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Observation of V-shaped defects in the growth of $In_{0.8}Al_{0.2}Sb/InSb$ layers: Temperature and V/III flux ratio dependences

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Abstract

$In_{0.8}Al_{0.2}Sb/InSb$ layers were grown under various growth temperature and V/III flux ratio conditions on semi-insulating (0 0 1)-oriented GaAs substrates by molecular beam epitaxy. The crystalline qualities of $In_{0.8}Al_{0.2}Sb/InSb$ layers were improved by decreasing the V/III flux ratio at a fixed temperature (380 °C) and increasing the growth temperature of the fixed V/III ratio (6). Dislocations were only observed in the $In_{0.8}Al_{0.2}Sb/InSb$ layers grown at the optimal condition. On the other hand, many planar defects, including microtwins, were observed when the $In_{0.8}Al_{0.2}Sb/InSb$ layers were grown in the Sb-rich condition. Specifically, V-shaped defects drawn boundaries in the microtwins were observed in the $In_{0.8}Al_{0.2}Sb/InSb$ layer.

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1. Introduction

Studies of antimony (Sb)-based compound semiconductors have attracted much attention due to their optical, electrical, and structural properties. Antimonides have the smallest band gaps of any of the III–V compound semiconductors [1,2]. In actuality, devices based on the Sb-based compound semiconductors have shown the high performance [3–5]. Additionally, many of the ternary or quaternary antimonides exhibit interesting structural properties, including spinodal decomposition and ordering phenomenon [6–8].

The InAlSb alloy system covers a range of energy gaps suitable for laser emission throughout the approximately 0.8–7 μm spectral region. The InAlSb epitaxial layers offer a wide range of opportunities for the development of optoelectronic devices, particularly for high frequency and nonlinear optical applications. Potential applications for this system rely on the ability to grow thick defect-free layers of different compositions. This requires a better understanding of the relaxation of the elastic strain. For Sb-based ternary compound semiconductors, studies of structural characteristics have been insufficient and have not been deeply investigated until now.

InAlSb/InSb bilayer and/or superlattice structures have attracted the attention of compound semiconductor researchers because AlSb has the closest match to InSb in lattice parameter (misfit $f = \sim 5.3\%$) and its band gap (1.58 eV) is much larger than that of InSb (0.172 eV). The large band gap difference between the two materials leads to a strong quantum confinement effect even for low concentrations of Al in the barrier layers [9]. InAlSb provides a strain-compensating barrier material for mid-IR interband cascade lasers and other antimonide device structures [10,11]. InAlSb layers have been deposited by a magnetron sputter epitaxy system [12–14] and a molecular beam epitaxy (MBE) method [15–18] and the physical

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properties of the deposited InAlSb layer have been studied by Raman scattering, photoluminescence, etc. [19–21].

Sb-based compound semiconductors have no a good substrate for heteroepitaxy and there is a large difference in lattice constants. The high mismatch between film and substrate results in a high density of defect in the film. In general, the high density of defects degrades the properties of films. Although misfit strain is relaxed by the introduction of misfit dislocations located at the interface when a layer was grown beyond the equilibrium critical thickness, a complete relief of the strain is impossible. As a result, various defects exist in epitaxially grown Sb-based compound semiconductors. To overcome these defaults in the Sb-based semiconductors, many research groups have introduced various buffer systems and growth methods [22–29].

In this study, we investigated the temperature and V/III ratio effects in the growth of InAlSb/InSb layers from a microstructural point of view. We adopted a well-controlled buffer system for high-quality InAlSb/InSb layers. Specifically, we show V-shaped defects related to microtwins and discuss the influence on surface morphology and crystal quality.

2. Experimental process

III-Sb based compound semiconductors have been grown by a MBE. In this study, Riber 32-PMBE system with effusion cells for the III sources and the dual filament cell for antimony (Sb) source was used to synthesize compound semiconductors. The targeted layer structure is shown in Fig. 1.

The targeted structures were deposited on semi-insulating (0 0 1)-oriented GaAs substrates. The growth of the targeted structures was begun from the deposition of an unintentional doped GaAs buffer layer to obtain a smooth GaAs surface. The GaAs buffer layer was grown to a thickness of 200 nm on a GaAs substrate at 530 °C. In the targeted structures, a controlled buffer system was used to grow high-quality layers as reducing the large mismatch f between InSb (and/or InAlSb) and the GaAs substrate (~14.6%). At the initial stage, the GaSb layer considered as a good substrate for Sb-based compound semiconductors was deposited with a thickness of 500 nm on a very thin low-temperature (LT) AlSb buffer (~6 monolayers). The mismatch f was reduced to ~6.3% by using GaSb as the buffer layer for InSb on the GaAs substrate.

In addition, metamorphic buffer (M-buffer) including the compositionally graded $In_xAl_{1-x}Sb$ has been used for the growth of materials having a high indium (In) content on GaAs. The M-buffers for high-speed electrical devices are extensively studied. A few research groups have reported that M-buffer-adopted devices have excellent performances [30,31]. The growth temperatures of M-buffer and the layers above it were 400 and 380 °C in sample A and the sample B and C, respectively. The V/III flux ratios of the sample A and B and the sample C were 6 and 4, respectively. The indium composition x in the $In_xAl_{1-x}Sb$ M-buffer was increased from 0% to 80%. In the targeted structure, the $In_{0.8}Al_{0.2}Sb$ layer was deposited under the same conditions as the M-buffer and the InSb layer was grown at 350 °C for all samples. A strained layer superlattice (SLS) of $In_{0.6}Al_{0.4}Sb$/InSb with 20 periods was introduced to take advantages from a structural and electrical point of views.

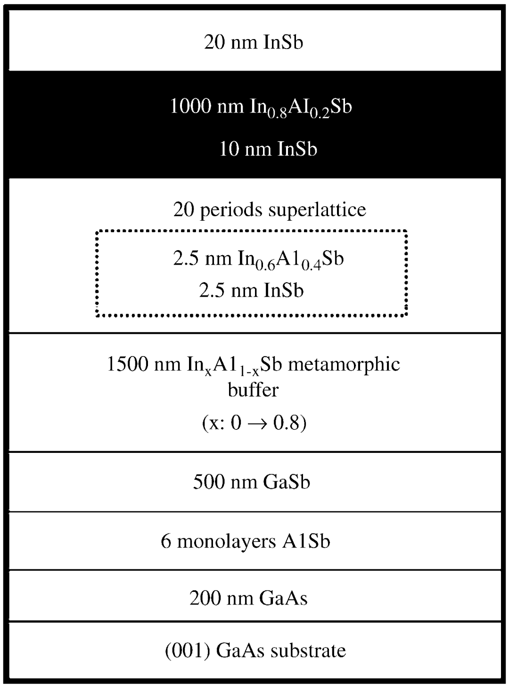

Fig. 1. Targeted $In_{0.8}Al_{0.2}Sb$/InSb layered structure on GaAs substrate. The growth temperatures and the V/III flux ratios of metamorphic buffer (M-buffer) and the layers above it were 400 °C and 6 in sample A, 380 °C and 6 in sample B, and 380 °C and 4 in sample C, respectively.

The grown structures were characterized by several methods for the detailed study of the structural properties. Atomic force microscope (AFM) images of the products were taken with a SPA400AFM of Seiko Instruments Inc (SII). Bright field (BF) images under various conditions and selected area electron diffraction (SAED) patterns for transmission electron microscopy (TEM) study were taken with a JEOL-2000EX and JEOL-3010. Specifically, the microstructural analysis of defects and orientation relationships were deeply treated using TEM. X-ray diffraction (XRD) data were taken using a Rigaku D/max-RC (12 kW) thin-film measurement with a monochromator.

3. Results and discussion

The typical AFM images taken from the targeted layered structures to investigate surface properties are shown in Fig. 2. Sample A, grown at the high V/III ratio (6) and the high temperature (400 °C), shows a smooth surface (Fig. 2(a)). Sample B, grown at the decreased growth temperature (380 °C) and the identical V/III flux ratio (6), has the