

Epitaxial InSb(111) layers on Sb(111) substrates characterised by Raman spectroscopy

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

1989 J. Phys.: Condens. Matter 1 SB93

(<http://iopscience.iop.org/0953-8984/1/SB/016>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 129.252.86.83

The article was downloaded on 27/05/2010 at 11:11

Please note that [terms and conditions apply](#).

Epitaxial InSb(111) layers on Sb(111) substrates characterised by Raman spectroscopy

U Rettweiler†, W Richter†, U Resch‡, J Geurts‡, R Sporcken§,
P Xhonneux§|| and R Caudano§

† Institute of Solid State Physics, Technical University, Berlin, Federal Republic of Germany

‡ I. Physikalisches Institut, Rheinisch-Westfälische Technische Hochschule, Aachen, Federal Republic of Germany

§ Laboratoire Interdisciplinaire de Spectroscopie Electronique, Facultés Universitaires Notre-Dame de la Paix, Namur, Belgium

Received 20 April 1989

Abstract. InSb overlayers on Sb, obtained by UHV deposition of In onto heated substrates, are analysed by Raman spectroscopy. Well defined peaks from the InSb phonons are observed already at five monolayers coverage. The phonon frequencies of the overlayer as well as the substrate show shifts which reveal the following strain: compressive in the InSb overlayer and tensile in the Sb substrate top region. Also, the InSb LO intensity shows an anomalous behaviour for thin coverages, possibly due to the gradual development of the InSb electronic band structure.

1. Introduction

The still increasing miniaturisation of microelectronic devices and the search for novel semiconductors and semiconductor devices is stimulating extensive research activity on the formation and properties of semiconductor interfaces. III–V compound semiconductors play an important role in this field because of their application in some high-speed devices and owing to their fundamental interest related to the physical properties of artificial structures such as compositional superlattices.

In this paper, we report the formation of the interface which is obtained when a group III metal (In) is deposited on a group V semimetal (Sb). The substrates are Sb single crystals, cleaved perpendicular to their *c* axis and heated at 600 K during the In deposition. It has been shown in previous publications [1, 2] that InSb can be grown epitaxially on Sb following this procedure. This was deduced from classical surface-sensitive techniques such as photoelectron spectroscopy, Auger electron spectroscopy (AES) and low-energy electron diffraction (LEED). Using the same techniques, it has been shown that AlSb can also be grown epitaxially on Sb(111) substrates by simply evaporating Al onto heated Sb(111) single crystals [3, 4]. This means that some III–V semiconductors can be grown and analysed *in situ* very easily, without the need for

|| Present address: Institute of Semiconductor Research, Technical University, Zürich, Switzerland.

sophisticated techniques such as molecular beam epitaxy (MBE) or metallo-organic vapour phase epitaxy. We believe that a similar method would also be useful for the fabrication of other epitaxial materials such as metal silicides on Si. The reason why InSb or AlSb can be grown epitaxially on Sb(111) is that the (111) planes of both Sb and InSb or AlSb have a threefold symmetry with a lattice mismatch of 0.3% for AlSb and 6% for InSb within the planes.

Here we describe a Raman spectroscopy study of InSb layers with various thicknesses on Sb(111). This technique combines the potential of optical techniques to probe through quite thick layers (100 monolayers (ML)) with the sensitivity to coverages of a few ML.

2. Experimental details

The Sb substrates were obtained by air cleavage of crystals from Metal Crystals and Oxides Ltd (purity, 99.999% Sb) or from Rheinisch-Westfälische Technische Hochschule, Aachen. Subsequently they were loaded into the UHV system. This system has been described in more detail elsewhere [5]. The samples were cleaned *in situ* by a few cycles of gentle Ar⁺ ion sputtering (5 min; 500 eV; 1 $\mu\text{A cm}^{-2}$) and annealing at 550 K. The sample cleanliness was checked with AES, and a well defined (1×1) LEED pattern was observed. In was evaporated from a Knudsen cell at a base pressure in range of 10^{-8} Pa. The substrate temperature during deposition was 600 K. The thickness of the deposited film was determined from the evaporation rate which was calibrated using a quartz thickness monitor and corrected for the difference between the quartz and sample position according to a r^2 dependence. All the thicknesses quoted here are given in ML. One ML is defined here as the number of Sb atoms in an InSb(111) layer on Sb(111) (One ML equals 6.22×10^{14} atoms cm^{-2}).

A set of samples with InSb layer thickness between five ML and 170 ML was prepared for this study. In the Raman experiments the Ar laser line at 20141 cm^{-1} was used for resonance at the $E_1 + \Delta_1$ gap of the InSb. The samples were cooled at 90 K in a liquid-nitrogen cryostat. The Raman experiments were performed in back-scattering geometry. A Spex double monochromator with a GaAs photomultiplier was used to record the spectra.

3. Results

Raman spectra taken in the unpolarised configuration for different thicknesses of InSb layers are shown in figure 1. On the clean substrate, two peaks belonging to the E_g and A_{1g} mode of Sb appear. At coverage of five ML the TO and LO phonon modes of InSb are observed. Their strength increases with increasing InSb layer thickness, while simultaneously the intensity of both Sb phonons decreases owing to the light absorption in the InSb layer. However, we observe that the InSb phonon intensities increase at different rates; the LO-to-TO intensity ratio changes from 1 to 4 at five ML to 3 to 1 at 100 ML. The latter ratio was also observed in a reference experiment using a bulk sample. The phonon linewidth at 100 ML also corresponds to the bulk value, thus indicating good crystal quality of the layer. The observed variation in the intensity ratio shows that the increasing phonon intensity cannot be for both LO and TO just a result of the increasing scattering volume. It is also worth pointing out in figure 1 the weak and broad structure in between the Sb phonons, which is observed in the samples with InSb coverage of 10

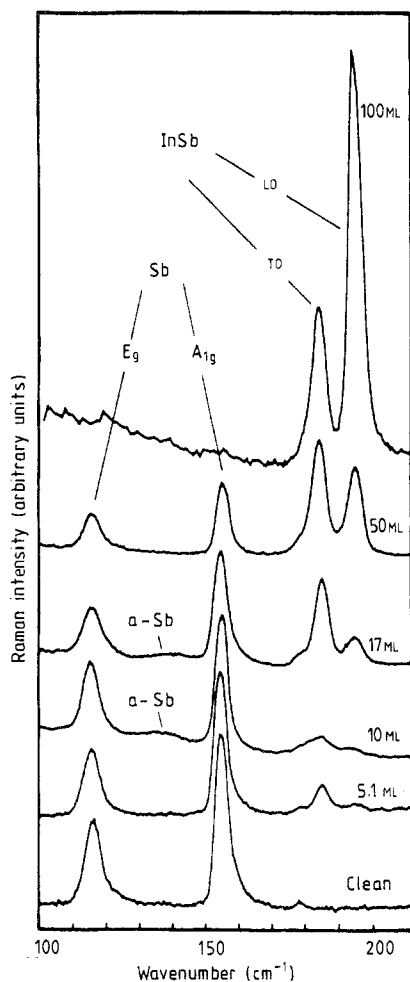


Figure 1. Raman spectra from the Sb E_g , A_{1g} and the InSb TO and LO phonons for Sb substrates, covered with InSb layers of different thicknesses.

and 17 ML. From its frequency and linewidth this structure strongly indicates that some amorphous Sb might exist in these two samples [6]. Finally, the background in the 100-ML spectrum, which increases strongly at low wavenumbers reflects the fact that the surface roughness increases with increasing layer thickness, leading to more diffusely scattered laser light.

In addition, the phonon frequencies show a slight dependence on the overlayer thickness. Since this is not resolved on the wavenumber scale in figure 1, the phonon peak positions are plotted on an enlarged scale against overlayer thickness in figure 2. In InSb there is an upward shift for the thinnest overlayers which is most pronounced for the TO phonon while, for Sb, only the E_g phonon shifts. The shifts indicate a thickness-dependent biaxial strain in the overlayers as well as in the uppermost substrate region, which mainly influences the vibration modes parallel to the interface. The sign of the frequency shifts predicts a compressive stress in the InSb [7] and a tensile stress in the uppermost part of the Sb substrate [8]. This is in agreement with the lattice mismatch; the interatomic distance at the Sb substrate face is 6% below that for the InSb(111) plane. A stress of the order of kilobars can be estimated at an InSb coverage of five ML

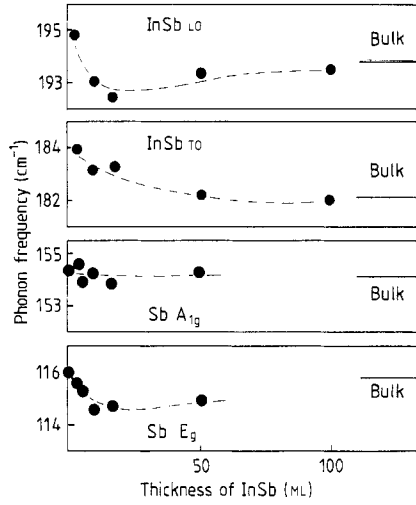


Figure 2. Peak positions of the InSb and Sb phonons plotted against InSb layer thickness.

by using the phonon deformation potentials in [6]. The strain in the uppermost region of the Sb can be explained in terms of its layer-like crystal structure.

Polarised experiments showed that the TO scattering is mainly due to the allowed deformation potential mechanism, whereas the LO scattering has a strong contribution from the forbidden diagonal scattering.

4. Discussion

We have shown from phonon linewidths, intensities and frequencies that, with this very simple method, InSb can be grown whose quality at least equals bulk Czochralski-grown InSb. The interesting fact still to be explained, however, is the anomalous intensity development of the InSb TO and LO phonons with layer thickness. Under the assumption of a constant scattering cross section S_j the increase in the intensity of the overlayer phonons as well as the decrease in the intensity of the substrate phonons should be governed solely by the absorption constant K and thickness d of the overlayer. One obtains for the substrate phonon intensity

$$I_{\text{Sb}}(A_{1g}, E_g) = S_{A_{1g}, E_g} \exp(-2K_{\text{InSb}}d) \quad (1)$$

and similarly for phonons from the overlayer

$$I_{\text{InSb}}(\text{LO}, \text{TO}) = S_{\text{LO}, \text{TO}}[1 - \exp(-2K_{\text{InSb}}d)]. \quad (2)$$

Equation (1) can be used to determine the absorption constant K_{InSb} of the overlayer via the intensity decrease of the substrate phonons. With the data from figure 1, one obtains an absorption constant K of $6 \times 10^5 \text{ cm}^{-1}$ in good comparison with data from literature [9]. This allows us to predict from equation (2) the intensity of the InSb phonons as a function of the layer thickness. The result is displayed as a full curve in figure 3. The intensities are normalised to their infinite-coverage values. Clearly the experimentally observed TO phonon intensity follows closely the dependence given by equation (2). This shows that the assumption of a constant scattering cross section is justified in this case. The LO phonon, however, apparently does not follow the full curve. Consequently,

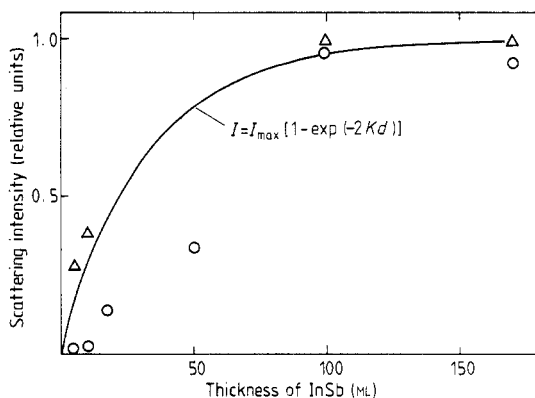


Figure 3. InSb phonon intensities plotted against layer thickness. —: calculated values for a constant cross section; experimental values: Δ , $3I_{TO}$; \circ , I_{LO} .

the cross section must depend on the layer thickness. Since we are dealing here with forbidden LO phonon Raman scattering which is strongly resonance enhanced at the E_1 or $E_1 + \Delta_1$ gaps [10], we believe that the cross section increase with increasing layer thickness is caused by changes in the electronic states. For very thin layers the density of electronic inter-band transitions or their matrix elements might not yet be fully developed to bulk values. Although the TO resonance, which is mainly determined by deformation potential contributions, is not sensitive to the details of the electronic transitions, the LO phonon resonance shows a strong dependence [11]. It would therefore be extremely interesting to check on this hypothesis by testing the dielectric function of these very thin overlayers by a different experimental method. Spectroscopic ellipsometry is probably a technique well suited to this purpose.

References

- [1] Sporcken R, Louette P, Gérard J, Caudano R and Delrue J P 1987 *Fresenius Z. Anal. Chem.* **329** 370
- [2] Sporcken R, Louette P, Caudano R, Barth J, Ghijsen J, Johnson P L and Richter H W 1987 *J. Vac. Sci. Technol. B* **5** 1057
- [3] Sporcken R, Xhonneux P, Caudano R and Delrue J P 1988 *J. Vac. Sci. Technol. A* **6** 1565
- [4] Sporcken R, Thiry P A, Xhonneux P, Caudano R and Delrue J P 1989 *Appl. Surf. Sci.* at press
- [5] Sporcken R 1988 *PhD Thesis* Namur, Belgium
- [6] Lannin J S 1977 *Phys. Rev. B* **15** 3863
- [7] Anastassakis E 1981 *J. Raman Spectrosc.* **10** 64
- [8] Richter W, Fjeldly T, Renucci J and Cardona M 1978 *Lattice Dynamics* ed. M Balkanski (Paris: Flammarion Sciences) p 104
- [9] Aspnes D E and Studna A A 1983 *Phys. Rev. B* **27** 985
- [10] Richter W 1976 *Springer Tracts in Modern Physics* vol 78 (Berlin: Springer) p 236
- [11] Yu P Y and Shen Y R 1974 *Proc. Int. Conf. Physics of Semiconductors (Stuttgart) 1974* (Stuttgart: Teubner) p 453