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Formation of InGaAs-On-Insulator Structures by Epitaxial Lateral Over Growth from (111) Si

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1. Introduction

The Si CMOS technology is currently demanding the performance improvement techniques without scaling such as channel materials with high carrier mobility, because of the limitations of device scaling. Among them, III-V compound semiconductor channels are desirable for future advanced n-channel MOSFETs [1] owing to their high electron mobility. In order to realize III-V devices on the Si platform, the formation of high quality III-V materials on Si substrates is very important. Particularly, III-V on insulator (III-V-OI) structures [2] are more desirable for superior device properties in short channel regime, such as the suppression of short-channel effects, the reduction in the performance variation and the reduction in the leakage current.

Epitaxial lateral overgrowth (ELO) from selective area growth (SAG), where SiO_2 films are used as mask of SAG on Si substrates, is one of promising techniques for fabricating III-V OI structures. When sufficiently large lateral overgrowth regions on SiO_2 mask are obtained, III-V-OI MOSFETs can be fabricated as shown Fig.1. We have reported in our previous study that dislocation-free GaAs films can be formed on SiO_2 mask regions on Si substrates by using MBE [3].

In this study, we report ELO of InGaAs films on Si substrates by using MOVPE and successful fabrication of InGaAs-On-Insulator structures. It is found that (111) surface Si is preferable to the formation of uniform InGaAs growth and allows us to fabricate InGaAs-OI layers succeeding the crystal information from the Si substrate.

2. Experiments

Mirror-polished (100) and (111) Si wafers were used as substrates. These substrates were masked by ~100nm thick SiO_2 films with windows, where the Si surfaces were exposed as seed regions. The shapes of the windows were stripe patterns (2-5 μm wide and ~1 mm long) and the directions were changed from 5° along <110> to 180° by every 5°.

All the film deposition was performed by low-pressure MOVPE under the total pressure of 10 kPa and the temperature of 610°C. H_2 gas was used as career gas. TMIn ($In(CH_3)_3$), TMG ($Ga(CH_3)_3$), TBAs ($(CH_3)_3CAsH_2$), and TBP ($(CH_3)_3CPH_2$) were used as source of In, Ga, As and P, respectively. The deposition of InGaAs was performed after the surface treatment with TBP of 9.0 Pa. Here, the partial pressures of TMIn, TMGa, and TBAs were chosen to be 0.16 Pa, 0.26 Pa, and 5.4 Pa, respectively.

3. Result and Discussion

Figs. 2(a) and 2(b) show the results of XRD of InGaAs films on (100) and (111) Si substrates, respectively. It is found that InGaAs on (111) Si exhibits high (111) peaks than those of any other InGaAs facets, while InGaAs on (100) Si does not exhibit the sufficiently large (004) InGaAs peak, but exhibits the peaks attributed to various orientations. Figs. 3(a) and 3(b) show the SEM images of InGaAs on (100) and (111) Si, respectively. The surface on (100) Si is rough, while that on (111) Si has flat regions locally. These results of the surface morphology are in agreement with the XRD results. On the other hand, it is confirmed for both cases that InGaAs growth on Si has good selectivity against SiO_2 mask regions.

Fig.4 shows the XRD results of InGaAs on (111) Si with different InGaAs thickness. While a peak is observed around 25.5° at the beginning of the InGaAs growth, the peak shifts to higher degrees with an increase in the thickness. This fact suggests that the out-of-plane lattice constant of the InGaAs is tensily-strained at the beginning as a result of in-plane compressive strain associated with lattice mismatch between Si and InGaAs, and becomes relaxed with an increase in the film thickness.

Fig. 5 shows the cross sectional TEM image of ~1 μm thick InGaAs on (111) Si. It is confirmed in a high resolution image that the lattice constant of (111) InGaAs is relaxed as sufficiently far from the Si substrate. It is found, on the other hand, that many twins are generating near the Si interface, while, around 300 nm above the Si interface, the twin defects suddenly disappear and low-defect region appears. This disappearance of the twin defects might originate from the strain relaxation of InGaAs films with a progression in the crystal growth, seen in Fig.4. It is expected, thus, that the superior crystal quality can be realized by growing films over a certain thickness.

Figs. 6(a) and 6(b) show TED images of the Si substrate and InGaAs-OI region, respectively. Here, the measurement points are shown in Fig. 5. In the measurement the InGaAs -OI, particularly, a point in the region over the critical thickness, where the twins are disappearing, is chosen. It is found that both diffraction patters are in good agreement, indicating that the InGaAs-OI layer is succeeding the crystal information from the (111) Si substrate and, thus, ELO has been successfully realized.

4. Conclusion

It is found that the InGaAs films on (111) Si are superior to those on (100) Si, in terms of the film uniformity, flatness and the orientation control. It is also found that this InGaAs films succeed the crystal information of the Si substrate. It has been demonstrated, as a result, that InGaAs-On-Insulator structures can be successfully fabricated by ELO using MOVPE.

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References [1] S. Takagi et al., Tech. Dig. IEDM (2003) 57. [2] S. Takagi et al., Solid State Electron. 51 (2007) 526 [3] M. Shichijo et. al., Ext. Abs. SSDM (2006) p. 1088

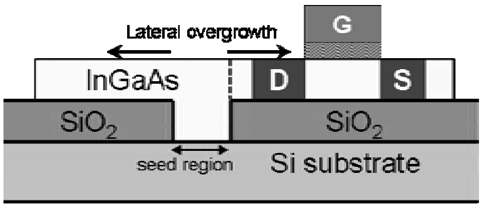

Fig.1 Schematic view of III-V-OI MOSFETs. MOSFETs are fabricated on InGaAs on SiO_2 grown from seed region.

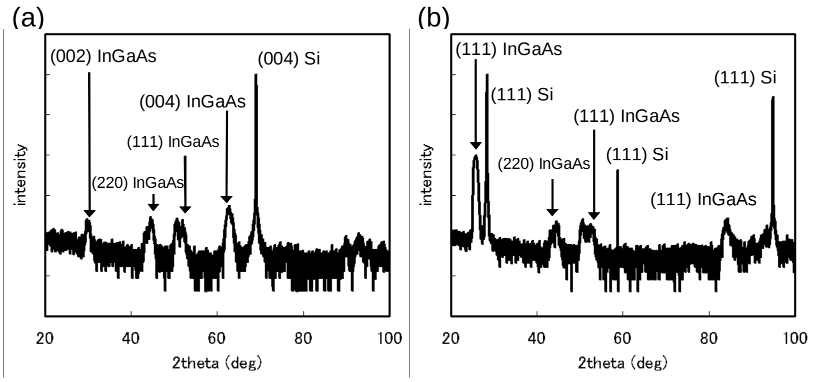

Fig.2 ω-2θ scan of InGaAs on (a) (100) Si and (b) (111) Si by XRD. InGaAs on (100) Si has various orientations. InGaAs on (111) Si has sufficiently large peaks due to (111) InGaAs.

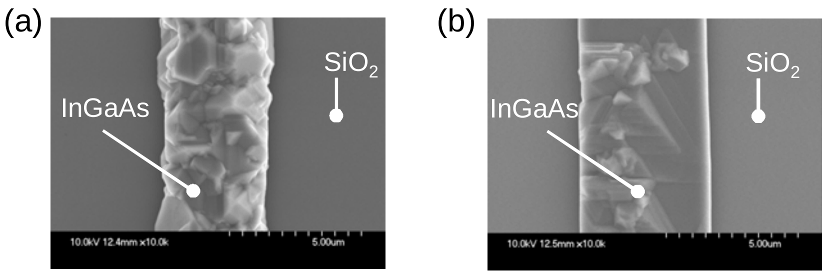

Fig.3 SEM image of InGaAs on (a) (100) Si and (b) (111) Si. The surface of InGaAs on (100) Si is rough and seems to have various facet . The surface of InGaAs on (111) Si is more flat with a single facet.

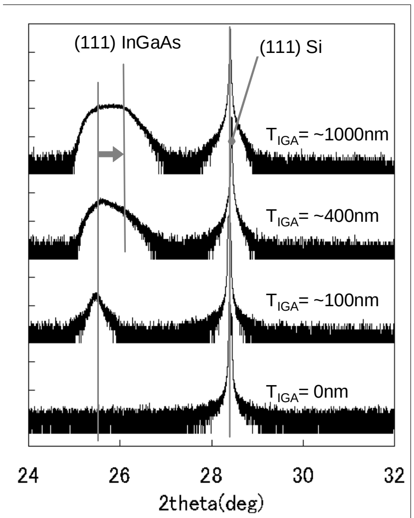

Fig.4 ω-2θ scan of InGaAs on (111) Si with different InGaAs thickness (T_{IGA}). InGaAs peak shifts as the growth proceeds.

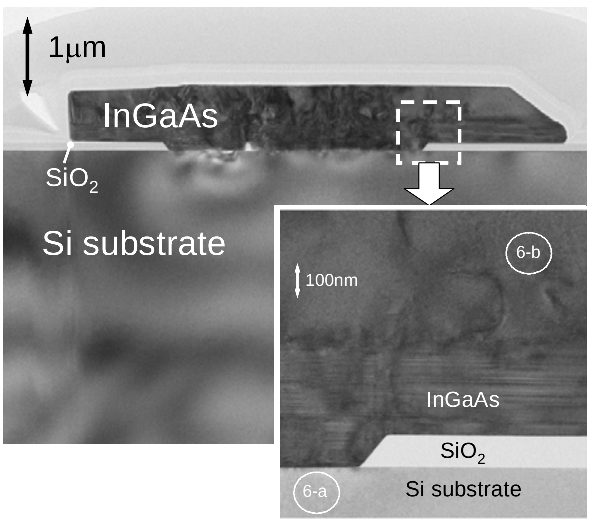

Fig.5 Cross-sectional TEM image InGaAs on (111) Si. There are many twin defects in InGaAs near the Si surface. They disappear around ~360 nm far from the Si surface.

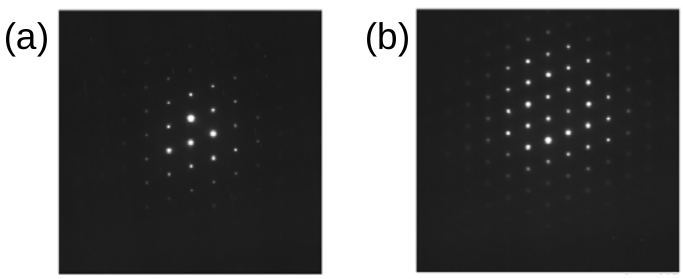

Fig.6 TED image of (a) Si substrate at 6-a in Fig.5, and (b) InGaAs at 6-b in Fig.5. InGaAs in no-twin-defects region is found to succeed the crystal information of the (111) Si substrate.