Thickness-dependent Defect Evolution in GaAs-based Low-misfit Heterostructures

Gangopadhyay, A.[1], Maros, A.[1], Faleev, N.[1], McCartney, M.R.[1] and Smith, D.J.[1]

[1] Arizona State University, United States

Epitaxial growth of thin films on rigid substrates combines two or more semiconductor materials to produce heterostructures that find wide applications in many electronic devices such as multi-junction solar cells, light-emitting diodes, lasers, etc. The difference in lattice parameters between film and substrate causes misfit strain at the film/substrate interface. When the film thickness is greater than the critical thickness of the system, the strain energy build-up leads to generations of misfit dislocations at the interface. These misfit dislocations and their associated threading segments are extremely deleterious for device performance. In this study, transmission electron microscopy (TEM) has been used to investigate defect evolution during different stages of strain relaxation in low-mismatched (misfit strain ~ 0.6%) GaAs-based heterostructures such as $GaAs_{0.92}Sb_{0.08}$/GaAs(001) and $In_{0.08}Ga_{0.92}As$/GaAs(001) with film thicknesses in the range of 50 to 4000 nm. All samples were grown by molecular beam epitaxy and had a GaAs capping layer of 50 nm thickness. Polishing, dimpling and liquid-nitrogen ion-milling were used to prepare plan-view (PV) and cross-sectional TEM samples, which were examined using 200 keV Philips-FEI CM-200 FEG and JEOL ARM-200F microscopes.

Figure 1(a) shows a representative PV-TEM image revealing asymmetric distribution of 60° misfit dislocations along orthogonal <110> directions at the film/substrate interface of the heterostructure with 125-nm $In_{0.08}Ga_{0.92}As$ layer. The asymmetric distribution of dislocations is generally attributed to different mobility of two types of 60° dislocations, namely alpha-dislocation (As-terminated core) and beta-dislocation (Ga-terminated core). In thicker films (≥ 250 nm), however, the asymmetry disappeared and relaxation occurred by formation of dislocation loops . Asymmetric strain relaxation (see fig.1b) was observed at the cap/film interfaces of the heterostructures in which the films were sufficiently relaxed to initiate plastic deformation in the capping layer. A simple method was developed to distinguish between the two <110> directions in PV orientation, which involved crystal polarity determination by matching experimental convergent beam electron diffraction patterns with simulated patterns in <110> zone-axis orientation. By measuring dislocation spacings from collage of PV-TEM images recorded from an area of over 100×100 μm^2 along the <110> directions, it was found that beta-dislocation density was higher at the compressively-strained film/substrate interface in both InGaAs/GaAs and GaAsSb/GaAs heterostructures whereas alpha-dislocation density was higher at the tensile-strained cap/film interface. Possible mechanisms explaining this kind of asymmetry reversal will be discussed.

Aberration-corrected STEM was used to obtain information about atomic arrangements at the defect cores. All 60° misfit dislocations at both film/substrate and cap/film interface were dissociated to create intrinsic stacking faults (ISFs) bounded by 90° and 30° Shockley partial dislocations (see fig. 2a). The core of the 30° partial dislocations in most cases was comprised of an unpaired atomic column, which matches with atomic structural model corresponding to glide-set dissociated 60° dislocations. In addition to ISFs, atomic resolution images of dissociated interfacial Lomer edge dislocation (fig. 2b) and stair-rod dislocation (fig. 2c) were also obtained. The atomic structure of these dislocation cores will be discussed in detail.

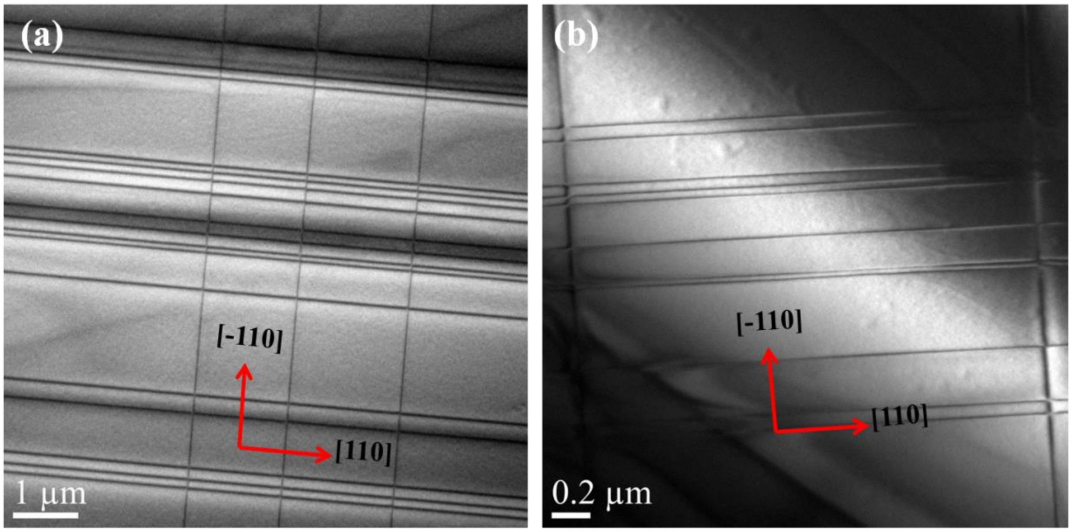

Figure 1. Plan-view <001> TEM images showing distribution of misfit dislocations (a) at the film/substrate interface of the heterostructure with 125-nm-thick $In_{0.08}Ga_{0.92}As$ layer, and (b) at the cap/film interface of the heterostructure with 2000-nm-thick $GaAs_{0.92}Sb_{0.08}$ layer.

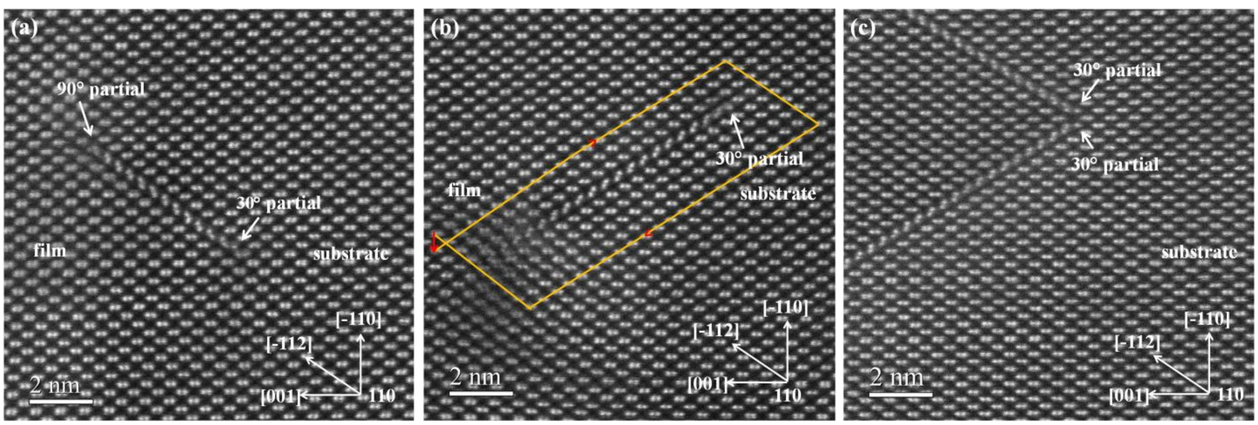

Figure 2. Aberration-corrected high-angle annular-dark-field STEM images of (a) intrinsic stacking fault, (b) dissociated Lomer edge dislocation (Burgers circuit shown), and (c) stair-rod dislocation at the film/substrate interface of the heterostructure with 1000-nm-thick $GaAs_{0.92}Sb_{0.08}$ layer.

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