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TEM dislocations characterization of $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) on mismatched InP substrate

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ABSTRACT

Dislocation behavior in $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) grown by low pressure chemical vapor deposition (LP-MOCVD) at temperature about 430 °C was analyzed thoroughly by [110] cross-section transmission electron microscopy (TEM), scanning transmission electron microscopy (STEM) and high resolution transmission electron microscopy (HRTEM). The 2% lattice mismatch between InP (100) and $In_xGa_{1-x}As$ ($x=0.82$) results in various types of defects such as stacking faults as well as 60° and 90° threading dislocations. Very high density of threading dislocation (TD) was shown in the $In_xGa_{1-x}As$ ($x=0.82$) epilayer. The epilayer was incompletely strain relaxed by the formation and multiplication of MDs.

1. Introduction

$In_xGa_{1-x}As$ ($x=0.82$) detectors with the cut-off wavelength of 2.5 μm [1–3] in applications of aerospace imaging (such as earth observation, remote sensing and environmental monitoring, etc.) and spectroscopy have attracted more interesting in recent years. Large lattice mismatch of about 2% existing in $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructure brings the epilayer into stress. The progress of stress relaxation of the heterostructure is usually determined by the formation of dislocations which will degrade the performance of the detectors [4,5]. Therefore, it is important to properly realize the stress relaxation mechanism and unequivocally identify dislocations in $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructure. Stress relaxation mechanism in the strained epitaxial layers was discussed by Matthews [6] in the formation of misfit dislocations (MDs). But for the high dislocation density heterostructure relaxation is not sufficient by the formation of MDs, the multiplication of MDs in epitaxial layers has become the focus of current research [7–9]. And based on the rapid development of photomicrographs, high-resolution TEM (HRTEM) can help us to analyze the dislocations accurately and intuitively.

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2. Experimental

In this letter, $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructures were grown by low pressure metalorganic chemical vapor deposition (LP-MOCVD). The growth was performed using trimethylindium (TMIn), trimethylgallium (TMGa), and 10% arsine (AsH_3) in H_2 as precursors. Palladium-diffused hydrogen was used for carrier gas. The substrates on a graphite susceptor were heated by inductively coupling radio frequency power, the temperature was detected by a thermocouple, the reactor pressure was kept at 1×10^4 Pa, and the growth temperature was 430 °C with a growth rate of 300 nm h. The microstructure of the interface of $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructure and the epilayer was detected by transmission electron microscopy (TEM, JEM-2100F, JEOL). Scanning transmission electron microscopy (STEM) and high resolution transmission electron microscopy (HRTEM) were used for a [110] cross-section sample operating at 200 kV.

3. Results and discussions

Fig. 1 illustrates the [110] cross-section TEM micrograph and the SAED pattern examined along the [110] zone axis of the $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructure. The thickness of the epilayer was measured to be 565 nm. Because of the large lattice mismatch of about 2% and $\alpha_e > \alpha_s$ (α_e and α_s denote the lattice parameter of the epilayer and the substrate, respectively), the epilayer was under compression strain. So, a lot of dislocations can be seen in the

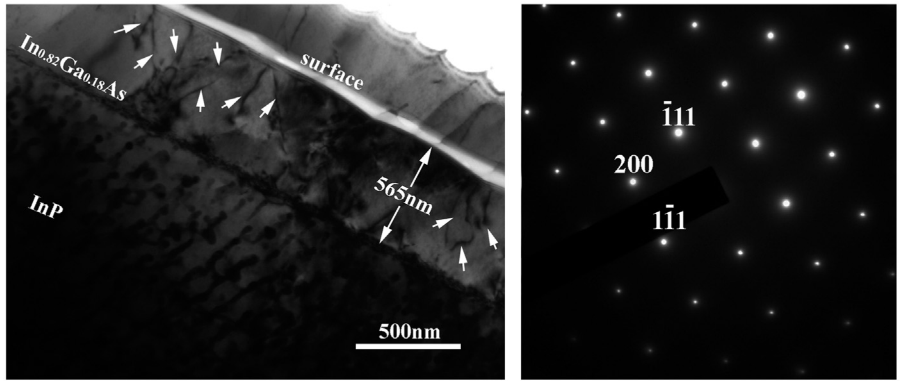

Fig. 1. Cross-sectional TEM micrograph of the $In_xGa_{1-x}As$/InP (100) (x=0.82) heterostructure (left) and [110] zone SAED pattern of $In_xGa_{1-x}As$ (x=0.82) (right).

interface and epilayer. The main structural defects are MDs and threading dislocations (TDs). Fig. 1 shows a very high density of TDs in the $In_xGa_{1-x}As$ (x=0.82) epilayer (signed by white arrows). The dislocation density was estimated to be 5.4×10^8 cm^{-2} by a lot of HRTEM micrographs. These TDs are seen randomly distributed with a low correlation between their positions. The segments of interaction dislocations inclined toward the $In_xGa_{1-x}As$ (x=0.82) epilayer to form threading dislocations. These threading dislocations propagate into the $In_xGa_{1-x}As$ (x=0.82) layer below the $In_xGa_{1-x}As$/InP (100) (x=0.82) interface. Some of it propagated to the surface of the epilayer.

Fig. 2 shows the [110] cross-section fragments of the $In_xGa_{1-x}As$/InP (100) (x=0.82) heterosystem and the corresponding simulated schematic configuration of dislocation lines. High density MDs have been seen in the interface, and it can be clearly seen that there are some TDs that lie on its glide plane as segments such as lines marked as a, b, d, f, k and a subcritical dislocation half-loop (marked as h). These demonstrated that the strain was not relaxed completely. Due to high In component of $In_xGa_{1-x}As$ (x=0.82) epilayer, there must be a lot of point defects. The action between the dislocations and point defects will restrain dislocation motion that brought resistance to the multiplication of MDs. The dislocation lines marked as c, e, i and j were the TDs that formed from the Frank–Read source [8].

To analyze the dislocations at the interface in detail the [110] cross-section sample was characterized by HRTEM and shown in Fig. 3(a)–(c). Fig. 3(a) shows the HRTEM of the interface with a typical MD; the magnified Inverse Fast Fourier Transform (IFFT) of white frame area is shown in the right. Extra half-planes of atoms are found to be along the (1–11) plane (signed by white arrow). The projections of the total Burger's vectors of the defect complexes on the image plane are determined by constructing Burger's circuits (e.g. the Burger's circuit marked with MD) around the defect regions in the HRTEM images (shown with white points). Burger's vector analysis indicates that the projection of the Burger's vector b is $(a/2)<110>$, parallel to the interface. The misfit dislocation at the interface is a perfect 60° dislocation and it has been realized that most misfit dislocations at the interface are 60° dislocations.

Because of low stacking fault energy of Zinc blende structure material, the stacking faults were seen at the interface of $In_xGa_{1-x}As$/InP (100) (x=0.82) (shown in Fig. 3(b)). On the boundary, there exists a group of stacking faults. The FFT image of the white frame shown at the right corner that gives a typical diffraction pattern of the stacking fault. A magnified IFFT of the stacking fault is shown in right. It can be seen that below the two stacking faults there is a Lomer dislocation with a Burger's vector $(a/2)<110>$, parallel to the interface.

A lot of TDs were seen near the interface. In order to analyze clearly, the HRTEM image of some typical dislocations was taken near the interface shown in Fig. 3(c). At the right of Fig. 3(c), the magnified IFFT of white frame area is shown. The dislocations observed are indicated by white arrows. Two arrows show extra (1–11) and (−111) planes of $In_xGa_{1-x}As$ (x=0.82), which do not continue in the InP layer. It indicates that the existence of a threading dislocation accommodated the lattice mismatch: two (111) half-planes are characteristic of a 90° dislocation.

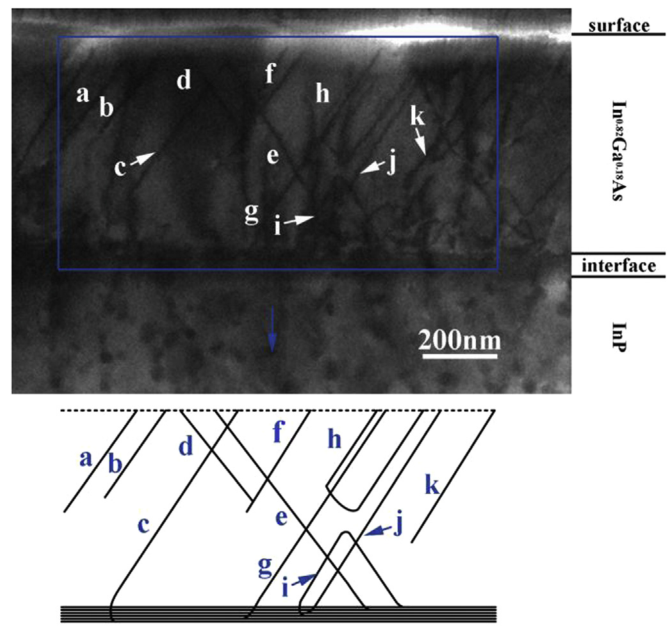

Fig. 2. STEM image of [110] cross-sectional of the $In_xGa_{1-x}As$/InP (100) (x=0.82) heterostructure. The scheme below shows threading dislocations, misfit dislocations with threading branches and dislocation half-loop propagating from the surface. Two-beam condition, g=−220.

4. Conclusions

As a consequence, $In_xGa_{1-x}As$/InP (100) (x=0.82) grown by low pressure chemical vapor deposition (LP-MOCVD) at temperature about 430 °C was incompletely strain relaxed by the formation and multiplication of misfit dislocations (MDs). Various types of defects such as stacking faults as well as 60° and 90° threading dislocations were identified near the interface. According to all the analyses, the plastic relaxation of strained heterostructure is obtained by the creation of MDs. The dislocation which ensures the accommodation between two perfect crystals is a periodic array.

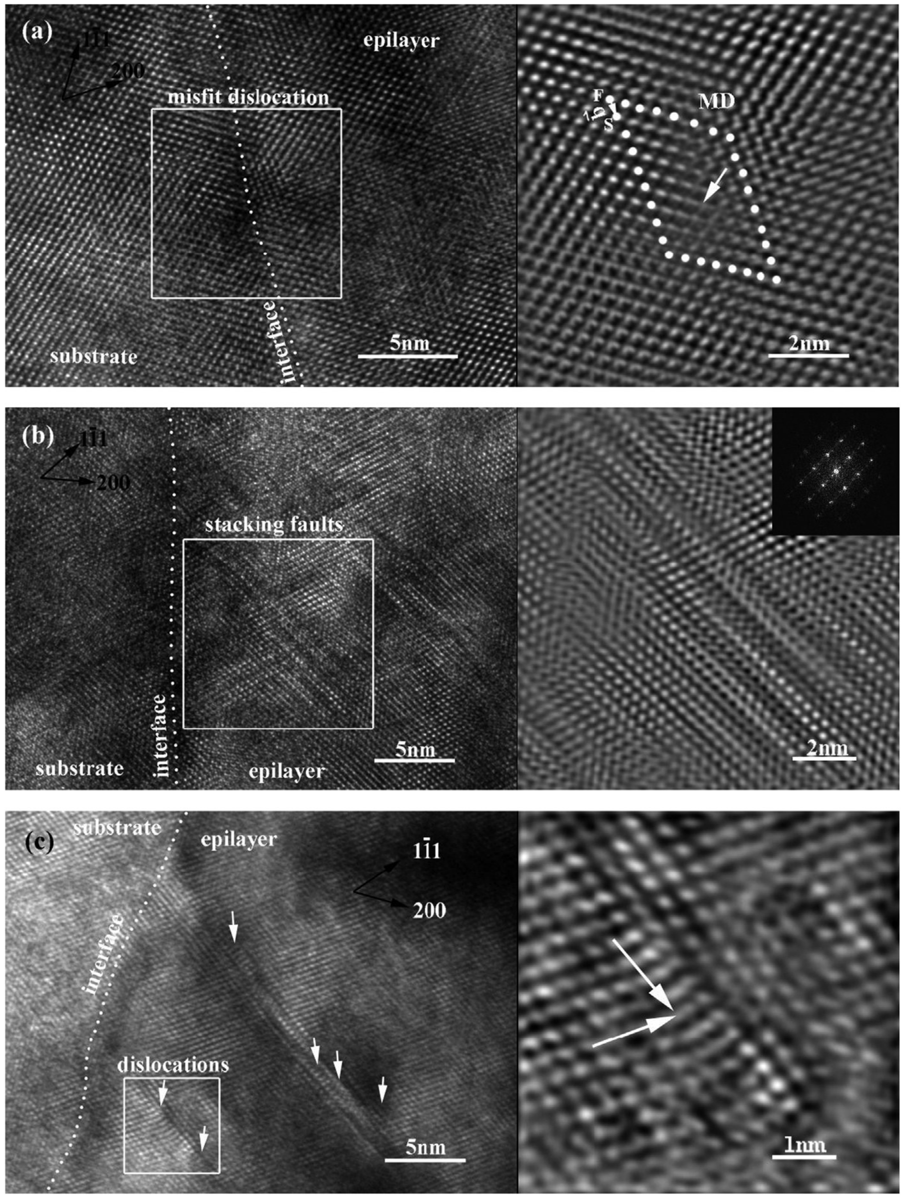

Fig. 3. [110] Cross-sectional HRTEM micrographs of the interface of $In_xGa_{1-x}As/InP$ (100) ($x=0.82$) heterostructure: (a) typical misfit dislocations; (b) typical stacking faults; and (c) typical threading dislocations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Acknowledgments

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