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Optical and transport properties of InSb thin films grown on GaAs by metalorganic chemical vapor deposition

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Abstract

Optical and transport properties of InSb thin films grown on GaAs by metalorganic chemical vapor deposition (MOCVD) have been investigated by far-infrared (FIR) reflectance spectroscopy. The lattice vibration behaviors of a series of MOCVD InSb/GaAs(100) materials grown under different growth conditions were studied. Effects of III–V source ratios on the films crystalline quality were examined. Two additional weak modes in the wavenumber regions of 210–240 cm^{-1} were observed and they appeared more prominent at low temperatures. Interference fringe effects modify the FIR reflectance band of the GaAs substrate, which are related to the uniformity of film thickness and crystalline perfection. The dielectric constant, phonon modes and other optical parameters, as well as transport properties including carrier concentration, mobility, effective mass were calculated theoretically and compared with experimental results. The obtained distribution values of the InSb LO phonon mode frequency, line width, relative integrated intensity ratio between the forbidden and defect-related TO phonon and the allowed LO mode are adopted as figures of merit for the quality of the InSb films. The electrical transport properties of carrier concentration, mobility, and effective mass as well as the dielectric constant of these films have been determined by optical method non-destructively.

Keywords: Metalorganic chemical vapor deposition (MOCVD); Characterization; InSb; GaAs; Fourier transfer infrared spectroscopy

1. Introduction

InSb has important applications in infrared, optical, microwave, and millimeter-wave devices [1–4]. It is a narrow gap semiconductor with a low effective mass and possesses the highest electron mobility among III–V compound semiconductors, which makes it very suitable for high-speed devices, magnetic sensors and so on [2,3]. InSb-based thin films are especially promising in the fabrication of long wavelength infrared detectors, and wavelengths greater than 12 μm can be detected with these compounds based photodiodes at 77 K [5]. For the preparation of InSb thin layers on GaAs substrate, it is required to have special technological treatments to overcome the large lattice mismatch of ~ 14.6% between InSb and GaAs and to ensure their growth quality with specified electrical as well as optical properties of the layers [3,4]. There have been a number of studies on this material concerning the growth and optical characterization of InSb based compound semiconductors [6–8]. Efforts of the growth of these materials on GaAs substrate have been explored by various growth technique, such as molecular beam epitaxy (MBE) [3,4,9–12], liquid phase epitaxy (LPE) [13], magnetron sputter epitaxy [14], metalorganic vapor phase epitaxy (MOVPE) or metalorganic chemical deposition (MOCVD) [15–17]. But there lacks penetrating investigation on transport and lattice behaviors of these epitaxial materials.

Metalorganic vapor chemical deposition (MOCVD) technology has been shown a good technology to produce large size InSb thin film materials on GaAs substrate for industrial infrared and automobile applications [15–18].

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In this paper, far-infrared (FIR) reflectance spectroscopy has been employed to study the lattice vibration behavior for a series of MOCVD-grown InSb films on GaAs substrates. From these MOCVD films, the effects of III–V source ratios on the film crystalline quality have been investigated.

2. Experimental

The experimental MOCVD InSb epitaxial films were grown on commercial GaAs (100) substrates. Trimethyindium (TMIn) and Tris-dimethylamino-antimony (TDMASb) were used as In and Sb sources, respectively. The indium and antimony bubblers were operated at 429 and 323 Torr, respectively. Flows through the indium and antimony bubblers were varied from 130 sccm to 270 sccm and the carrier H_2 gas flow were in the range of 320–775 sccm, respectively. Growth rates investigated were between 0.65 and 1.2 μm/h with an optimum growth rate of around 0.95 μm/h. Growth temperature was monitored using a single wavelength low temperature pyrometer. Samples N01-08 were prepared at a III–V ratio of between 4.2 and 4.5. Runs at these III–V values typically showed indium droplets on the surface of the film after growth. A second set of growth runs starting with run sample N09 was done using an III–V ratio of 6.2. These growths have resulted in surfaces with excellent morphology that were typically free of indium droplets. For all epitaxial InSb samples, a variety of characterization measurements have been performed, including surface morphology, Hall measurements, RF sheet resistivity, scanning electron microscopy (SEM), etc.

The far-infrared reflectance spectra were measured at near normal incident in far-infrared range, 60–500 cm^{-1}, by a BRUKER IFS 120HR Fourier transform infrared (FTIR) spectrometer at different temperatures between 80 and 300 K with the spectral resolution better than 1 cm^{-1}. Mercury-Arc lamp was used for infrared light source. A mirror-like gold plate was mounted next to the samples on the cold finger of cryogenic. The absolute reflectivity value of sample was determined by comparison with the gold mirror. An APD cryogenic system was employed to the temperature-dependent measurements. The temperature of finger tip inside the cryogenic

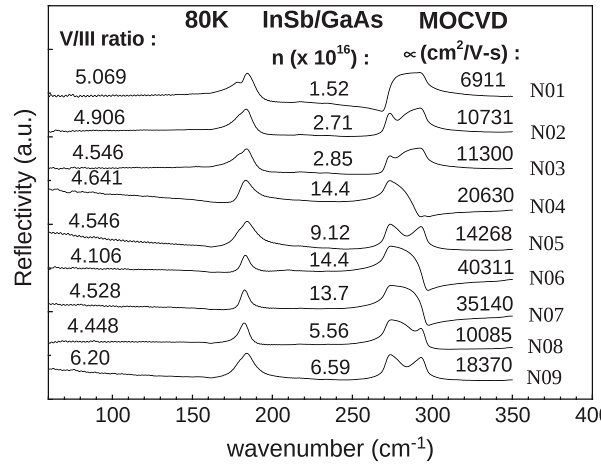

Fig. 1. FIR reflectance spectra of nine InSb/GaAs samples, measured at 80 K.

was controlled by a Lake-Shore 331 temperature controller with a temperature stability of 0.5 K or better.

3. Results and discussion

3.1. Experimental far-infrared spectra of MOCVD films

III–V source ratio has an important influence on the resulting epitaxial InSb films. Behet et al. [15] studied the dependence of InSb growth rate on III–V ratio in low-pressure (20 Pa) plasma MOVPE with triethylantimony (TESb) as Sb precursor. In this work, a series of InSb thin films were grown on GaAs under different III–V ratio conditions. The experimental values of III–V ratio and resulted sample surface Normaski microscopy and thickness uniformity are given in Table 1. Samples N01-N08 were grown with III–V ratio of 4.1–5.1. InSb films prepared at these III–V values typically showed indium droplets on the surface of the films after growth. Sample N09 was made using a III–V ratio of 6.2. This growth with a high III–V ratio had resulted in surfaces with excellent morphology that typically free of indium droplets. Hall measurements, sheet resistivity, SEM, and mid-infrared spectrum measurement for thickness showed a high thickness uniformity distribution, high mobility of the films which are very good for fast speed electron device applications.

Table 1
III–V ratio, surface morphology, thickness uniformity of samples

Sample No	N01	N02	N03	N04	N05	N06	N07	N08	N09
III–V ratio	5.069	4.906	4.546	4.641	4.546	4.106	4.528	4.448	6.20
Surface morphology	In-rich/ droplet	Sb-rich/ big lots	In-rich/ droplet	Good/ less drop	Good/ no drop	In-rich/ droplet	Good/ no-drop	Sb-rich/ less drop	Good/ no drop
Thickness uniformity (%)	6.06	6.16	7.81	6	6.88	2.59	1.69	3.29	4.76