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Threading Dislocations in Metamorphic $In_{0.20}Ga_{0.80}As$ Grown on GaAs Substrates

L. –M. Yang*, K. Swaminathan**, T. J. Grassman**, S. A. Ringel**, M. Mills*

*Department of Materials Science and Engineering, The Ohio State University, 2041 College Road, Columbus, OH 43210
**Department of Electrical and Computer Engineering, The Ohio State University, 2015 Neil Avenue, Columbus, OH 43210

III-V semiconductors with lattice constants between GaAs and InP have many important applications, including photovoltaics and photodetectors, due to the richness of bandgaps available [1, 2]. However, the vast majority of these materials are inaccessible in typical growth regimes due to the constraint of lattice-matching to conventional substrates. In order to grow high-quality and relaxed lattice-mismatched materials, compositionally graded buffer layers can be used to accommodate the lattice misfit to reach the desired lattice constants [3]. In this work, a three-step graded metamorphic $In_xGa_{1-x}As$ buffers with x = 0.10, 0.17 and 0.23 was used to accommodate the 1.5% lattice misfit between the GaAs substrate and target $In_{0.20}Ga_{0.80}As$ layer, which can achieve high performance photodetectors with a direct bandgap of 1.1 eV [4].

Ideal graded buffers are designed to minimize the dislocation density in the device layers. In the process of creating misfit dislocations at the mismatched interfaces of the buffer layers, threading dislocations may also remain, which can degrade the performance of the device layer. In this work, the dislocation structures were examined on a 200 kV FEI Tecnai F20 microscope using STEM diffraction contrast imaging [5]. Both the cross-sectional and plan-view transmission electron microscopy (XTEM, PVTEM) samples were prepared using the focused ion beam technique in a FEI Helios NanoLab 600 dual-beam system. Figure 1 shows the PVTEM sample preparation. The multiple-layer foil was dug-out by undercutting from the trench side on cleaved edge of substrate. In order to preserve the top layer for dislocation counting, the foil was carefully thinned to around 100 nm from the substrate side only.

Figure 2 shows a cross-sectional view of the InGaAs step-graded metamorphic buffer in a g<220> type diffraction condition. Due to the large lattice mismatch at the interface between the GaAs substrate and the $In_{0.10}Ga_{0.90}As$ layer, abundant dislocation nucleation occurs in the latter. As these dislocations glide on inclined {111} planes, they deposit their line length on the interface as misfit-accommodating dislocations (MDs). In the subsequent InGaAs layers, there is no significant increase in the dislocation density as shown in Fig. 2. This suggests that the nucleation of new dislocations is minimized because the pre-existing threads in the lower layers are re-used for structural relaxation at the subsequent mismatched interfaces by extending along the buffers [4]. The plan-view STEM image in Fig. 3 shows threading dislocations (TDs), indicating a density of around 1.5×10^{7} cm^{-2}. The lines of contrast running parallel to the foil plane may be due a low level of phase separation since they are still visible in Fig. 4, which is an ADF image taken with short camera length of 87 mm which should enhance atomic number contrast. Phase separation may pin dislocations and block the relaxation of the growing lattice-mismatched films [6], thus increasing the dislocation density. Present efforts are focused on understanding the defects structures and phase segregation phenomenon in detail using high resolution STEM imaging techniques.

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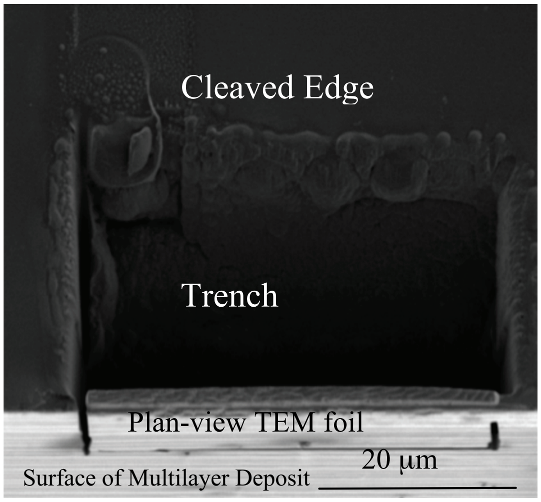

Fig. 1. Focused Ion Beam (FIB) microscope image showing the plan-view TEM foil undercut from trench side on cleaved edge before being taken out by Omniprobe.

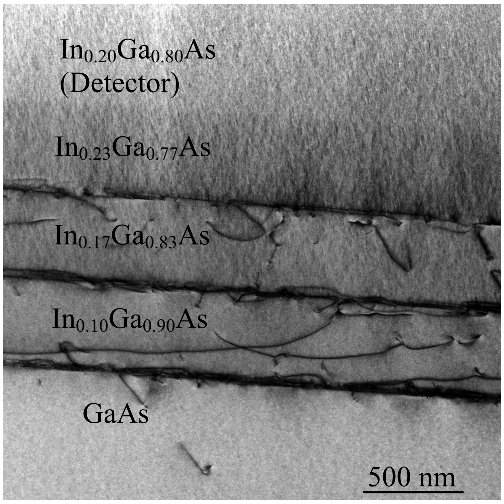

Fig. 2. Cross-sectional STEM image showing dislocation structures in the the InGaAs buffer layers, taken in g(220) diffraction condition.

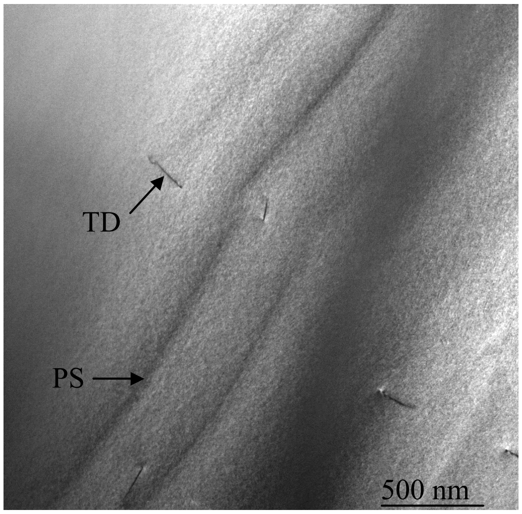

Fig. 3. Plan-view STEM image showing the threading dislocations (TD) terminating at the surface and lines of contrast due to possible phase segregation (PS).

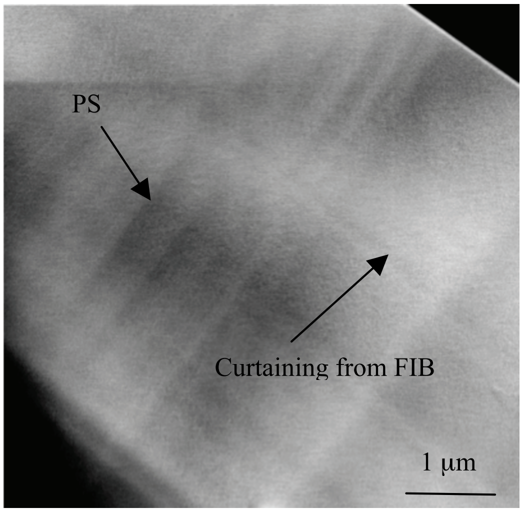

Fig. 4. Z contrast using annular dark field (ADF) image at short camera length lending support to the hypothesis that these are due to phase separation