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Field Mapping and Ohmic Contacts for AlGaN- or AlInN-Based Heterojunction Field Effect Transistors

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GaN-based heterojunction field-effect transistor (HFET) structures, with AlGaN or AlInN barriers, are of much interest for high-power microwave applications, due to the large breakdown voltage and formation of a high density, two-dimensional electron gas (2DEG) at the AlGa(In)N/GaN interface [1,2]. Therefore, the microstructure and the electrostatic potential across the HFET, as well as the reaction between the device contacts and the heterostructure, are very important. In this study, AlGaN and AlInN-based HFET structures were grown by metal-organic chemical vapor phase deposition on sapphire substrates. The microstructure of the heterostructures and devices was investigated using a range of TEM methods, including HAADF STEM imaging and EDXS analysis. Electrostatic potential profiles across the HFET heterostructures were measured using off-axis electron holography.

Figure 1(a) is a bright-field TEM image of a AuNiAlTi/GaN/AlN/$Al_{0.17}Ga_{0.83}N$/GaN HFET device structure. Most of the GaN capping layer has reacted with the Ti contact. However, the adjacent AlN layer blocks further reaction between the contact and the multilayer even in regions where there are threading dislocation (TDs), as indicated by the black arrow. Figure 1(b) is a diffraction contrast image of a AuNiAlTi/GaN/$Al_{0.85}In_{0.15}N$/ (GaN)/AlN/GaN HFET device. Large contact inclusions extending down into the AlInN and GaN layers, as indicated by the black arrows, are observed. These inclusions are generally associated with mixed-type TDs originating in the thick GaN layer underneath. High-resolution TEM images reveal that the inclusions are primarily crystalline TiN. HAADF STEM imaging (Fig. 2a) and EDXS line profiles (Fig. 2b) confirm that the contact inclusions are crystalline TiN with Au/Al shells. Moreover, the thin GaN capping layer is entirely transformed into TiN, although the AlInN layer remains intact. Figure 3a shows the reconstructed phase image from a hologram of the GaN/$Al_{0.85}In_{0.15}N$/AlN/ GaN HFET. Measurements of the electrostatic potential profile (Fig. 3b) indicated polarization-induced fields of 7.5MV/cm within the AlN layer, and 2.2MV/cm within the GaN(2) layer [3]. A 2DEG with a density of ~9.8 ± 1 $x10^{12}cm^{-2}$ was located in the GaN layer very close to the AlN/GaN interface, which is consistent with that measured by Hall effect ($9.8x10^{12}cm^{-2}$). Further electrostatic potential mapping of the AlGaN-based HFET is in progress [4].

References
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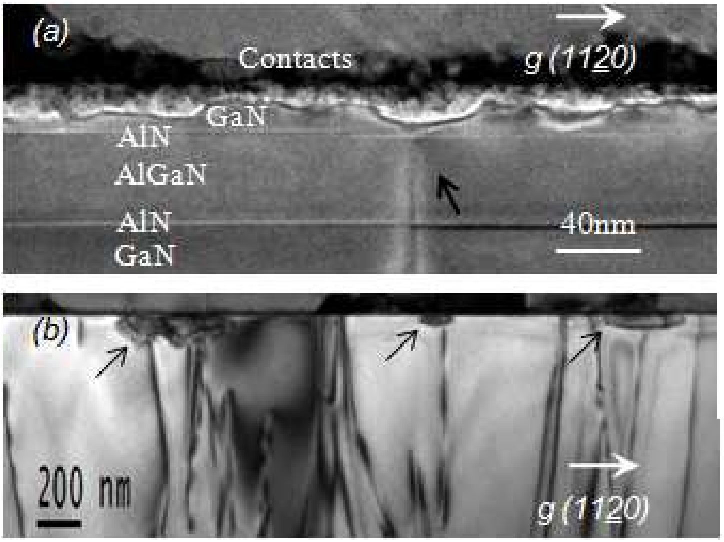

Figure 1 Diffraction contrast bright-field TEM images taken under $\mathbf{g}=11\bar{2}0$ diffraction condition showing
(a) AuNiAlTi/GaN/AlN/AlGaN/GaN HFET device structure;
(b)AuNiAlTi/GaN/AlInN/ (GaN)/AlN/ GaN HFET device structure;
Contact inclusions blocked by AlN layer in (a) whereas they penetrate deep into GaN layer in (b).

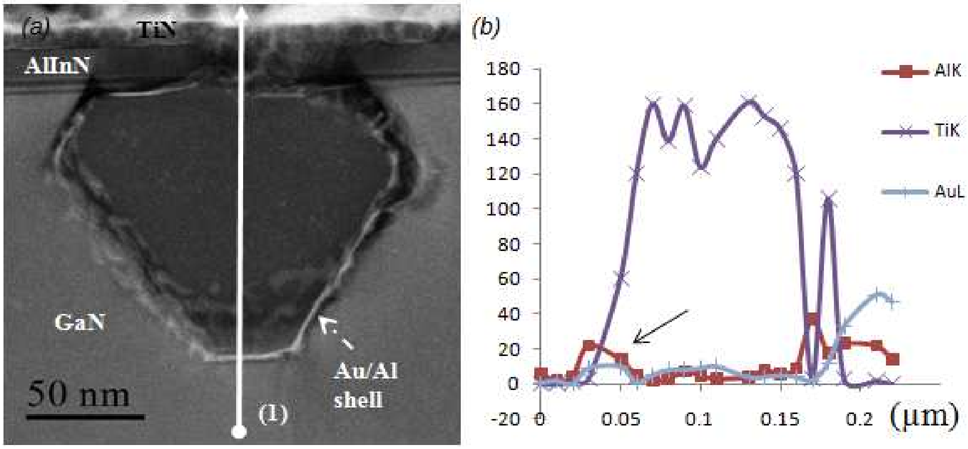

Figure 2. (a) HAADF STEM image; (b) EDXS line profile across contact inclusion from regions indicated in (a) showing that the inclusions are primarily TiN with Au/Al shells.

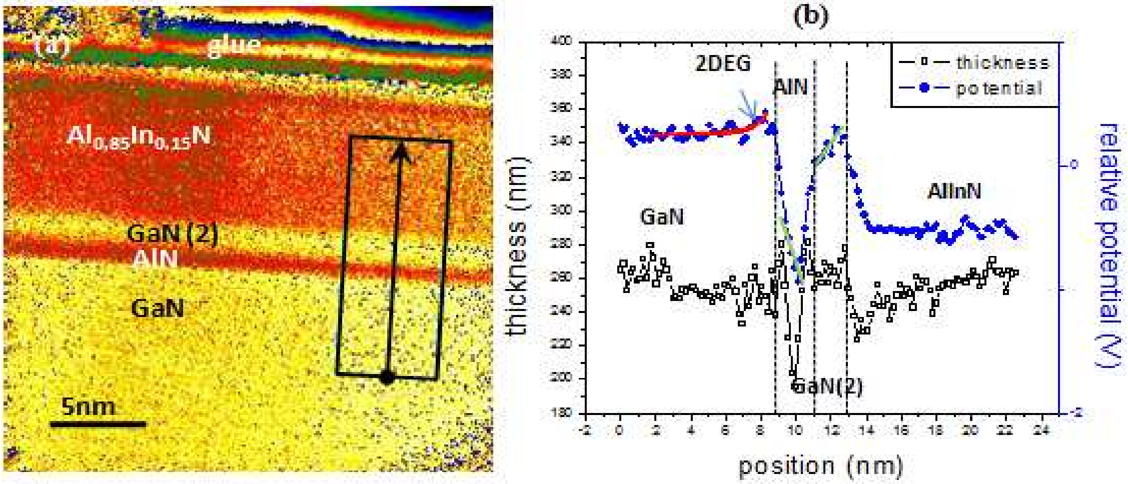

Figure 3. (a) Reconstructed phase image; (b) Calculated potential and thickness profile taken from hologram. Green line indicates the electric field within AlN and GaN(2) layers. Red line in GaN is the fitted line of the corresponding region using Gaussian fit.