

Materials Science & Engineering Doctoral Defense

Electron Microscopy Characterization of GaN-on-GaN Vertical Power Devices

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Abstract

Wide bandgap semiconductors are of much current interest due to their superior electrical properties. This dissertation describes electron microscopy characterization of GaN-on-GaN structures for high-power vertical device applications. Unintentionally-doped (UID) GaN layers grown homoepitaxially via metal-organic chemical vapor deposition on freestanding GaN substrates, were subjected to dry etching, and layers of UID-GaN/p-GaN were over-grown. The as-grown and regrown heterostructures were examined in cross-section using transmission electron microscopy (TEM). Two different etching treatments, fast-etch-only and multiple etches with decreasing power, were employed. The fast-etch-only devices showed GaN-on-GaN interface at etched location, and low device breakdown voltages were measured ($\sim 45\text{-}95\text{V}$). In comparison, no interfaces were visible after multiple etching steps, and the corresponding breakdown voltages were much higher ($\sim 1200\text{-}1270\text{V}$). These results emphasized importance of optimizing surface etching techniques for avoiding degraded device performance. The morphology of GaN-on-GaN devices after reverse-bias electrical stressing to breakdown was investigated. All failed devices had irreversible structural damage, showing large surface craters ($\sim 15\text{-}35$ microns deep) with lengthy surface cracks. Cross-sectional TEM of failed devices showed high densities of threading dislocations (TDs) around the cracks and near crater surfaces. Progressive ion-milling across damaged devices revealed high densities of TDs and the presence of voids beneath cracks: these features were not observed in unstressed devices. The morphology of GaN substrates grown by hydride vapor-phase epitaxy (HVPE) and by ammonothermal methods were correlated with reverse-bias results. HVPE substrates showed arrays of surface features when observed by X-ray topography (XRT). All fabricated devices that overlapped with these features had typical reverse-bias voltages less than 100V at a leakage current limit of 10^{-6} A. In contrast, devices not overlapping with such features reached voltages greater than 300V. After etching, HVPE substrate surfaces showed defect clusters and macro-pits, whereas XRT images of ammonothermal substrate revealed no visible features. However, some devices fabricated on ammonothermal substrate failed at low voltages. Devices on HVPE and ammonothermal substrates with low breakdown voltages showed crater-like surface damage and revealed TDs ($\sim 25\mu\text{m}$ deep) and voids; such features were not observed in devices reaching higher voltages. These results should assist in devising protocols to fabricate reliable high-voltage devices.

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