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Study by transmission electron microscopy of GaInSb layers grown on (001) GaAs substrates by molecular beam epitaxy

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ABSTRACT: The defect structure of GaInSb layers has been studied by Transmission Electron Microscopy. A change with In-content for the defect structure is observed. 60°-type threading dislocations appear when the In-content is less than 40%, whilst vertical-type threading dislocations appear when the In-content is greater than 40%. This defect structure suggests that the cation mixing (In/Ga ratio) seems to be an adequate candidate to be correlated to the appearance of vertical dislocations.

1.INTRODUCTION

Antimonide compounds have received increasing attention as the alternative materials for devices in the mid-infrared region of the spectrum, with a variety of applications in optical gas sensors and communication systems based on fluoride fibres. Mid-infrared emitters and detectors are required to operate efficiently at (or close to) room temperature. Heterostructure GaInAsSb/AlInAsSb lasers, lattice matched to GaSb substrate, emitting at wavelengths beyond 2μm (300K), have been reported (Caneau et al 1985, Choi and Eglash 1992).

Mismatched heterostructures have also proved to be appropiate for these purposes. High detectivity InAsSb mid-infrared photodiodes has been obtained on GaAs and Si substrates (Dobbelaere et al 1992, Dobbelaere et al 1993). Besides the application of this material system to photodetectors it is also used to fabricate light emitting diodes. The GaInSb ternary alloy provides another material available for device operation in the 2-7μm range.

Semiconductor heterostructures containing GaInSb layers will inevitably be strained since this ternary compound is not lattice-matched to any III-V substrate. Pascal-Delannoy et al (1992) reported the room temperature operation of GaInSb (40% In-content) p-i-n photodiodes with a 2% of mismatch on GaSb substrates. We have recently demonstrated (Pérez-Camacho 1994) a similar performance in GaInSb (40% In-content) p-i-n photodiodes grown on GaAs substrates despite the larger mismatch (10%). The assumption that larger lattice mismatch generates higher dislocation density seems natural. Dislocations are expected to be electrically active as recombination centres. The main consequences of dislocations in photodiodes are to generate an excess dark current (Longeway and Smith 1988) and to reduce the minority carrier lifetime, with the subsequent decrease in photosensitivity. A Transmission Electron Microscopy (TEM) study provides a deeper insight for a proper understanding of defect structure and its possible correlation with the operation of photodiodes.

2.EXPERIMENTAL

A series of $Ga_{1-x}In_xSb$ samples was grown by Molecular Beam Epitaxy (MBE) on (001) GaAs semi-insulating substrates, ranging from x=0 to x=0.4. A GaAs buffer layer was grown (at 580°C) in order to provide a smooth GaAs surface for epitaxy. The $Ga_{1-x}In_xSb$ layers were grown at 420°C under Sb_4 flux slightly higher than the minimum required for a Sb-stabilized growth.

The crystal defect structure was investigated by TEM in the two <110> cross section and planar view. These samples were thinned by mechanical polishing and Ar^+-ion milling. The TEM observations was performed with a JEOL 1200-EX at accelerating voltage of 120kV.

3.RESULTS

3.1 GaSb layers grown by MBE at 420°C

The defect structure in GaSb epilayers consists of 60° threading dislocations as shown in fig. 1. The threading dislocation density was 8 10^8 cm^{-2} which is of the same order of magnitude as GaAs on Si epitaxies (Fang et al 1990) in spite of different lattice mismatches between GaSb on GaAs (8%) and GaAs on Si (4%).

Misfit dislocations have been observed by weak beam as shown in fig. 2. They are characterized as 90° dislocations and their spacing corresponds to a relaxed GaSb epilayer. Moreover, half-period-shifts of 90° misfit dislocations are observed (fig. 2). These shifts have been explained as the interaction with 60° misfit dislocations (Zhu and Carter 1990) and they have been observed early in GaSb epilayer growth at different temperatures and thickness (Rocher et al 1990, Kang et al 1994).

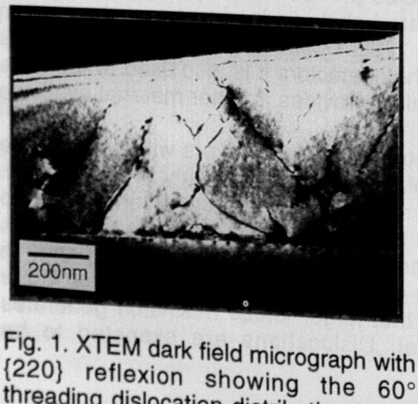

Fig. 1. XTEM dark field micrograph with {220} reflexion showing the 60° threading dislocation distribution in the GaSb epilayer.

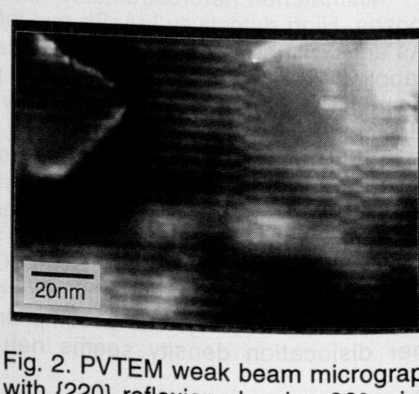

Fig. 2. PVTEM weak beam micrograph with {220} reflexion showing 90° misfit dislocations and the half-period-shifts between them in the GaSb/GaAs interface.

3.2 $Ga_xIn_{1-x}Sb$ layers grown by MBE at 420°C (x=0.07)

Fig. 3 shows the defect structure in the epilayer of GaInSb with 7% In-content. The defect structure consists of 60° threading dislocations and is similar to the GaSb epilayer previously described.

3.3 $Ga_xIn_{1-x}Sb$ layers grown by MBE at 420°C (x=0.4)

The defect structure in GaInSb with 40% In-content is now totally different in comparison with one in GaInSb with 7% In-content. The defect structure consists mainly of a high density of threading dislocations which run nearly parallel to the growth direction as shown in fig. 4. These vertical threading dislocations are possibly edge-type dislocations (Tamura et al 1992).

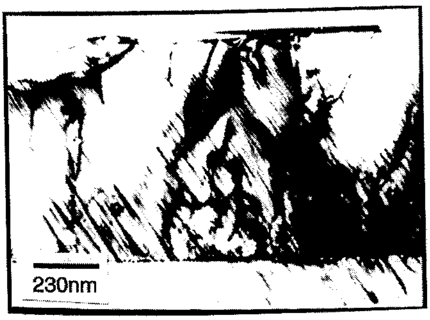

Fig. 3. XTEM bright field micrograph with {220} reflexion illustrating 60° threading dislocations in the GaInSb epilayer with 7% In-content.

Fig. 4. XTEM bright field micrograph with {220} reflexion illustrating a high density of vertical threading dislocations in the GaInSb eiplayer with 40% In-content.

4.DISCUSSION

According to our TEM study, the defect structure of GaInSb layers on GaAs(001) changes from 60°-type to edge-type threading dislocations when the In-content increases. The observed sequence of defect structure according to In-content in GaInSb on GaAs is similar to the defect structure in GaInAs on GaAs (Chang et al 1989, Tamura et al 1992). In the GaInAs/GaAs system, vertical-type threading dislocations appear for an In-content higher than 30%. Chang et al (1989) and Tamura et al (1992) suggested that the smaller the islands, the larger the number of vertical-type threading dislocations. However, the coalescence of many small islands may explain the high density of threading dislocations, but may not explain the generation of vertical-type threading dislocations. This type of threading dislocations may be generated from the coalescence of islands with different thickness where the spacing of 90° misfit dislocations is somewhat different due to the dependence of their spacing upon island thickness (Kang et al 1994). The interaction between 90° misfit dislocations may generate isolated 90° misfit dislocations which have to thread up to surface. The threading of 90° misfit dislocations is dominant where small, thin islands have many occasions of coalescence for growth conditions given by high Ga/In ratio (Ga/In approximately one) and low substrate temperature (420°C).

5. CONCLUSION

The defect structure of GaInSb layers grown on (001) GaAs substrates was studied by TEM. Vertical-type threading dislocations appear in GaInSb for high In-content. This type of theading dislocation generates from the interaction between 90°-misfit dislocations in small and thin islands.

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