Low-temperature transport properties of InSb films on GaAs(100)substrates

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Abstract

Low-temperature magnetoresistance (MR) has been studied for undoped and Sn-doped InSb thin films grown on GaAs(100) substrates by MBE. Sn-doped films show the Shubnikov-de Haas oscillations which reflect a large g-factor ($g^*\sim$ -40 depending on the carrier concentration) of electrons in InSb films. In undoped films, on the other hand, almost whole carriers fall into the accumulation layer at the InSb/GaAs interface at low temperatures, resulting in the advent of positive MR arising from the two-dimensional weak anti-localization due to spin-orbit interaction.

Key words: InSb films on GaAs, Shubnikov-de Haas oscillations, accumulation layer, weak anti-localization, spin-orbit interaction

1. Introduction

InSb has been useful for potential device applications, such as magnetic-field sensors [1,2] and high-speed devices [3] because of its highest mobility in III-V semiconductors. For device applications, InSb thin layers are often grown on semi-insulating GaAs by means of the molecular beam epitaxy (MBE) [2,4,5] and the metal-organic chemical vapor deposition (MOCVD) [6]. However, the growth on GaAs substrates is accompanied by high-density misfit dislocations (dangling bonds) at the InSb/GaAs hetero-interface because of the large mismatch of lattice constants between InSb and GaAs, producing the extraordinarily large carrier accumulation at the interface [5–7]. In this paper, we reveal the characteristic transport phenomena at low temperatures in InSb thin films grown on GaAs(100) substrates by MBE. Sn-doped films show the Shubnikov-de Haas oscillations which reflect a large g-factor depending on the carrier concentration of electrons in InSb films [8]. In undoped films, on the other hand, almost whole carriers fall into the accumulation layer at the InSb/GaAs interface at low temperatures, resulting in the advent of positive MR which arises from the two-dimensional (2D) weak anti-localization (WAL) due to spin-orbit (SO) interaction caused by the underlying band structure.

2. Results and Discussion

InSb thin films were grown directly on the semi-insulating GaAs(100) substrate, ignoring the large lattice mismatch of about 14 %. The films studied in this work are the Sn-doped and nominally undoped ones whose thickness is 1μm.

In four Sn-doped films with the sheet carrier density ranging $n_s = 5.5\ 10^{12} \sim 2.8\ 10^{13}$ cm^{-2} (degeneracy temperature $T_d = 480 \sim 1300$ K, respectively), Shubnikov-de Haas (SdH) oscillations which reflect a large g-factor ($g^*\sim$ -40 depending on the carrier concentration [8]) of electrons in InSb films have been observed in every configuration of magnetic field at liquid He temperatures. Fig.1 shows the SdH oscillations observed in the transverse magnetoresistance (MR) under in-plane magnetic-field configuration. The periods

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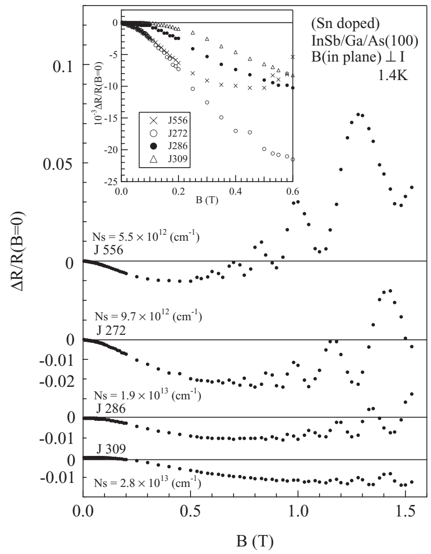

Fig. 1. SdH oscillations in the transverse magnetoresistance (MR) under in-plane magnetic-field configuration for four Sn doped films. Inset: negative MR observed in weak magnetic fields before the appearance of the SdH oscillations are relatively shown.

in B^{-1} plots of the SdH oscillations are well explained with the effective mass of electrons in bulk InSb ($m^*= 0.014m$). The negative MR observed in weak magnetic fields before the appearance of the SdH oscillations is inexplicable at present.

The analysis of temperature dependence of the Hall coefficient (at $B = 0.05$ T) for an undoped film shows the existence of two types of carriers: one is the intrinsic carriers in InSb film and the other is low-mobile carriers in the accumulation layer at the InSb/GaAs interface which dominate the low-temperature transport [5,6,9]. Effective thickness d of the accumulation layer is estimated as $\sim$18 nm from the magnetic field ($\sim$ 7.5 T) where the classical MR with B^2 dependence starts ($2dl_B$) under in-plane field configuration.

The positive MR data (the decrease of sheet conductance) in magnetic fields perpendicular to the film plane are shown in Fig. 2. The low-temperature MR shows a steep rise in weak magnetic fields arising from the WAL due to SO interaction caused by the underlying band structure, reaching a maximum at abut 0.3 T. After that it gradually decreases taking a minimum and finally increases with increasing magnetic field. The maximum of the MR becomes smaller (but recognizable) as temperature increases to about 80 K. These MR data can be explained by the 2D WL theory including SO and spin-flip scattering time (τ_{so} and τ_s) [9]. The best fits cannot be obtained, however, without taking the Zeeman effect into account [9]. In order to improve the fits, it is plausible that the interplay between the Zeeman effect and SO scattering should be

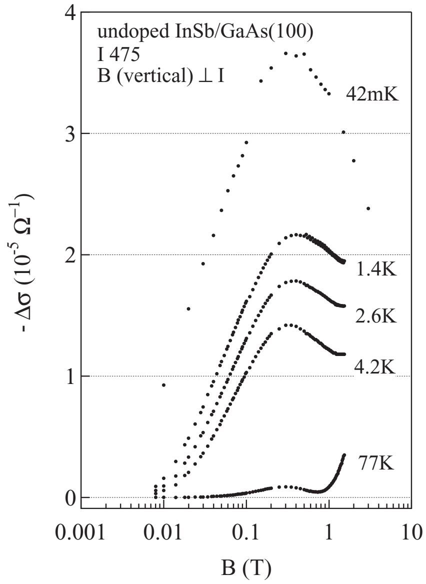

Fig. 2. Decrease of the sheet conductance in magnetic field perpendicular to the film at various temperatures.

taking into account in the final analysis [10] because of the large g-factor of electrons in InSb films. Rough estimates for inelastic scattering time τ_i as well as τ_{so} and τ_s have been made from the fits without the Zeeman effect for the present: $\tau_{so} \sim 5\ 10^{-13}$ s, $\tau_s \sim 10^{-9}$ s and τ_i T^{-2} (for T 1K) . The T^{-2} dependence of τ_i appears to reflect the electron-electron interaction in a 2D system in the pure limit.

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