Origins of Epitaxial Surface Haze on GaN Substrates for kV Power Devices

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To fully utilize GaN for high-power devices operating in the ~kV regime, thick drift layers on the order of tens of microns are needed [1,2]. Maintaining smooth surfaces during the growth of thick GaN layers is crucial because surfaces free of morphology lead to consistent and well-performing devices [1]. Surface roughening due to the formation of macro-steps and macro-terraces due to substrate defects is the focus of this current study. We utilize X-ray topography imaging and find that localized lattice distortions in GaN substrates can serve as nucleation sites for epitaxial macro-steps and macro-terraces. These device-detrimental, macro-scale features give rise to optically hazy surfaces. These hazy features have been reported in the literature [3], but the initial growth stages of these macro-steps and macro-terraces have yet to be documented and studied.

In this work, we utilized so-called dot-core GaN substrates as defect-engineered templates to study the origins and evolution of macro-step and macro-terrace formation. Dot-core GaN substrates are prepared by growing GaN on a 0.8 × 0.8 mm^2 patterned substrate using hydride vapor phase epitaxy (HVPE). The pattern consists of an array of cores (inversion domains) that concentrate defects at the core centers to produce low defect density GaN between the cores. Five to sixty μm of metal organic chemical vapor deposition (MOCVD) homoepitaxial GaN layers were grown on the dot-core substrates. The hazy features only covered a fraction of the total substrate area, enabling us to identify the macro-feature nucleation sites with optical microscopy imaging. Islands of surface haze appeared in a 0.8 × 0.8 mm^2 array (with haze-free areas between the islands), indicating that the highly distorted cores serve as nucleation sites for macro-feature formation. The high density of threading dislocations at the cores induced localized lattice distortions. Imaged with X-ray topography, these distortions are predominantly due to lattice tilt, on the order of hundreds of arcsec. The resulting macro-features that nucleated at these localized distorted sites were made up of macro-terraces with lengths of ~30 μm to ~150 μm and macro-step heights of ~200 nm to ~400 nm. Thick MOCVD homoepitaxial GaN were then grown on HVPE GaN substrates with a uniform distribution of threading dislocations (without periodic cores). Typically, only a fraction of the total substrate area was covered in haze. We find that threading screw dislocations or GaN nanopipes serve as another source of localized lattice distortion that result in spiral growth and hillock formation. We speculate that the coalescence of hillocks evolves into macro-terraces and macro-steps. While previous studies focused on substrate miscut as a means to control macro-feature formation, we show that localized lattice tilt from defects is another important contributor to macro-feature formation.

References

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