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High-quality InSb growth by metalorganic vapor phase epitaxy

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ABSTRACT

We have investigated the electron transport properties and crystallinity of InSb films deposited on GaAs substrates. The films were grown by metalorganic vapor phase epitaxy with trimethylindium and trisdimethylaminoantimony as In and Sb sources. Using a two-step growth method and investigating growth conditions extensively, we found that the electron mobility of films either 1.0 or 1.5 μm thick strongly depended on the temperature at which the first layer (25 nm thick) was grown. The highest mobility, 61,200 $cm^2 V^{-1} s^{-1}$, was obtained at growth temperature of 260 °C and the smallest full-width at half-maximum (FWHM) of the X-ray deflection rocking curve, 205 arcsec, was obtained at 320 °C. These mobility and FWHM values, both of which are for a total InSb thickness of 1.5 μm, are superior to those of InSb films grown by molecular beam epitaxy. Secondary ion mass spectrometry measurements showed that below 340 °C the carbon impurity concentration increased drastically with decreasing growth temperature. This carbon incorporated InSb indicated p-type behavior at low temperature by Hall measurement. These results suggest that high concentrations of carbon impurities compensated the extrinsic electrons generated from InSb/GaAs interfacial dislocations.

1. Introduction

InSb is a candidate material for magnetic and mid-infrared sensors because of its high electron mobility (78,000 $cm^2 V^{-1} s^{-1}$) and because its small direct band gap (0.18 eV) corresponds to the absorption of wavelengths in the range from 3 to 8 μm [1,2]. High-quality InSb films are very important in these sensors, and InSb-based devices are mainly being developed by using molecular beam epitaxy (MBE) [3–5]. Although metalorganic vapor phase epitaxy (MOVPE) is more suitable for mass production, there are few reports of high quality InSb growth by MOVPE.

One reason for this is the narrowness of the temperature range suitable for MOVPE growth of InSb. Trimethylantimony (TMSb), one of the typically used Sb source materials, decomposes only at temperatures above 400 °C, and InSb melts at 525 °C [6]. InSb therefore needs to be grown at temperatures between those values. This temperature range is narrower than that in which typical compound semiconductors like GaAs can be grown [7]. In last two decades, the typical temperature for InSb growth by MOVPE has gone down more than 100 °C because trisdimethylaminoantimony (TDMASb), which decomposes at temperatures over 275 °C, has been used as a new Sb source [8]. Partin et al. reported that the mobility of 1.5-μm-thick InSb grown by MOVPE using trimethylindium (TMIn) and TDMASb is 56,000 $cm^2 V^{-1} s^{-1}$, Yang et al. reported that the mobility of 0.66-μm-thick InSb is 40,300 $cm^2 V^{-1} s^{-1}$ and Biefeld and Phillips reported that the full-width at half-maximum (FWHM) of the X-ray diffraction (XRD) rocking curve for 1.6-μm-thick InSb is 420 arcsec [9–11]. These properties, however, are inferior to those of InSb grown by MBE [12].

In the work reported in this paper, we used a two-step method for InSb growth and investigated growth conditions extensively. We found that good crystallinity and electrical transport properties can be obtained by growing an interface layer at an extremely low temperature.

2. Experimental procedures

InSb was grown on semi-insulating GaAs (001) substrates by using an AIXTRON close-coupled showerhead reactor system. TMIn and TDMASb were used as In and Sb sources, and their bubbler temperatures were set at 18 and 25 °C, respectively. The growth pressure was maintained at 100 mbar with purified H_2 as a carrier gas. Prior to the growth, the GaAs substrate was thermally annealed for 10 min under tertiarybutylarsine (TBAs) vapor at 650 °C and this annealing was followed by GaAs homoepitaxial growth at the same temperature. The growth temperature on the substrate surface was monitored by using a two-wavelength pyrometer. Two kinds of growth procedures were used in this study: single-step growth and two-step growth with a very thin

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first layer. In the single-step growth, InSb was grown at a constant temperature and the V/III ratio was kept to 7.0. In the two-step growth, a 25-nm layer was first grown at a temperature between 240 and 360 °C and the second layer was then grown at 500 °C. The V/III ratio was kept to 7.0 and the film was grown to a total thickness of either 1.0 or 1.5 µm.

Thickness was estimated by X-ray fluorescence analysis with the fundamental parameter method. The surface morphology of films was measured by atomic force microscopy (AFM). The electron mobility and carrier concentration were measured using the van der Pauw method. The crystallinity of the epitaxial films was evaluated using XRD. Secondary ion mass spectrometry (SIMS) was used to clarify the concentrations of incorporated carbon and oxygen.

3. Results and discussion

First we prepared and studied 600-nm-thick InSb films grown, in a single step, at growth temperature ranging from 260 to 480 °C. The root-mean-square surface roughness (R_{rms}), the electron mobility and the FWHM of the XRD rocking curve are shown in Fig. 1 as functions of the growth temperature. The R_{rms} decreased monotonically with decreasing temperature, whereas the mobility was highest at 380 °C and the FWHM was smallest at 340 °C. These values are inferior to that of MBE [12].

Fig. 2 shows AFM images of films grown in a single-step at (a) 260 °C, (b) 360 °C and (c) 460 °C. One sees that the film obtained at the lowest temperature had a flat surface because of its micro-crystal grain size but had poor crystallinity presumably due to insufficient adatom migration. The films obtained at the higher temperatures, on the other hand, had rough surfaces and poor characteristics because of three-dimensional island growth. In brief, there was a trade-off relationship between surface flatness and crystallinity. We therefore used a two-step growth method with only the first 25 nm grown at a low temperature and the upper layer grown at high temperature to enhance surface adatom migration. The surface of an InSb film grown in two steps is shown in Fig. 2(d), where one clearly sees atomic step-and-terrace structure. This result proves that a two-step method is very effective for growing InSb with a smooth surface.

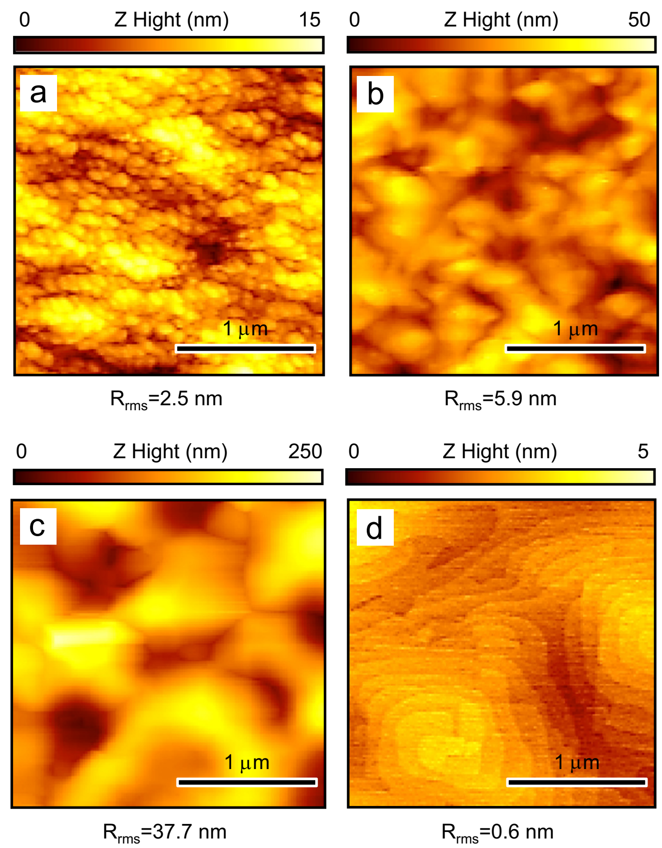

Fig. 2. AFM images comparing films grown in a single step at (a) 260 °C, (b) 360 °C or (c) 460 °C and (d) a film grown in two steps (first layer grown at 360 °C and upper layer grown at 500 °C).

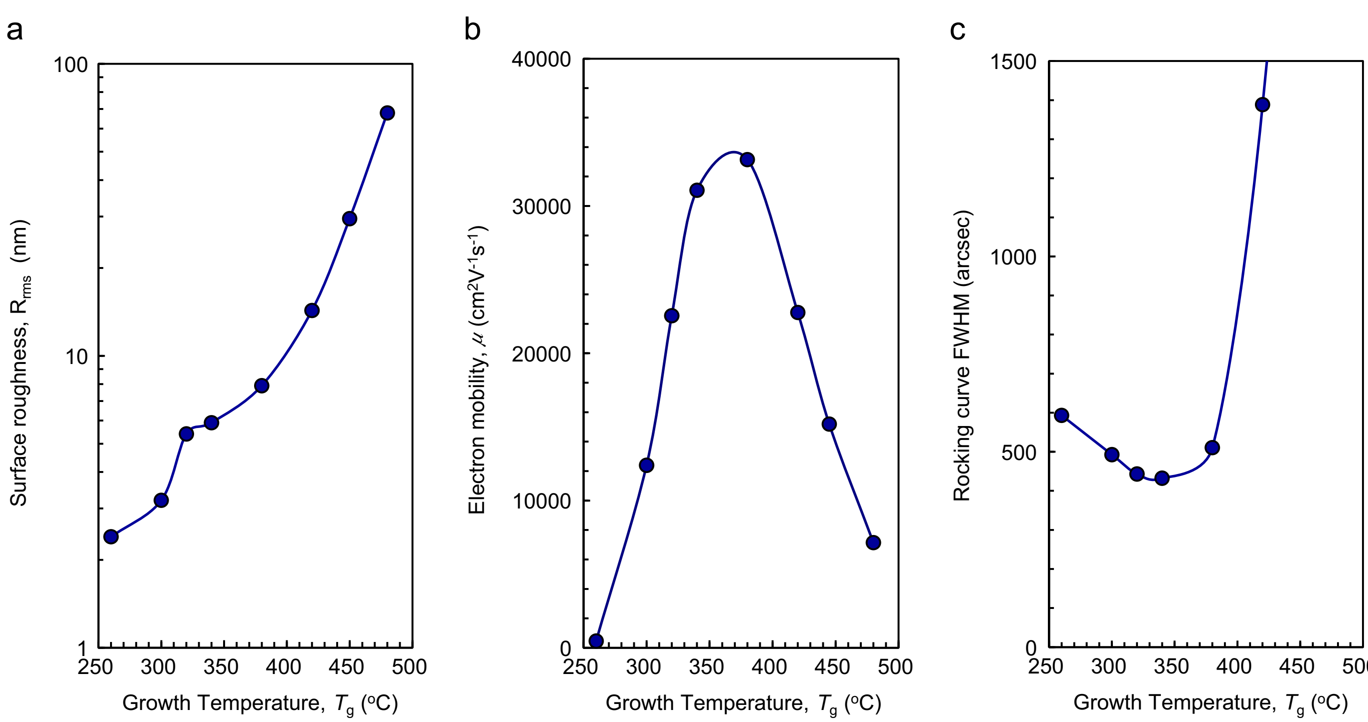

Fig. 1. Relations between growth temperature and the characteristics of InSb films grown on GaAs substrates by MOVPE: (a) surface roughness, (b) electron mobility, and (c) FWHM of X-ray rocking curve.