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Lateral MOMBE of GaAs on a Patterned (111)B Substrate

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GaAs layers were grown on patterned (111)B substrates with various arsenic fluxes at a fixed temperature of 480 °C by metalorganic molecular beam epitaxy (MOMBE) using trimethylgallium (TMGa) and metal arsenic. By optimizing the growth conditions, only lateral epitaxy was achieved. Real-time scanning microprobe reflection high-energy electron diffraction (μ–RHEED) observations showed that the surface smoothness of the epitaxial layer was maintained throughout the growth time under the optimized condition.

1. Introduction

Lateral epitaxial growth is attracting much interest because of its potential application to advanced structures of electronic and optoelectronic devices. Intense work concerning growth on masked substrates by metalorganic chemical vapor deposition (MOCVD) or chloride vapor phase epitaxy (chloride-VPE) has been reported.[1-5] However, only few papers concerning growth on maskless substrates have been written so far. Jones et al.[6] have demonstrated that growth is hardly observed on a (111)B surface even after about 10 μm thick-layer growth on the sidewall of a patterned (111)B substrate by MOCVD.

Although metalorganic molecular beam epitaxy (MOMBE) is a promising growth technique for the fabrication of devices consisting of sophisticated heterostructures, there have been no reports on the lateral epitaxy. In this paper, we report the maskless lateral epitaxy of GaAs by MOMBE on an $(1\bar{2}\bar{2})$A sidewall of a patterned (111)B substrate by optimizing the arsenic flux.

2. Experimental

The experiments were performed in an MOMBE system with a gas manifold for supplying trimethylgallium (TMGa). The growth apparatus used in the present work has been described elsewhere.[7] GaAs MOMBE was carried out on patterned $(\bar{1}\bar{1}\bar{1})$ substrates. In this paper, we denote the $(\bar{1}\bar{1}\bar{1})$ plane by the (111)B one. Mesa-grooves along the $[01\bar{1}]$ direction were formed on the GaAs (111)B wafers by chemical etching using a H_2SO_4:H_2O_2:H_2O (5:1:1) solution. The schema of the substrate is shown in Fig.1. The depth and width of the mesa-grooves were about 3 and 100 μm, respectively. They had outward sloping sidewalls. After conventional chemical treatments, each of the patterned substrates was introduced into the growth chamber. The substrate was then heated in an arsenic flux at 600°C for 20 min to obtain a clean surface. A $(\sqrt{19}\times\sqrt{19})$ reconstruction was observed from the (111)B surface after cleaning.

The TMGa was delivered through a low-temperature (100°C) effusion cell without carrier gas. The flow rate of TMGa was set at 1.0 SCCM. The growth temperature was monitored by an infrared pyrometer, and kept at 480°C. Arsenic was supplied as a molecular beam, and the flux ranged from 1.7×10^{-4} to 4.8×10^{-3} Pa on a beam flux monitor.

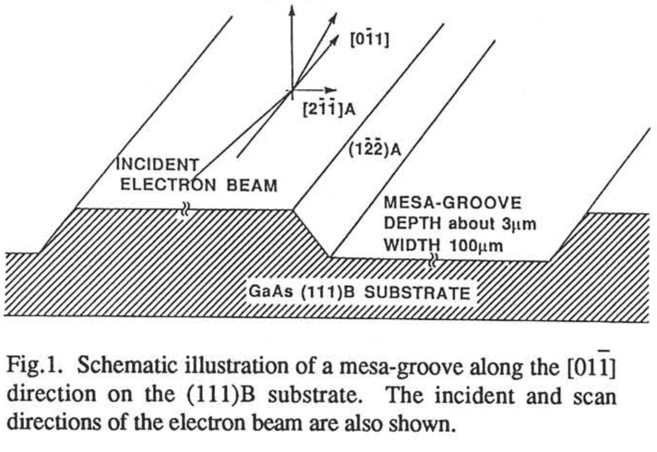

Fig.1. Schematic illustration of a mesa-groove along the $[01\bar{1}]$ direction on the (111)B substrate. The incident and scan directions of the electron beam are also shown.

The morphologies of the GaAs epitaxial layers grown with various arsenic fluxes were investigated by in-situ observation using scanning microprobe reflection high-energy electron diffraction (μ-RHEED) and by secondary electron microscope (SEM) observation after growth. For μ-RHEED measurements, a 25 keV electron beam with a diameter of about several hundred Å was aligned along the $[01\bar{1}]$ azimuth at a glancing angle of about 1°. The incident electron beam scanned the surface around the sidewall along a line normal to the edge of a mesa-groove, allowing us to obtain RHEED patterns from different surfaces between the bottom and the top of a mesa-groove.

3. Results and Discussion

3.1. Dependence of growth rate on As4 flux

Figure 2 shows a set of $(01\bar{1})$ cross-sectional SEM photographs of GaAs epitaxial layers after 3 h of growth for three different As_4 fluxes. The average thickness normal to the sidewall was about 0.4 μm for all the samples, showing that the lateral growth rate (about 0.13 μm/h) is irrespective of the As_4 flux. On the other hand, the vertical growth rate, estimated from a thickness measurement of the epitaxial layer, strongly depended on the As_4 flux. The growth rate on the (111)B surface decreased rapidly as the As_4 flux was increased ; the value decreased from 0.16 to 0.09 μm/h, as the As_4 flux was increased from 1.7×10^{-4} to 9.0×10^{-3} Pa, and at last, for an As4 flux of 4.8×10^{-3} Pa, growth was hardly observed on the (111)B surface. These results indicate that only lateral epitaxial growth occurs at a growth temperature of 480 °C with an As4 flux of 4.8×10^{-3} Pa by MOMBE.

3.2. μ-RHEED observations

RHEED patterns from restricted regions of the surfaces using μ-RHEED were observed during growth at a growth temperature of 480°C with different As4 fluxes. Figure 3 shows the RHEED patterns along the $[01\bar{1}]$ direction from the sidewalls and from the bottoms of mesa-grooves (a) before growth and after 3 h of growth with As4 fluxes of (b) 1.7×10^{-4} and (c) 4.8×10^{-3} Pa. Before growth almost the same patterns were observed for both As4 fluxes. The index of the initial sidewall was estimated to be an $(1\bar{2}\bar{2})$A plane from an angle measurement of the RHEED patterns between the sidewall and the (111)B surface.

The streaky RHEED pattern from the sidewall changed to the spotty one after growth with an As4 flux of 1.7×10^{-4} Pa, indicating that the three-dimensional growth occurred on the sidewall. On the other hand, in the case of growth with an As4 flux of 4.8×10^{-3} Pa, the RHEED pattern from the sidewall remained streaky during growth. These results indicate that the surface smoothness of the sidewall is improved with a higher As4 flux.

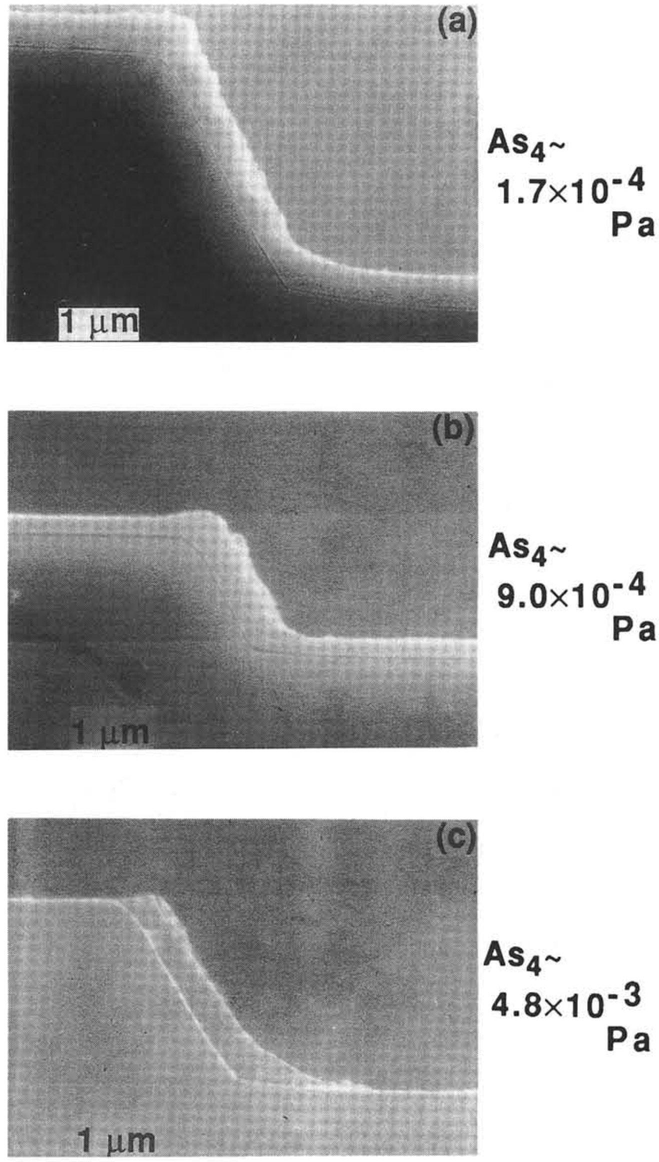

Fig.2. $(01\bar{1})$ cross-sectional SEM photographs of epitaxial layers grown with As_4 fluxes of (a) 1.7×10^{-4} (b)9.0×10^{-4} and (c)4.8×10^{-3} Pa.

The RHEED pattern from the bottom of mesa-grooves showed the two-fold reconstruction before growth. The onset of growth led to the disappearance of the half-order streak with an As4 flux of 1.7×10^{-4} Pa. On the other hand, in the case of growth with an As4 flux of 4.8×10^{-3} Pa, the two-fold reconstruction remained during growth. These results suggest that no growth occurs on the (111)B surface under growth conditions in which the two-fold reconstruction is observed during growth. This result agrees well with that obtained by Ohki et al.[8] ; reflection of almost all of incident TMGa without decomposition from the two-fold reconstructed (111)B surface was observed by the quadruple mass spectrometer.

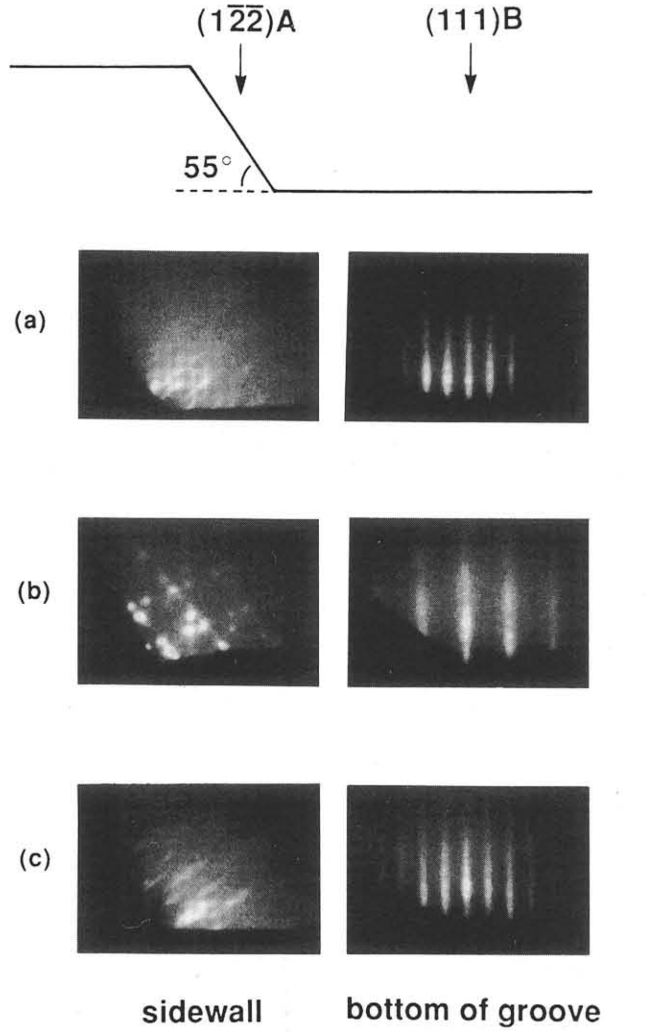

Fig.3. Changes in the RHEED patterns along the [01$\bar{1}$] azimuth (a) before growth and after 3 h of growth with As_4 fluxes of (b) 1.7×10^{-4} and (c) 4.8×10^{-3} Pa.

Another distinctive feature of the change in the RHEED patterns was observed during growth with an As4 flux of 4.8×10^{-3} Pa. A RHEED pattern with a different characteristic angle (Fig.4(a)) appeared at the intersection region between the bottom (111)B surface and the (1$\bar{2}\bar{2}$)A sidewall after about 1.5 h of growth. The intersecting angle of the facet with the (111)B surface was about 35°, indicating that the face is a (0$\bar{1}\bar{1}$) plane. This new facet is considered to be formed by the various effects such as the diffusion of surface speacies during growth and the reaction of source materials on the surface. Further investigation is necessary in order to control the shape of the lateral epitaxial layer.

4. Conclusion

GaAs epitaxial layers grown on patterned (111)B substrates by MOMBE using TMGa and arsenic was investigated. It was found that the growth rate on the (111)B surface decreased rapidly as As4 flux was increased. Only lateral epitaxy on

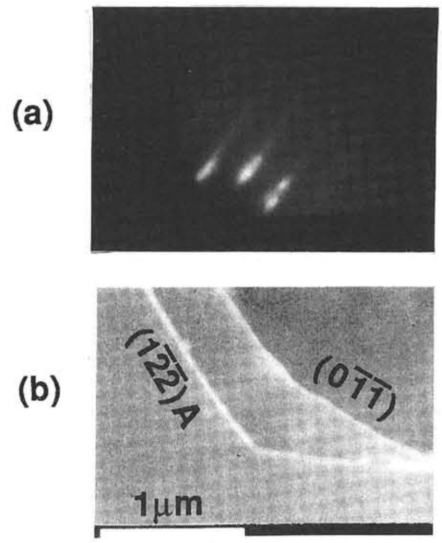

Fig.4. (a) RHEED pattern from intersection region between the bottom (111)B surface and the (1$\bar{2}\bar{2}$)A sidewall after 1.5 h of growth with an As4 flux of 4.8×10^{-3} Pa.
(b) A (011) cross-sectional SEM photograph after 3 h of growth.

the sidewall was achieved with an As4 flux of 4.8×10^{-3} Pa. The in-situ observations by μ-RHEED showed that the surface smoothness of the sidewall was also improved with higher As4 fluxes. The (0$\bar{1}\bar{1}$) facet, however, was formed at the intersection region between the bottom (111)B surface and the (1$\bar{2}\bar{2}$)A sidewall during growth. The lateral growth technique will be useful for quantum structures for electronic and optoelectronic devices.

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