Abstract

In the era of modern power semiconductor devices, AlGaN/GaN High Electron Mobility Transistor (HEMT) has a high application potential due to wide energy band gap, large breakdown electric field, and high saturation velocity. Despite that, AlGaN/GaN HEMTs still suffer from performance and reliability issues during operation across a wide range of power electronic applications. More specifically, in power switching applications, the device must support higher voltage operation when switching from OFF state to ON state, demanding higher reliability of the device.

This dissertation explores the reliability and performance optimization of GaN-HEMTs for power electronics applications. It begins with an introductory overview encompassing the historical background, fundamental principles, device structures, reliability considerations, and research objectives. Methodologies for assessing the reliability of Ferroelectric-Gate (FEG) GaN-HEMTs are then explored, focusing on fundamental stability and reliability through Time-Dependent Dielectric Breakdown (TDDB) tests. Results demonstrate robust device performance with a projected 10-year lifetime and low failure rate. Furthermore, the suitability of FEG-HEMTs for power electronics is evaluated, particularly concerning temperature-induced threshold voltage (V_T) instability. Insights into V_T instability origins are proposed, considering temperature variations and electrical dependencies.

Enhancements are introduced in power, performance, and V_T stability of quaternary InAlGaN/GaN Metal-Insulator-Semiconductor (MIS) HEMTs with gate field plate structures. Fundamental characteristics are examined, showcasing improvements in drain saturation current and breakdown voltage, alongside investigations into V_T instability under temperature variations. Further reliability aspects of optimized quaternary InAlGaN/GaN MIS HEMTs are investigated, analysing stability with temperature variations, and conducting positive and negative bias temperature instability experiments. The dynamics of threshold voltage instability are examined through ON resistance analysis and trap activation energy determination.

Additionally, reliability investigation of industry standard D-mode AlGaN/GaN HEMTs has been performed. It includes a detailed exploration of GaN-HEMT reliability, focusing on trap dynamics and negative bias stress in D-mode GaN-on-Si power MIS HEMTs under high temperatures. The study elucidates temperature-dependent negative bias-induced V_T instability and extracts thermal activation energy, providing insights into the underlying mechanisms for depletion-mode MIS HEMTs. Overall, this dissertation contributes to the understanding and advancement of GaN-HEMT reliability and performance optimization, crucial for the development of robust power electronic devices.