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Effect of AlSb buffer layer thickness on heteroepitaxial growth of InSb films on a Si(001) substrate

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Abstract

Aluminum antimonide (AlSb) layers with various thickness ranged from about 8 to 250 nm were grown at 520 °C as the buffer layer for the heteroepitaxial growth of InSb films on Si(001) substrates. InSb films were grown at 400 °C on the AlSb/Si(001), and were characterized by X-ray diffraction (XRD), atomic force microscope, as a function of the thickness of the AlSb layer. The XRD patterns of the InSb films grown on the AlSb layers show that even if the AlSb buffer layer, whose surface consists of many islands, is as thin as 8 nm, it is effective for the heteroepitaxial growth of InSb film on a Si(001) substrate, and the AlSb layer of about 40 nm is thick enough to grow heteroepitaxial InSb films on the Si(001) substrate. The results of the ϕ scan patterns of the films show that InSb films on a Si(001) substrate with AlSb buffer layer were heteroepitaxially grown without any rotation in the growth plane.

Keywords: Heteroepitaxy; InSb; Si(001); AlSb buffer layer; Atomic force microscope

1. Introduction

InSb has the smallest band gap (about 0.17 eV) and the highest electron mobility (about 78,000 $cm^2/V\ s$) at 300 K. The heteroepitaxy of InSb films on GaAs or Si substrate has been reported by many groups using a wide variety of preparation methods such as molecular beam epitaxy (MBE) [1–9], metalorganic chemical vapor deposition (MOCVD) [10–13]. It is very difficult to achieve the heteroepitaxy of InSb films on a Si(001) substrate, because of the large lattice mismatch of about 19.3% between them. In order to solve this difficulty, various buffer layers such as GaAs and Ge have been used [1,2,7–9]. By using these buffer layers, the lattice mismatch between InSb and Si is reduced down to about 14.6% for GaAs and about 14.5% for Ge, respectively.

Previously, we have reported the heteroepitaxy of InSb films grown on a Si(001) substrate with Ge or AlSb buffer layer [7–9,14,15]. In the case of Ge buffer layer, the heteroepitaxy of InSb on a Si(001) substrate with about 100-monolayer (ML) Ge which forms islands was achieved by means of the two-step growth procedure with a maximum temperature of 400 °C. However, the electrical properties of these samples are significantly poorer than that of bulk InSb. The low resistivity of Ge layers makes it difficult to measure the electrical properties of the grown InSb films accurately. In the case of AlSb buffer layer, it reduces the large lattice mismatch of about 19.3% between Si and InSb to about 5.6%. Furthermore, the resistivity of AlSb with stoichiometric composition is large enough for the measurement of electrical properties. It has been reported that AlSb layer has a wide growth window for the heteroepitaxy of InSb on both GaAs(001) and Si(001) [3]. We have found that the InSb films grown at 300 °C with flux ratio (Sb/In) of 2.9 on AlSb buffer layer using one-step growth procedure have good crystal quality and smooth surface [14,15].

However, one of the problems for the heteroepitaxy of InSb on AlSb/Si(001) is a difference of thermal expansion coefficient between InSb and AlSb. We have reported the occurrence of the cracks for the InSb films grown on AlSb at high growth temperature [14,15]. These cracks on the surface obstruct the measurement of the electrical properties. The successful growth

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of InSb on Ge islands [8,9] and this crack-problem encourage us to decrease the thickness of AlSb buffer layer. If we could reduce the bad influence while keeping the good effect of AlSb, high quality InSb films may be able to grow on AlSb/Si(001) at high growth temperature without any cracks.

Here, we report the effect of AlSb buffer layer thickness for the heteroepitaxy of InSb on a Si(001) substrate.

2. Experimental details

All the depositions were carried out in an MBE chamber equipped with Auger electron spectroscopy (AES) and low energy electron diffraction (LEED) systems. The base pressure in the growth chamber was about 3×10^{-8} Pa and found to be better than 1×10^{-6} Pa during AlSb deposition and 4×10^{-7} Pa during InSb deposition. Mirror-polished p-type Si(001) substrates with dimension of $10\times30\times0.6$ mm^3 were cut from a commercial wafer stock. The resistivity of these substrates at room temperature was about 20 Ω cm. They were chemically cleaned by a usual manner [16]. A thin oxide layer was prepared by dipping the substrates into $HCl:H_2O_2:H_2O=1:1:6$ solution for 15 min at the final step of the cleaning procedure. The substrates were then loaded into the vacuum chamber, where they were heated for 30 min at 950 °C to remove the oxide layer. After these treatments, the clean Si(001) surface has been confirmed by a clear (2×1) LEED pattern.

High purity (6N) elemental aluminum (Al), indium (In) and antimony (Sb) were used as source materials and evaporated from PBN cell for Al and hand-made quartz cell for In and Sb. The substrate temperature was monitored by an infrared pyrometer. Before the growth of InSb films, the AlSb layers with various thicknesses from about 8 to 250 nm were deposited at 520 °C and with the flux ratio Sb/Al of about 3.0. The thickness of the AlSb layer (d_{AlSb}) was controlled by the opening time of the shutters. After the growth of the AlSb buffer layer, the substrate temperature was held at 520 °C for 20 min before cooling down to 400 °C for the growth of InSb. The flux ratio of Sb/In during the deposition of InSb films was fixed to about 3.0. The thickness of all the InSb films was about 900 nm.

An interferometer attached to an optical microscope was used to measure the thickness of the grown InSb films. Atomic force microscope (AFM) images of AlSb and InSb films were taken by ex situ Nano-Scope III (Digital instruments). For structural analysis, the grown InSb films were characterized by X-ray diffraction (XRD) using Cu K_α radiation. We defined the XRD intensity ratio ($I_{(004)}/\sum I_{(hkl)}$) of the peak intensity of InSb (004) peak to that of the summation of each InSb(hkl) peak as the degree of heteroepitaxy.

3. Results and discussion

AlSb buffer layer with various thickness ranging from 8 to 250 nm was deposited on a Si(001) substrate at 520 °C. Fig. 1 shows AFM images of the surface of the AlSb buffer layer with thickness of (a) 8, (b) 40 and (c) 250 nm. For comparison purpose, the AFM image of 100-ML-thick Ge layer grown at

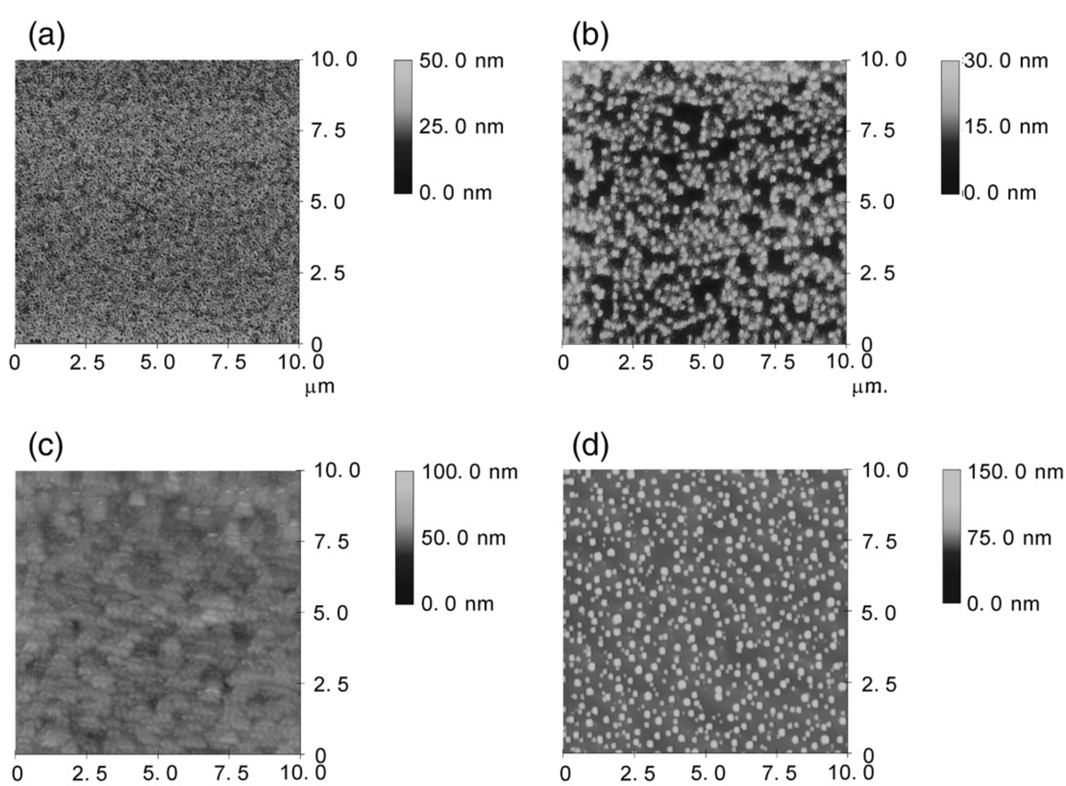

Fig. 1. AFM images of AlSb buffer layer grown on Si(001) substrate. The thickness of the layer is about (a) 8, (b) 40 and (c) 250 nm, respectively. (d) is the AFM image of 100 ML (Ge) grown on Si(001) [8].