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Advanced Electron Microscopy Characterization of GaN-based High Electron Mobility Transistors

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Abstract – Electron holography, scanning transmission electron microscopy (STEM), and energy-dispersive x-ray spectroscopy (EDX) have been used to characterize GaN-based high electron mobility transistor (HEMT) heterostructures and devices. Cross-sections prepared by the focused ion beam (FIB) lift-out and wedge-polish methods have been compared to determine the impact of ion-beam damage on phase imaging. Potential profiles and polarization fields within HEMT devices were measured by electron holography. Nanoscale chemical analysis was used to study the variations in electric fields between the device source and gate in terms of interdiffusion with contact and capping materials.

The AlGaN/GaN heterostructure provides the basis for the current generation of high electron mobility transistor (HEMT) devices [1]. In the case of III-nitride materials grown in the usual *c*-plane direction, spontaneous and piezoelectric polarization fields give rise to a two-dimensional electron gas (2-DEG) at the heterostructure interface. The presence of the 2-DEG leads to devices with high electron mobility that are suitable for high voltage, high frequency applications such as microwave communications and high power amplifiers [2]. This research focuses on the characterization of HEMTs by advanced electron microscopy methods including nanoscale chemical analysis and off-axis electron holography [3]. The investigation is broken into three subgroups: sample preparation using focused-ion-beam, off-axis holography to image electrostatic fields, and chemical and micro-structural analysis of devices.

Figure 1 shows an example of a HEMT device prepared by FIB for electron holography. Although the FIB is very useful for site-specific sample preparation, amorphization and implantation by the ion beam can easily alter the material structure. To determine the impact of FIB damage on phase imaging, both wedge and FIB samples were prepared from bulk HEMT heterostructures. Lorentz- and diffraction-mode electron holography was performed on both bulk and device samples. The potential profile across the heterostructure was calculated from the phase image using the relationship: $\Delta\phi = C_e t V$, where V is the potential, t is the sample thickness, and C_e is an energy-dependent interaction constant. Figure 2 shows the potential profile of a GaN/AlN/AlGaN heterostructure. The Pt capping layer was deposited as part of the FIB sample preparation. The 2-DEG is located on the substrate side of the GaN/AlN interface, as evidenced by the peaked region in the potential profile. High-angle annular-dark-field STEM imaging and EDX were used to qualitatively probe the chemical composition of these HEMT heterostructures. An EDX linescan across the channel of a HEMT device is show in Fig 3 [4].

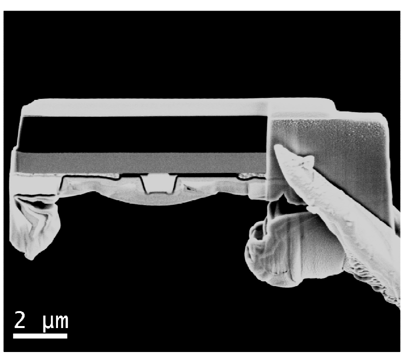

Figure 1: SEM image of HEMT device prepared by FIB lift-out method.

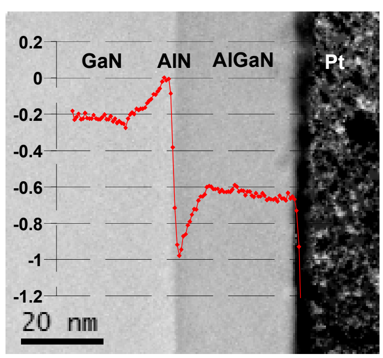

Figure 2: Phase image of GaN/AlN/AlGaN heterostucture obtained by holography with calculated potential profile (overlay).

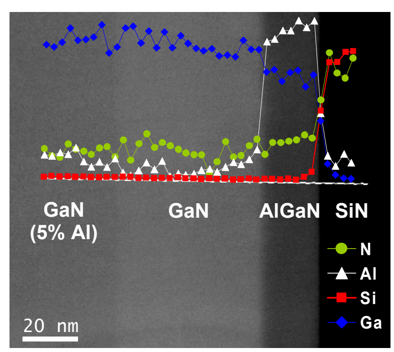

Figure 3: STEM image of HEMT device with EDX linescan profiles (overlay).

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