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Microstructural Characterization of Closely-Lattice-Matched AlIn(Ga)N Alloys for High Electron Mobility Transistors

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Materials based on $Al_{1-x}In_x(Ga)N$ have much potential for the fabrication of high electron mobility transistors (HEMT) due to the large breakdown voltage and formation of a high density, two-dimensional electron gas (2DEG) at the AlIn(Ga)N/GaN interface [1, 2]. It is predicted by Vegard's law that $Al_{0.825}In_{0.175}N$ should be lattice-matched (LM) to fully-relaxed GaN so that the $Al_{0.825}In_{0.175}N$/GaN heterostructures should ideally be free of interface strain. Moreover, problems associated with strain relaxation, such as defect generation and device degradation, should then be alleviated [3]. However, the immiscibility of the constituent materials in these alloys severely impedes the growth of high quality material by molecular beam epitaxy (MBE) [3]. Quaternary AlInGaN compounds with suitable Al/N ratio may be more miscible than AlInN while remaining LM to GaN. However, reports about HEMTs based on quanternary alloys are limited [4]. In this study, AlIn(Ga)N-based HEMT structures with novel AlN/GaN/AlN interlayers were grown by MBE on sapphire or SiC substrates. The microstructure of the heterostructures was investigated using a range of TEM methods, and compared with conventional samples grown with AlN interlayer.

Figure 1 shows bright-field TEM images of AlInN layers grown on SiC substrate with: (a) AlN spacer; and (b) AlN/GaN/AlN spacer, both taken under $\boldsymbol{g}=11\underline{2}0$ diffraction condition. Threading dislocations penetrating through the AlInN layer to the top surface are observed. Both images show black and white stripes parallel to the [0001] growth direction distributed throughout the entire AlInN film thickness, which is most likely an effect caused by phase separation [3]. These stripes are less distinct inside the sample with the AlN/GaN/AlN spacer. Figure 2 shows bright-field TEM images of AlInGaN films grown on SiC substrates with: (a) AlN spacer; and (b) AlN/GaN/AlN spacer layer. High densities of basal plane stacking faults (BSFs) are visible at ~10nm away from the AlInGaN/interlayer interfaces in both samples. However, the first ~10nm of the AlInGaN film has high crystalline quality. Cross-sectional HAADF STEM analysis showed no distinctive phase separation in the AlInGaN layer. Formation of the BSFs may due to strain relaxation. Sample with AlN spacer also has some V-pits on its surface. Figure 3 is a high-resolution TEM image of a ~6nm thick AlInGaN HEMT structure with AlN/GaN/AlN spacer, showing well-defined interfaces and the AlInGaN layer has excellent crystallinity. Further plan-view and chemical studies of heterostructures grown on sapphire or SiC substrates are ongoing [5].

References

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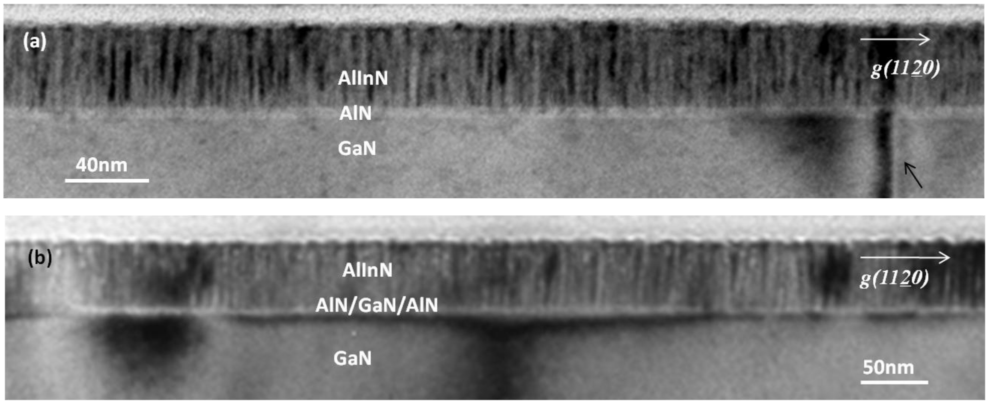

FIG. 1 Bright-field TEM images of AlInN layer grown on SiC substrate with: (a) AlN spacer and (b) AlN/GaN/AlN spacer, taken under g=11$\underline{2}$0 diffraction condition, showing phase separation in the AlInN layer. Threading dislocation penetrates through the AlInN to the top surface, as indicated by black arrow.

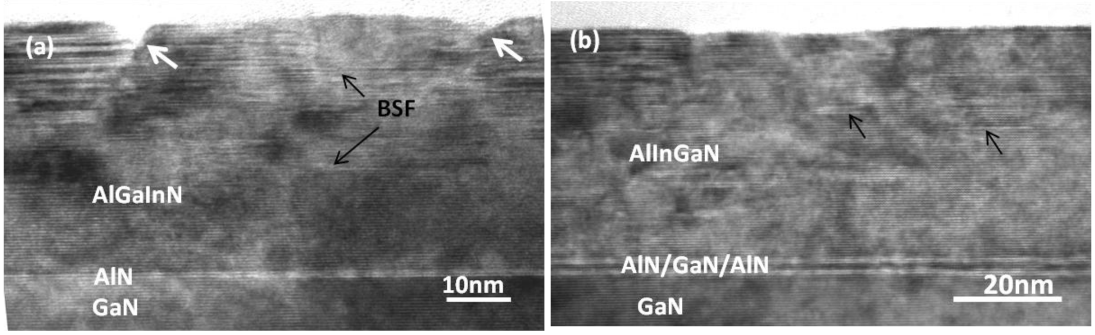

FIG. 2 Bright field TEM images of AlInGaN film grown on SiC substrate with: (a) AlN spacer and (b) AlN/GaN/AlN spacer layer. High density of basal plane stacking faults (BSFs), as indicated by black arrows, are visible ~10nm away from the AlInGaN/interlayer interface in both samples. Surface pits were also observed in sample with AlN spacer, as indicated by white arrows in (a).

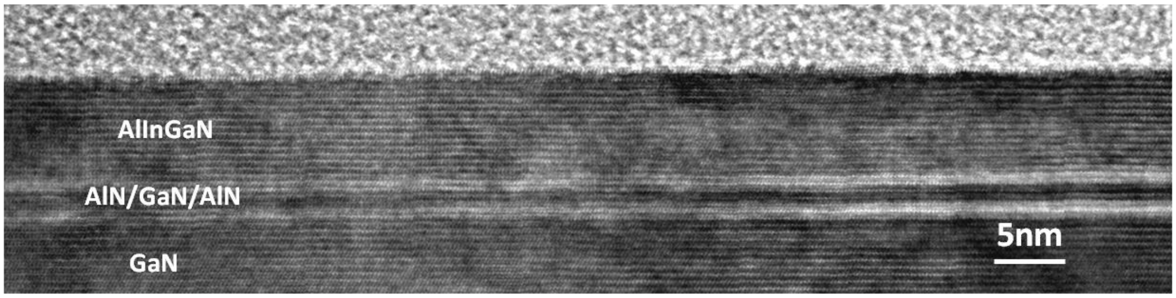

FIG. 3 High-resolution TEM image of a AlInGaN HEMT with AlN/GaN/AlN spacer showing AlInGaN layer of excellent crystallinity and well-defined interfaces.