High-mobility thin InSb films grown by molecular beam epitaxy

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The problem of preparing high-mobility thin InSb films is revisited for magnetoresistive and spintronic sensor applications. We introduce a growth process that significantly improves the electrical properties of thin unintentionally doped InSb layers (60–300 nm) epitaxially grown on GaAs(100) substrates by reducing the density of dislocations within the interfacial layer. The epilayer properties are well described by a differential two-layer model. This model confirms that the contribution of the interface can only be donor-like. Moreover, the electrical properties of the InSb layers change continuously away from the interface up to sample thickness of the order of 1 μm. © 2004 American Institute of Physics. [DOI: 10.1063/1.1748850]

The electrical properties of InSb have been of interest for decades due to the narrow band gap, low effective mass, and high mobility, μ. Interest in this material has been rekindled recently by the discovery of extraordinary magnetoresistance (EMR) in a composite metal–semiconductor structure, which has made possible the fabrication of entirely different types of macroscopic magnetic sensors for read head applications.1–12 As the EMR effect at low magnetic field, B, is proportional to (μB)2, it is desirable to have a material that has high RT mobility. A thin surface-active region is preferred in order to maximize the effective information storage medium bit field. High mobility thin InSb is also interesting for spintronic applications because of the high spin-orbit coupling and large electron g factor (~50.6). Recent measurements of the spin lifetime in n-type degenerate epilayers of InSb are encouraging, suggesting a RT spin lifetime of the order of 300 ps.

Unfortunately, InSb itself cannot be used as a substrate due to its very large parallel conduction. Semi-insulating GaAs has been widely employed as the substrate for InSb growth.4–11 The main obstacle to acquiring high mobility of the hybrid system comes from the strain at the InSb/GaAs interface due to the large lattice mismatch of 14.6%, which is particularly detrimental to thin films. Kanisawa et al.12 obtained high mobility thin InSb layers on GaAs(111)A substrates by a two-step growth process (referred to as the “NTT recipe”). Nevertheless, this technique failed to improve InSb films grown on GaAs(100). In this letter, we describe the results of a method for InSb growth by molecular beam epitaxy (MBE). It is greatly helpful to the improvement of unintentionally doped InSb layers (60–100 nm) directly grown on GaAs(100) substrates by producing smoother surfaces and reducing the dislocation donor density.

Thin InSb films were deposited on semi-insulating GaAs(100) substrates in a VG Semicon V80 MBE chamber. Reflection high-energy electron diffraction (RHEED) was used for in situ calibration of the V/III flux ratio, i.e., Sb3/In, and monitoring InSb surface morphology. The growth procedure in this work, referred to as the “Imperial recipe,” follows the two-step mode of the NTT recipe with some additional treatment. First of all, a GaAs buffer layer was not required, as it shows no apparent improvement of mobility. The growth rate of InSb was kept at 0.66 μm per hour. It has been reported that, for low substrate temperature (Tsub <400 °C), two-dimensional mirror-like InSb was obtained under a low V–Ill flux ratio (1–2.5).13,14 This is due to the lower volatility and longer surface lifetime of Sb compared to As under these circumstances. An optimized Sb3/In flux ratio of 1.3 was employed throughout the work as it always provides the highest mobility samples.

The present work lies in the optimization of the LT layer thickness and an additional anneal step. The LT growth of undoped InSb (20 nm) was performed at the minimum temperature capable of maintaining binary growth, which in our case was found at 300 °C.13 The growth of 20 nm of InSb at the LT stage always started in the Volmer–Weber mode, i.e., three-dimensional. The RHEED patterns remained spotty and streaky patterns started to appear at the end of the LT stage. The sample was then annealed at a specified temperature for fixed time. Streaky patterns of (1×3) reconstruction were observed. The temperature was then adjusted for the HT growth step. In order to determine the optimum temperature for the HT growth step, a series of 300-nm-thick InSb epilayers was studied as a function of growth temperature by the measurement of RT mobility and full width at half maximum of the x-ray rocking curves.13,14 As a result, the HT growth of a set of InSb films (60 nm–2 μm), was performed at the optimized temperature of 380 °C. At the conclusion of the growth, the Sb3 flux was sustained until the sample temperature fell to 290 °C. The growth temperature was calibrated by monitoring the “system-measured” temperature at which the surface reconstruction during homoeptaxial growth changed between “pseudo (1×3)” and (2×4) when the samples were cooled from the annealing temperature to that of the HT step. The temperature was also periodically

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concentration, subscript 1 now refers to the interfacial layer. Note that sheet the usual and Hall sheet conductivities, respectively. The give a zero field This was attained using the constraint that the parameters a best fit to the experimental data can be easily achieved. interfacial layer. Assuming the interfacial layer is donor-like, to the experiment data could not be achieved, a fit measured value. If the interfacial layer is acceptor-like a best fit ~thin InSb films grown on GaAs ~donor-like and electrical properties of the layer change con-
tinuously away from this interface, which is consistent with the expected dislocation density distribution in this material.

To summarize, the electrical and structural properties of thin InSb films grown on GaAs(100) by an improved growth method have been investigated. Although three-dimensional island growth cannot be suppressed, we have greatly improved the electrical properties over a thickness range around 100 nm. The two-layer model with its high-field approximation demonstrates that the InSb at the interface with GaAs is donor-like and electrical properties of the layer change con-

\[ \sigma_{xx} = \frac{n_s e \mu_2}{1 + (\mu_2 B)^2} + \frac{n_1 e \mu_1}{1 + (\mu_1 B)^2}, \]

where \( \rho_{xy} \) is the Hall sheet resistivity, and \( \sigma_{xx} \) and \( \sigma_{xy} \) are the usual and Hall sheet conductivities, respectively. The subscript 1 now refers to the interfacial layer. Note that sheet concentration, \( n_s \), are employed in Eqs. (3) and (4), instead of bulk values. Figure 3 shows the experimentally obtained RT values of \( \rho_{xy} \) for a 100 nm InSb film with a 20 nm LT interfacial layer. Assuming the interfacial layer is donor-like, a best fit to the experimental data can be easily achieved. This was attained using the constraint that the parameters give a zero field \( \rho_{xy} \) equal to that of the experimentally measured value. If the interfacial layer is acceptor-like a best fit to the experiment data could not be achieved, a fit (weighted to the low field region) is shown by the dash line in Fig. 3.

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FIG. 2. Fitting of RT mobility and carrier concentration (open squares) as a function of thickness with differential two-layer model. For comparison, the apparent values are—experimental (solid squares) also shown in the same graphs.

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FIG. 3. Experimental RT Hall sheet resistivity (solid circles) for a 100 nm InSb film with a 20 nm LT interfacial layer as a function of applied magnetic field, with best fits for donor- (solid line) and acceptor-like (dash line), interfacial layers using a two-layer model at high field. The inset shows \( (\rho_{xx}/R_H)B \), where \( R_H \) is the low field Hall coefficient, as well as its corresponding best fits.

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