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Effect of Initial In Coverage for Preparation of InSb Bilayer on Electrical Properties of InSb Films Grown By Surface Reconstruction Controlled Epitaxy

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1. Introduction

Due to its excellent electrical properties such as high electron mobility of about 78,000 $cm^2/(Vs)$ and high electron saturation velocity of about $5x10^7$ cm/s at RT, InSb is one of the most attractive materials for high speed and low power device applications [1-3]. The heteroepitaxial growth of InSb on Si is of interest from the viewpoint of integration of InSb-based devices and Si-LSI. However, the heteroepitaxy of InSb on Si is very difficult to achieve because of the large lattice mismatch of about 19.3% between them. To overcome the difficulty, various buffer layers such as GaAs [4], AlSb [5] and Ge [6-8], have been used.

Recently, we have reported that the surface reconstruction by In and Sb atoms formed on Si (InSb bilayer) is a good solution for solving the lattice mismatch problem [9-12]. The InSb films grown on the InSb bilayer, prepared by the adsorption of 1 monolayer (ML) Sb onto a In-induced surface reconstruction such as Si(111)-√7x√3-In, were rotated by 30^o with respect to the Si(111) surface. In this case, the lattice mismatch between InSb and Si was nominally reduced to about 3.3%. Previously, we optimized the growth condition of the first layer such as growth rate, growth temperature and thickness in the two-step growth method, and demonstrated the growth of 1μm-thick InSb film with high electron mobility of about 38,000 $cm^2/(Vs)$ using lower growth rate, higher growth temperature, and thinner thickness [13].

To grow the InSb films with higher electron mobility, we try to optimize the initial In coverage for the preparation of InSb bilayer. We have used the Si(111)-√7x√3-In, in which In coverage is 1.2 ML, as an initial In-induced surface reconstruction, because a part of In atoms in the initial In-induced surface reconstruction would desorb due to a substitution with Sb atoms during the Sb deposition onto the In-induced surface reconstruction [10, 11]. However, in the preparation process of the InSb bilayer, the excess In atoms will become to large clusters and/or islands, and luck of In atoms will give rise to formation of 2x1-Sb surface reconstruction on the surface, on which InSb film doesn't rotate. These situations cause the dislocation in the films. Therefore, it is necessary to choose adequate In coverage for the preparation of InSb bilayer.

In this paper, we report the effect of the initial In coverage on the electrical properties of InSb films grown by surface reconstruction controlled epitaxy.

2. Experimental Procedure

All the deposition were carried out in an OMICRON molecular beam epitaxy (MBE) chamber with a base presure of about $2x10^{-8}$ Pa, equipped with a reflection high-energy electron diffraction (RHEED) system. The substrate with dimensions of about 15 x 4 x 0.6 mm^3 was cut from a mirror-polished p-type Si(111) wafer with a resistivity of about 20 Ωcm. The substrates were degassed at about 600 ^{o}C for 12h, followed by flush annealing at 1250 ^{o}C, and then slowly cooled in the chamber. This process gave a clean (7x7) surface, as confirmed by RHEED. High purity (6N) elemental indium and antimony were used as sorce materials and evaporated from each PBN K-sell. The substrate temperature was monitored by an infrared pyrometer. Prior to the growth of InSb films, the InSb bilayer was prepared by the following process. First, a Si(111)-√3x√3-In surface phase was prepared by the deposition of 0.33 ML In atoms onto the clean Si(111)-7x7 surface at 450 ^{o}C. After cooling down to RT, additional In atoms of 0.92, 1.17 and 1.67 ML (total In coverage was 1.25, 1.5 and 1.5 ML, respectively) were deposited onto the √3x√3-In surface. The InSb bilayer was obtained by 1 ML Sb deposition onto these surface at about 180 ^{o}C.

The growth of InSb films was then performed by the two-step growth method on the InSb bilayer. In this procedure, the first layer was deposited at an initial growth temperature of 200 ^{o}C, which was gradually increased to 330 °C during deposition. The growth rate and thickness of the first layer was fixed at 0.1 nm/min and 3 nm, respectively. Prior to the second layer deposition, the growth was interrupted by closing the shutters. The second InSb layer was then deposited at a starting growth temperature of 380 ^{o}C, which was gradually increased to 440 ^{o}C during deposition. The growth rate of the second layer was fixed at 0.5 μm/h. The total film thickness was about 1 μm. The growth conditions except for the initial In coverage were fixed.

The evolution of the RHEED pattern operating at 15 kV was observed in the <1$\bar{1}$0> azimuth of the Si substrate during deposition. For structural analysis, the InSb films were characterized by X-ray diffraction (XRD) using $CuK_{\alpha1}$ radiation. The surface morphology of the InSb films was observed by scanning electron microscope (SEM). To evaluate the electrical properties of the films, Hall measurement was performed by using the van der Pauw method.

3. Results and discussions

In RHEED patterns after preparing of InSb bilayer, there are no obvious differences except for brightness, because most of the surface is covered with the InSb bilayer though excess In atoms tend to agglomerate. However, this slight change may imply the difference of the reconstructed surface.

Figure 1 shows SEM images of the InSb film, which was grown on the InSb bilayer prepared with initial In coverage of (a) 1.25, (b) 1.5 and 2.0 ML, respectively. Some line features contrast related to dislocations can be seen on the surfaces of the films [13]. The density of the dislocations is very large in Fig.1(a), and is few in Fig.1(b). The density of the dislocations in fig.1(c) is slightly larger than that in Fig.1(b). These results may imply that amount of In atoms of 1.2 ML as an initial In coverage was not enough to cover the entire surface by InSb bilayer, and in the case of 2.0 ML-In, a part of In atoms started to agglomerate.

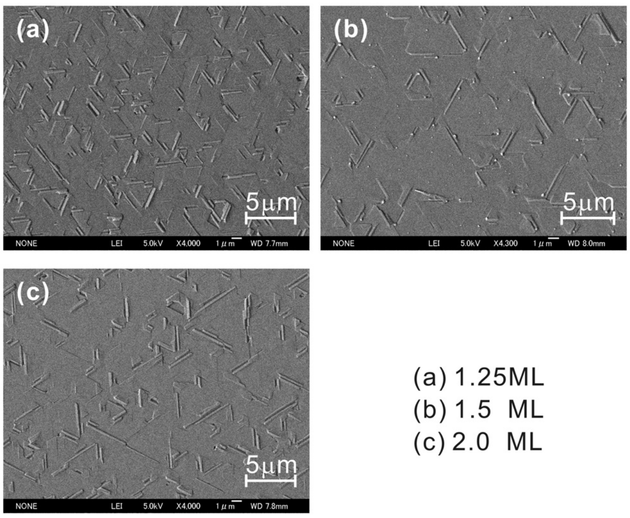

Fig.1 SEM images of the surface of the InSb films

The results of Hall measurement are shown in Table II. The room temperature mobility of the sample, which was grown on the InSb bilayer prepared with initial In coverage of 1.5 ML was 40,000 $cm^2/(Vs)$. This value is very high as the mobility of the 1μm-thick InSb film directly grown on the Si substrate. As mentioned above, existence of 2x1-Sb surface reconstruction and agglomerated In on the surface give rise to generate the dislocations at the interface. The dislocations in the films degrade the electrical properties. Because the InSb film grown on the InSb bilayer, which was prepared with 1.5ML-In shows the highest electron mobility, it has the lowest dislocation density. This is consistent with the results of SEM observation.

The XRD patterns of the InSb films showed no obvious difference. It indicates that the distinctive feature (30^o-rotation of InSb film) of the surface reconstruction controlled epitaxy doesn't affect with modification of the growth condition of the InSb bilayer.

Table II Electrical properties of InSb films at RT

Inisial In coverage [ML]	Mobility [$cm^2/(Vs)$]	Carrier Density [$/cm^3$]
1.25	32,800	2.1×10^{16}
1.5	40,000	1.8×10^{16}
2.0	36,200	1.6×10^{16}

4. Conclusions

The heteroepitaxial growth of InSb films with a high crystalline quality and a high electron mobility was achieved by modifying the coverage of In atoms of the initial In-induced surface reconstruction. A InSb film with a high electron mobility of 40,000 $cm^2/(Vs)$ at RT was obtained, implying the high capability of this film for high-speed and low-power device applications.

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