Structural Investigations of $InAs/Ga_{1-x}In_xSb$ Strained-Layer Superlattices

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$InAs/Ga_{1-x}In_xSb$ superlattices have been grown on GaAs substrates on relaxed GaSb buffer layers. The best structural properties were obtained when the buffer layer was more than 1 μm thick. The structural properties benefited from the use of In contents, $0 < x < 0,3$ in the $Ga_{1-x}In_xSb$ superlattice layers and the preparation of InSb-like interfaces.

1. Introduction

Strained-layer superlattices are interesting semiconductor materials that in recent years have been suggested for various applications [1, 2]. Of particular interest are the type-II superlattices, where one material confines the electrons and the other confines the holes, e.g. $InAs/Ga_{1-x}In_xSb$ and $InSb/InAs_{1-y}Sb_y$ (Figure 1). In such structures it becomes possible to achieve transition energies between electron and hole levels that are smaller than the host materials' band gaps. A considerable body of work has been devoted to both theoretical and experimental exploration of these materials [3, 4]. Several problems are associated with the epitaxial growth. One is the simultaneous use of arsenic and antimony in molecular beam epitaxy (MBE) that can lead to cross-incorporation [5] and unsharp interfaces [6]; another is the risk of forming misfit dislocations. A further problem relates to the choice of substrate. GaSb can be used as a substrate for $InAs/Ga_{1-x}In_xSb$ superlattices, but it is more expensive than GaAs and is not available as a semi-insulator. This paper reports investigations on the growth of $InAs:Ga_{1-x}In_xSb$ superlattices on GaAs substrates using a thick stress-relaxed buffer layer of GaSb, and how the nature of the interfaces between the InAs and $Ga_{1-x}In_xSb$ layers affects the properties.

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2. Experimental procedures

The investigated samples were grown by MBE in a modified Varian 360 system. The (001)-oriented semi-insulating GaAs substrates were thermally cleaned *in situ* and a 0.3 μm thick smoothing GaAs layer was grown on them. Next, a 10-period 1 ML GaAs/ 1 ML GaSb superlattice was grown followed by a thick GaSb buffer layer grown at 500°C. The thickness of the latter was varied in different samples from 0.5 to 2 μm. On top of this structure the $InAs/Ga_{1-x}In_xSb$ superlattice was finally grown. Two schemes were tested. In the first, no particular procedure was carried out at the interfaces. In the second, the opening and closing of the shutters was controlled so as to produce In-Sb bonds between the InAs and $Ga_{1-x}In_xSb$ layers.

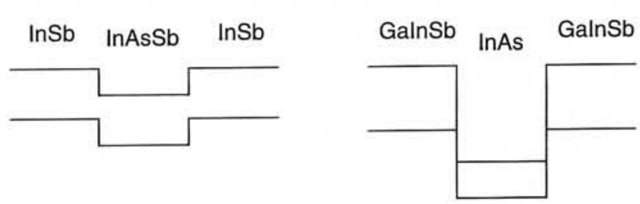

Fig. 1. The conduction and valence-band line-ups for InSb/InAsAb and InAs/GaInSb superlattices.

X-ray diffraction (XRD) analysis was performed with Cu-Kα_1 radiation and a four-crystal Ge monochromator on the incident beam. Low-field Hall effect characterisation was carried out on 3×3 mm^2 pieces in the square van der Pauw arrangement at various temperatures.

3. Results and discussion

Figure 2 shows the influence of the GaSb buffer-layer thickness on the XRD rocking curves. According to a simple model for X-ray diffraction [7], the strength and width of the satellite peaks are related to the corresponding Fourier component of the composition profile. Strong and well defined satellite peaks are a sign of excellent structural quality. The presence of dislocations will also broaden the features of the rocking curves due to the distortion of the lattice. In Figure 2, it is seen that the satellite peaks from a superlattice grown on a 1.5 μm thick buffer layer are better resolved than for a 0.5 μm thick layer. Evidently the thicker layer gives improved structural quality of the overlying superlattice. A comparison between buffer-layer thicknesses of 1 and 2 μm showed almost no discernible difference. These observations are in accord with transmission electron micrographs of InSb grown on GaAs, where the range of threading dislocations from the interface can be estimated to be approximately 1 μm [8]. InAs/$Ga_{1-x}In_xSb$ superlattices had in general more well defined satellite peaks than InAs/GaSb, possibly due to the better lattice match of the superlattice to the GaSb. A similar improvement has also been noted for the InSb-like interfaces [9].

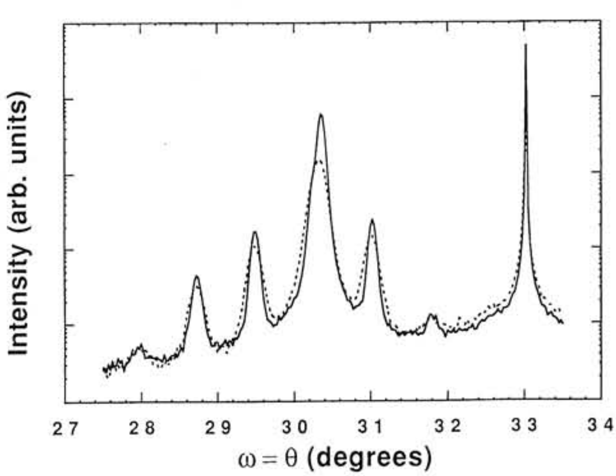

Fig. 2. X-ray diffraction (004) rocking curves of two 42 Å InAs/ 25 Å $Ga_{0.8}In_{0.2}Sb$ superlattices grown on a 0.5 μm thick GaSb buffer (dashed line) and a 1.5 μm buffer (solid line), respectively. The satellite peaks are noticeably narrover for the sample with the thicker buffer layer.

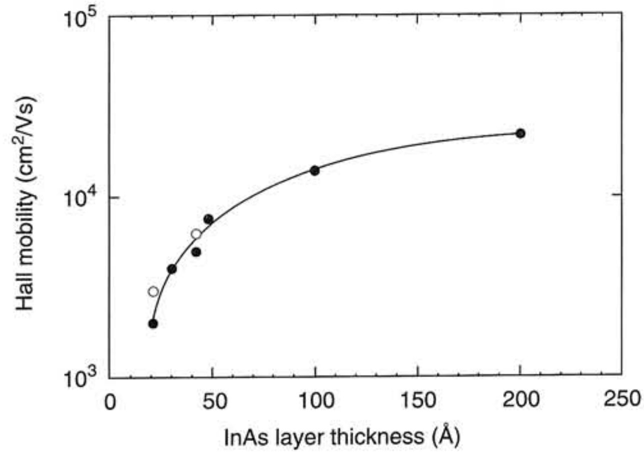

Fig. 3. The room temperature electron mobility for a series of InAs/GaSb superlattices with InSb-like (open symbols) and unprepared (solid symbols) interfaces as a function of InAs layer thickness.

Especially superlattices with thin layers had broad and weak satellite peaks. This is possibly due to the fact that for a short period superlattice (e.g. 21+21 Å), the unsharp interface zone will occupy a large part of the period.

Figure 3 shows the Hall mobility of some InAs/GaSb superlattices, with prepared and unprepared interfaces, as a function of InAs layer thickness. A sharp drop in Hall mobility is seen for InAs layer thicknesses below 75Å. This is believed to be caused by the interface-roughness scattering [10]. The two samples with InSb-like interfaces fell on the higher side of the mobility curve in agreement with a reduced scattering from smoother interfaces. A similar increase in mobility in InAs/AlSb quantum wells was observed by Tuttle *et al.* [11]. The samples with the InSb-like interfaces also had stronger and better resolved satellite peaks than the corresponding samples with unprepared interfaces. The improvement was more pronounced for the short period samples, again indicating that the preparation of the interfaces helps to make them smoother.

4. Conclusions

InAs/$Ga_{1-x}In_xSb$ superlattices can be grown on relaxed GaSb buffer layers on GaAs substrates. For the best structural properties, the buffer layer should be at least 1 μm thick. The structural properties benefit from the use of In contents, $0 < x < 0.3$ in the $Ga_{1-x}In_xSb$ superlattice layers and the preparation of InSb-like interfaces.

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