Heteroepitaxial growth of GaN on AlN towards RF device applications

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GaN promises significant application in high power RF devices. It is critical to reduce dislocation density in GaN epilayers for reliable HEMT device operation. This study investigates the epitaxial growth of GaN on AlN buffer layers by MBE. The growth started with a 100-nm thick AlN buffer layer on SiC substrate. For sample 240812B(S1), only an AlN buffer layer was grown. Two methods were utilized for the subsequent growth of GaN at 780℃. For Sample 240815A (S2), 640nm GaN was grown under a Ga/N flux ratio of 1.8, while for Sample 240822A(S3), 70nm GaN buffer layer was first grown at Ga/N flux ratio of 0.9 prior to the growth of 540nm GaN at Ga/N flux ratio of 1.8. For both samples, an AlGaN barrier layer and a GaN cap layer were grown on top.

XRD study reveals that FWHMs of AlN(002) in S1 and S3 are comparable, much lower than that of Sample S2 (130 vs. 530 arcsec), indicating severe nucleation of screw-type or mixed-type dislocations in AlN buffer layer upon Ga-rich growth of GaN. The FWHMs of GaN (002)/(102) in Sample S3 (228/1109 arcsec) are significantly improved vs. those of S2(860/1360 arcsec). Pits were observed in AFM of S2, potentially due to higher density of c-component dislocations. For heteroepitaxial growth of GaN on AlN, it has been widely studied that 3D nucleation of GaN together with subsequent transition to 2D growth of GaN is an effective approach for strain relaxation and dislocation annihilation in GaN.[1-3] However, we identified that, for the first time, Ga-rich growth of GaN on AlN has a detrimental effect on the underlying AlN buffer layer.

TEM study reveals that excessive screw-type and mixed-type dislocations nucleate at the GaN/AlN interface, extending across the interface downwards into AlN and upwards into GaN. We postulate that the liquid metallic Ga bi-layer on AlN at the start of GaN growth could facilitate misfit dislocation nucleation and inject point defects into the underlying AlN buffer layer, leading to threading dislocation propagation both upwards and downwards. T-dependent Hall measurement reveals that the carrier mobilities of S3 at RT and T<100K are 1050 $cm^2/V \cdot s$ and 2420 $cm^2/V \cdot s$, much higher than those of S2(782 and 1470 $cm^2/V \cdot s$). Improvement in carrier mobility is related to the reduction of dislocation density and surface pits. This work provides crucial insights into interfacial engineering for GaN RF device applications.

References

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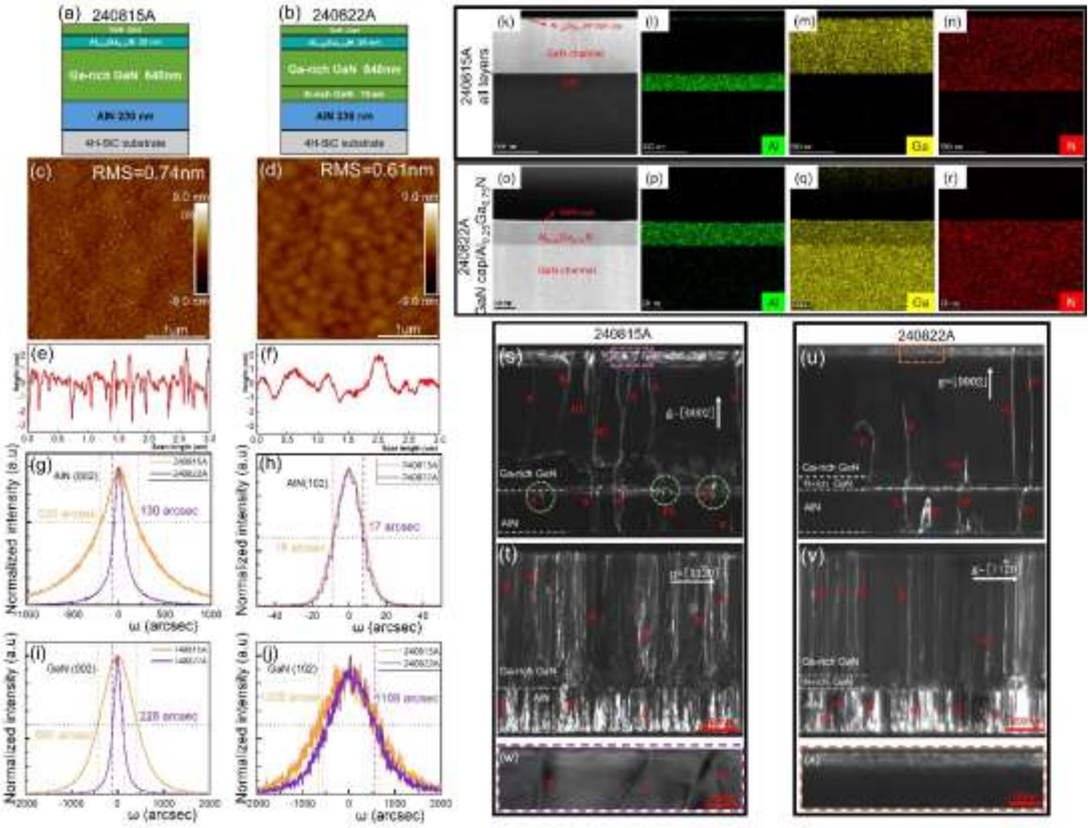

FIG.1 Structural characterization of samples 240815A and 240822A. (a) and (b): Structural schematics; (c) and (d): AFM images; (e) and (f) show the line scan depth variation curves of samples 240815A and 240822A, respectively. (g) and (h): Comparison of the (002) and (102) X-ray ω rocking curves of AlN buffer layers in 240815A and 240822A. (i) and (j): Comparison of the (002) and (102) ω rocking curves of the GaN epilayers. Figures (k) and (o) show the STEM-HAADF images of samples 240815A and 240822A, respectively. (l-n) and (p-r) are EDS distribution images of Al, Ga, and N elements, respectively. Cross-sectional TEM images of sample 240815A taken with the diffraction vectors g=[0002] (s) and g=[11$\bar{2}$0] (t).Cross-sectional TEM images of sample 240822A taken with the diffraction vectors g=[0002] (u) and g=[11$\bar{2}$0] (v). Figures (w) and (x) are enlarged partial images of the GaN cap layer of samples 240815A and 240822A, respectively.

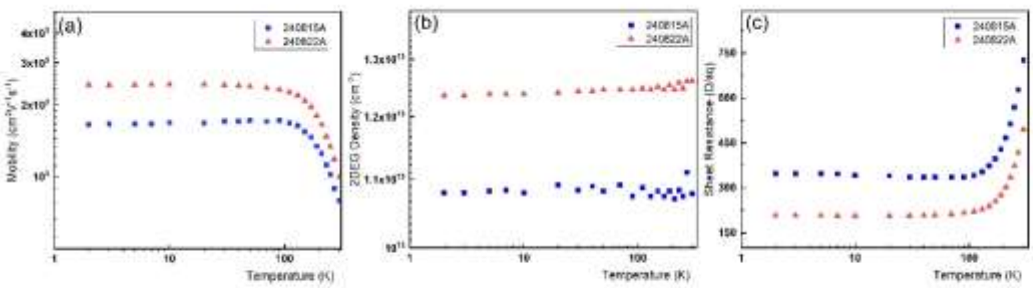

FIG.2 Temperature-dependent Hall effect measurements on AlGaN/GaN heterostructures. (a) Mobility vs. Temperature.(b) 2DEG concentrations vs. Temperature.(c) Sheet resistance vs. Temperature. Blue: Sample 24N0815A; red: 240822A.