PS-8-8

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp284-285

Heteroepitaxial Growth of GaSb Films on Si(111)-√3x√3-Ga Surface Phase

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Abstract

We investigated the heteroepitaxial growth of GaSb on Si(111) substrate via Ga-induced surface reconstruction. We found that high-quality GaSb films can be grown on Si substrate by two-step growth procedure, in which the 1st layer is grown by precisely controlling the Sb/Ga flux ratio at low temperature of 260 ºC. The GaSb film showed a narrow peak FWHM of about 96 cm^{-1} in 550nm-thick film and single crystalline nature in XRD ϕ scan pattern.

1. Introduction

The group III-antimonide materials are attractive candidates as channel materials for CMOS technology due to the excellent electronic properties of them. Especially, InSb has widely noticed as a candidate material for ultra-fast and very low power device [1]. We have reported the high quality InSb grown by surface reconstruction controlled epitaxy [2,3], and have demonstrated the n-InSb/Al_2O_3/Si MOSFETs [4,5]. To realize the CMOS with the InSb-based nMOSFETs, the compound semiconductor with higher hole mobility is needed. GaSb has higher hole mobility of about 1,000 cm^2/(Vs) compared with that of InSb. However, the heteroepitaxial growth of GaSb on Si is very difficult to achieve because of the large lattice mismatch of about 12.2 % between them. Some research groups reported the growth of GaSb film on Ga- and/or Sb-induced surface reconstruction on Si(111) [6,7] and the effect of the surface reconstruction in the initial stage of the growth. In this work, we report the heteroepitaxial growth of GaSb on Ga-induced surface reconstruction on Si(111) substrate by using two-step growth procedure, in which the 1st layer is grown at lower growth temperature less than 300 ºC.

2. Experimental

All the deposition were carried out in an OMICRON molecular beam epitaxy (MBE) chamber with a base pressure of about 2 x 10^{-8} Pa, equipped with reflection high-energy electron diffraction (RHEED). The substrate with a dimension of about 15 x 5 x 0.6 mm^3 was cut from mirror polished p-type Si(111) wafer with a resistivity of about 20 Ωcm. A clean Si(111) surface was obtained by flashing at 950 ºC for 10 min after outgassing at 600 ºC for 12 h. High purity elemental Ga and Sb were evaporated from each Knudsen cell. Before GaSb films were grown by using two-step growth procedure, Si(111)-√3x√3-Ga surface phase was prepared by the deposition of 0.33 ML Ga on a clean Si(111) surface at 550 ºC. Then 0.33 ML-Sb atoms were deposited at 260 ºC onto the Si(111)-√3x√3-Ga surface phase. The deposition rate of Ga and Sb for the first layer were fixed at 1 monolayer (ML)/min, respectively. During the growth, the Sb/Ga flux ratio was precisely controlled to be 1.0. For the second layer deposition, in which the substrate temperature was gradually increase from to 430 ºC, the deposition rate was increased to 1.5 ML/min for Ga and Sb atoms, respectively. The samples were characterized by RHEED, X-ray diffraction (XRD), and transmission electron microscope (TEM).

3. Results and Discussion

Figure 1 compares the evolution of RHEED pattern of initial stage of the growth of 1st layer of GaSb at 260 ºC and 300 ºC, respectively. These patterns shows the asymmetric feature to the (00) streak line in the center. This may imply single crystalline nature of the film. The samples grown by using Sb/Ga flux ratio shifted from 1.0 showed symmetric pattern. This means that precise control of Sb/Ga flux ratio to 1.0 is necessary to grow the GaSb films with the single crystalline nature. The RHEED patterns of the sample grown at 260 ºC changed from spotty feature to streaky feature until 20ML. However, the 20ML-thick sample grown at 300 ºC remains spotty feature in the RHEED pattern. This result may indicate that GaSb tends to agglomerate at the higher growth temperature of 300 ºC.

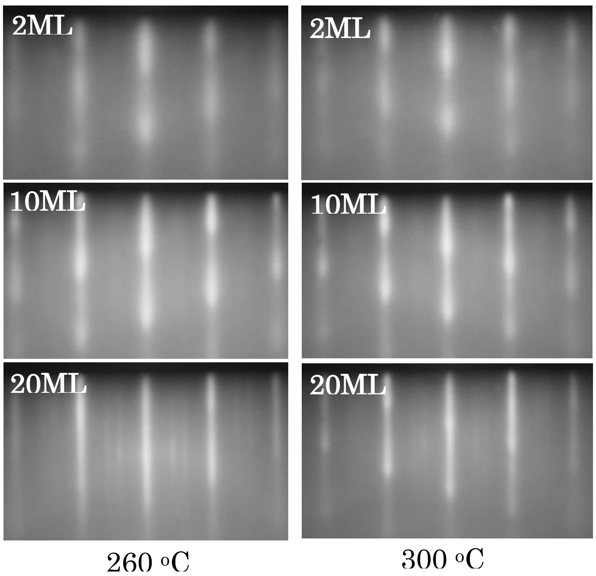

Fig. 1 The evolution of RHEED pattern of the samples grown at 260 ºC (Left) and 300 ºC (Right).

We prepared GaSb films with different thickness ranged from 80 to 550 nm. Figure 2 shows a full width at half maximum (FWHM) of the GaSb(111) peak of the samples as a function of film thickness. The FWHM data of the samples grown on compound semiconductors such as InP and GaAs, which reported by other research groups, are also shown in the figure [8-10]. As shown in Fig.2, the FWHM of GaSb(111) peak decreased from with increase of the film thickness. The values in this work were narrower than those of the samples grown on the compound semiconductor substrate with smaller lattice mismatch. The peak position of GaSb(111) peak in the 550 nm-thick sample was about 25.29 °. This is almost equal to that of bulk GaSb, implying completely relaxed film.

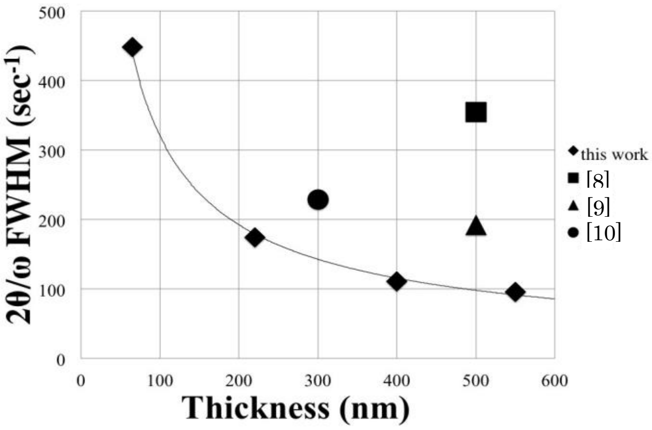

Fig. 2 FWHM of GaSb(111) peak as function of the film thickness.

The XRD ϕ-scan pattern of the {111} reflection peak of 550 nm-thick GaSb film and Si is shown in Fig. 3. The solid circles indicate the peak position of Si substrate. As shown in this figure, the ϕ-scan pattern of GaSb film shows three intense peaks separated by intervals of 120 °. The peak positions of the three peaks agree with those of Si substrate. This means the GaSb grown on Si(111) doesn't rotates with respect to the Si(111) surface, and has single crystalline nature without twins (180 ° rotated crystals).

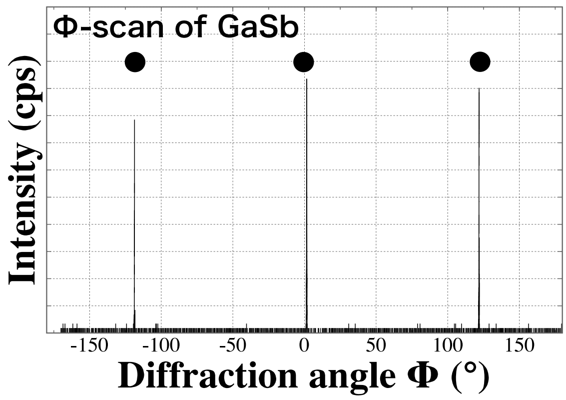

Fig. 3 ϕ-scan pattern of the (111) reflection of GaSb. Solid circles indicate the peak positions of Si.

The cross sectional TEM image of the 400 nm-thick sample is shown in Fig. 4. The circles in the figure shows the positions of interfacial misfit dislocations. The misfit dislocations is introduced every 8 or 9 atomic lines. This value is almost consistent with 8.16 which is the theoretical periodicity, indicating effective relief of large lattice mismatch at the interface.

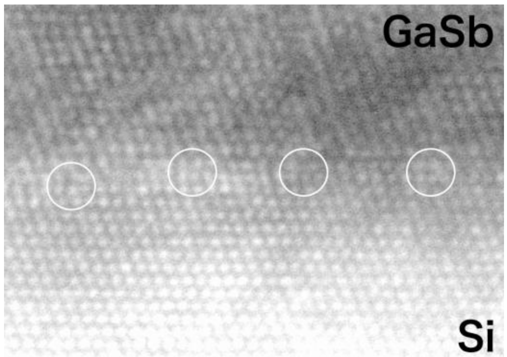

Fig. 4 cross sectional TEM image of 400nm-thick GaSb film. The circles indicate interfacial misfit dislocations.

4. Conclusions

We studied the heteroepitaxial growth of GaSb on Si(111)-√3x√3-Ga surface phase by using two-step growth procedure, in which the flux ratio of Sb/Ga is precisely controlled to 1.0, and found that high quality GaSb film with narrow FWHM and single crystalline nature can be grown on Si(111) substrate without insertion of the buffer layer of different materials.

Acknowledgements

A part of this work is financially supported by Hitachi Kokusai Electric Inc. and IT program of the Ministry of Education, Culture, Sports, Science and Technology of the Japanese Government (No. 25289099)

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