaF$_2$ was initiated three-dimensionally and the crystalline quality of the film degraded near the interface between GaAs and CaF$_2$. So, it was considered to be insufficient to make the best use of the merit of SOI structure, that is, high speed characteristic due to reducing the loading capacitance and suppressing the short channel effect.

In this presentation, a novel heteroepi-

*Present address: Electrotechnical Laboratory, 1-1-4 Umezono, Sakuramura, Ibaraki 305, Japan
1µm/hr and the flux ratio of As$_4$ to Ga was kept around 60.

3. Results and Discussion

Figure 1(a) shows an RMEED diffraction pattern taken from a 320nm-thick GaAs film grown on unexposed CaF$_2$/Si(111) structure. The pattern is spotty and a number of off-angle streaks are observable, which indicates that the surface is rough and many facet planes exist on the surface. This is probably due to three dimensional nucleation of the growth of GaAs on CaF$_2$. On the other hand, as shown in Fig. 1(b), a GaAs film grown on e-beam exposed CaF$_2$/Si(111) structure under impingement of As fluxes gives a sharp streaky pattern, indicating a smooth surface. In addition, we can see the As-stabilized (2×2) surface structure in the pattern of Fig. 1(b). This pattern was taken under As flux impingement. On the contrary, when the As beam was cut off at 550°C, the diffraction pattern changed to the Ga-stabilized ($\sqrt{19}×\sqrt{19}$) structure, as shown in Fig. 1(c). From this transition of surface structure, it can be said that the uppermost layer of GaAs films grown on e-beam exposed CaF$_2$/Si(111) structures is (111) As face.

The crystalline quality of the GaAs films grown by EBE-epitaxy was investigated as a function of an electron dose using Rutherford backscattering spectroscopy (RBS) with 1.5MeV $^4$He$^+$ ions. It is found from Fig. 2 that the crystallinity of the films strongly depends on the dose and it is improved with increase of the electron dose up to a dose of 540µC/cm$^2$. The best channeling minimum yield $X_{\text{min}}$ near the surface of the film is 4.6%, which is close to the value obtained from a bulk GaAs crystal (≈3.5%). At the higher dose, however, the crystallinity of the films again deteriorates.

![Figure 1](image1.png)

**Fig. 1** Diffraction patterns of the surfaces of 320nm thick GaAs films grown, (a) on the unexposed CaF$_2$/Si(111) structure, (b) and (c) on the electron-beam exposed CaF$_2$/Si(111) structure. The As-stabilized (2×2) surface structure (b) is transmited to the Ga-stabilized ($\sqrt{19}×\sqrt{19}$) structure (c) at 550°C without As flux impinging. The exposure was done under impingement of As fluxes with an electron dose of 540µC/cm$^2$. 3keV, <110> azimuth.

![Figure 2](image2.png)

**Fig. 2** Electron dose dependence of the channeling minimum yield $X_{\text{min}}$ near the surface of GaAs films grown on the e-beam exposed CaF$_2$/Si(111) structures under impingement of As fluxes. The film thicknesses were about 320nm.
The crystallographic orientation of the GaAs films was examined by the electron channeling pattern method using SEM). The in-plane orientation can be determined from the triangles formed by (311) bands, as indicated in the insets of Fig. 3. It is found from the pattern shown in Fig. 3(a) that the intermediate CaF$_2$ film has the 180° azimuthal rotation on the Si substrate, namely type B orientation, as it can be expected from our previous RBS measurement. The orientations of the top GaAs films grown on the unexposed CaF$_2$/Si(111) structures were found to be either type A dominant (the same orientation with the underlying CaF$_2$ film) or mixture of both type A and B crystallites. A typical channeling pattern for a GaAs film with the mixed crystallites is shown in Fig. 3(b). On the contrary, the orientation of the GaAs films grown on the CaF$_2$ exposed to an e-beam at moderate doses was found to be always type A dominant. Figure 3(c) shows the channeling pattern for a sample, in which the CaF$_2$ surface was exposed to electrons to a dose of 540μC/cm$^2$ (3.4×10$^{15}$ electrons/cm$^2$) under impingement of As fluxes. We can see from the channeling pattern that no mixing of both crystallites occurs at this electron dose. However, mixing of both crystallites and degradation of the surface morphology were again observed at such a high dose as 2.6mC/cm$^2$ (1.6×10$^{16}$ electrons/cm$^2$).

In order to investigate the surface morphology and to determine the structural defects in the GaAs films, cross-sectional transmission electron microscopy (X-TEM) observation was carried out. A GaAs film grown on the unexposed CaF$_2$/Si(111) structure shown in Fig. 4(a), exhibits a very rough surface having a number of facets, as expected from the RMEED pattern in Fig. 1(a). Further, we find a number of linear defects (dislocations) in the GaAs film. On the contrary, as shown in Fig. 4(b), the GaAs film grown on the e-beam exposed CaF$_2$/Si(111) structure shows very flat surface. The defect density is remarkably reduced near the surface region about 100nm away from the interface between GaAs and CaF$_2$. It is noteworthy that a few planar defects (microtwins) appear in the film grown on the e-beam exposed CaF$_2$/Si(111) structure which are absent in the unexposed case. The reason for the appearance of the planar defects is not clear at present. However, it is considered from observations of similar defects in GaAs/CaF$_2$/Si(100) structure$^1$ and Si/CaF$_2$/Si structure$^7$ that the planar defects are generated by the compressive stress due to the difference in the thermal expansion coefficient between GaAs and CaF$_2$. Actually, we have preliminarily observed the strengthened adhesion of the GaAs film to the CaF$_2$ film by

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Fig. 3 Typical electron channeling patterns for (a) a CaF$_2$ film grown on the (111) oriented Si substrate, (b) a GaAs film grown on the unexposed CaF$_2$/Si(111) structure, and (c) a GaAs film grown on the e-beam exposed CaF$_2$/Si(111). The e-beam exposure conditions are the same as those in Fig. 1(b) and (c).
4. Conclusion

We succeeded in growing single-crystal GaAs films with both excellent crystalline quality and smooth surfaces by employing the novel EBE epitaxy (electron-beam exposure epitaxy) technique. It is speculated that the improvement of the quality of the SOI-GaAs films is caused by the improvement of the wettability between GaAs and CaF$_2$, due to the dissociation of uppermost fluorine atoms of CaF$_2$ by e-beam exposure. From this speculation and the appearance of the varied CaF$_2$ layer formed by an e-beam exposure, as known in the observation of X-TEM, it may be desirable to reduce the electron energy for an ideal EBE epitaxy. The similar effect as an EBE epitaxy in heteroepitaxy of semiconductors on fluorides may be also expected by other methods such as photons which can controllably dissociate the fluorine atoms from the CaF$_2$ surface.

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