Strain Relaxation and Dislocation Filtering in Metamorphic HBT and HEMT Structures Grown on GaAs Substrates

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InP-based HEMTs and HBTs offer significant improvements in performance over their GaAs-based counterparts in terms of higher operating frequency, reduced power consumption, and improved noise characteristics. However, issues associated with quality, price, diameter, and availability of InP substrates hinder potential high volume commercialization. The metamorphic approach to growing InP-like structures on GaAs substrates, using partially-relaxed buffer layers (M-buffers), represents a potential solution to realizing high volume, lower cost, high performance InP-like devices. The fundamental obstacle in the development of metamorphic epiwafers is the high density of threading dislocations and rough surface morphology resulting from the large lattice mismatch between the epilayers and substrate. Optimal M-buffer design and growth are the key factors to obtain dislocation-free active layers with properties comparable to those grown lattice matched on InP substrates. A graded InAlAs-based M-buffer is the standard for production M-HEMTs, while a bulk InP buffer offers superior thermal properties for higher current density circuits. This paper compares the structural and electrical properties of these M-buffers for M-HBT and M-HEMT applications.

Structural properties were evaluated using optical microscope, AFM, HRXRD, PL, and TEM. The distinct surface morphology and crystal structure of the two M-buffers (Figure 1) can be attributed to the difference in the underlying strain relaxation mechanisms. The graded InAlAs gave a cross-hatched pattern with nearly full relaxation, while the bulk InP had a uniform, isotropic surface that was only partially relaxed. Both types of M-buffers had AFM rms roughness values around 20–30 Å. TEM micrographs reveal that dislocations are filtered more effectively in the graded InAlAs M-buffer than in the bulk InP M-buffer (Figure 2). We will discuss the strain relaxation and dislocation filtering mechanisms, as well as the effect of growth conditions on surface morphology and device characteristics.

Hall measurements and large-area device testing were used to evaluate and compare the quality of the metamorphic epiwafers. The M-HBTs have similar properties to baseline structures grown on InP substrates, although those grown on the InP M-buffers tend to show more degradation in gain and breakdown. We speculate that this device degradation on the InP M-buffer was related to the incomplete dislocation filtering. Room temperature Hall measurements showed a channel charge of $\sim 3\times10^{12}$ cm^{-2} with a mobility >10,000 cm^2/V-s for both the baseline InP-HEMT and the M-HEMT with the InAlAs M-buffer. For M-HEMTs using the InP M-buffer, a modest reduction in Hall mobility was observed, and the properties are very sensitive to the growth conditions of the InP M-buffer. On the other hand, there is no clear correlation between surface roughness and large-area DC characteristics for either M-HEMTs or M-HBTs grown on the InP M-buffer. SEM images reveal sharp interfaces between the etch planes and surface roughness resulting from metamorphic growth does not seem to pose any fundamental problem to device processing.

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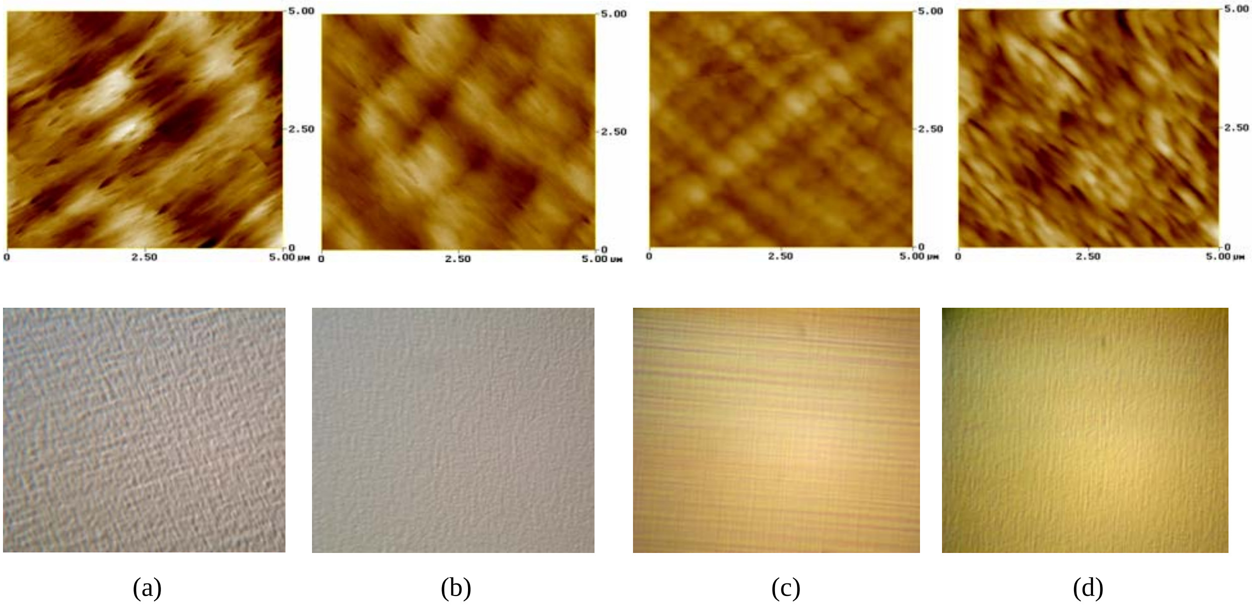

Figure 1. AFM (top) and optical microscope (bottom) surface morphology of M-HBTs (a, b) and M-HEMTs (c, d) grown using a graded InAlAs M-buffer (a, c) and using a bulk InP M-buffer (b, d).

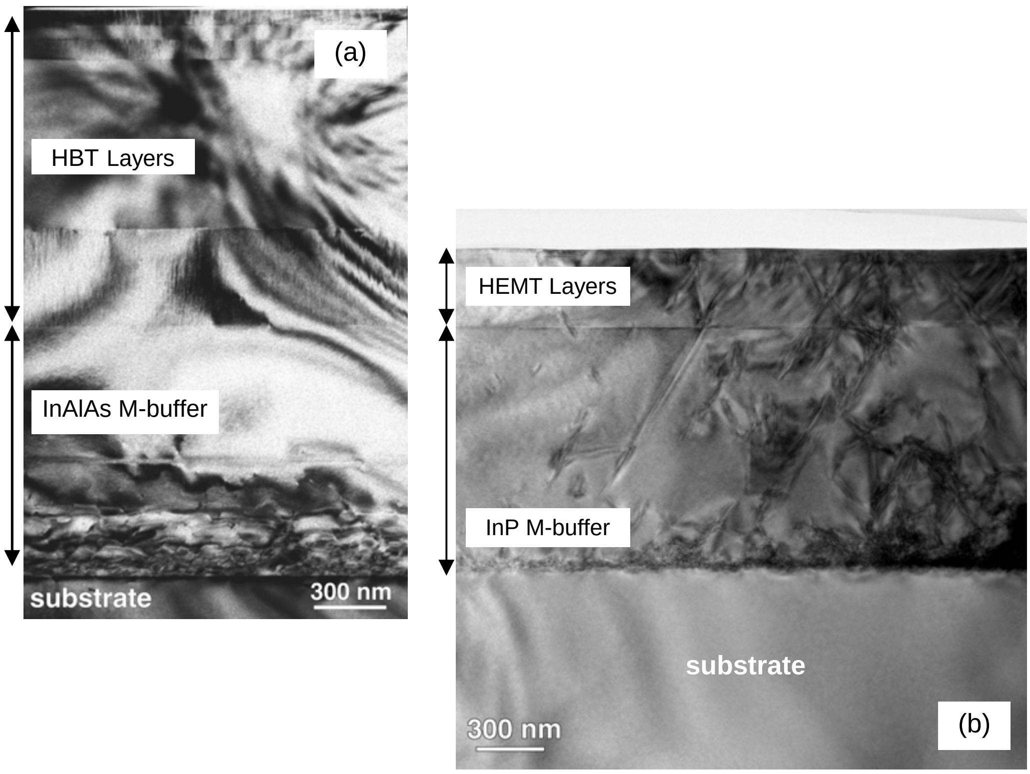

Figure 2. Low magnification TEM overview image of (a) an M-HBT structure with graded InAlAs M-buffer and (b) an M-HEMT structure with bulk InP M-buffer. Layers with different chemical composition are recognized by their contrast difference.