Abstract

AlGaN/GaN High Electron Mobility Transistors (HEMTs) are the prime contenders for replacing incumbent and competing technologies in all domains of high-frequency high-power applications. However, even with the outstanding material attributes of III-nitrides or with the excellent theoretical electrical characteristics of the GaN HEMTs themselves, this technology is yet to achieve widespread adoption in RF and power applications. The present thesis attempts to counter the bottlenecks by aiding in the conceptualization of better heterostructures, and by focusing on the inherent physical phenomena that limit their efficiency and reliability potentials. In the first part of the thesis, an analytical framework was developed that predicted the AlGaN/GaN (or GaN/AlGaN) metal-insulator-semiconductor (MIS) heterostructure charge density irrespective of structural polarity and polymorphism. The model allows customization according to specific applications such as E-mode/D-mode, MIS/MS (metal-semiconductor) structure. These charge-control solutions were later incorporated into a 2-D transport model to simulate the current and transconductance of fabricated HEMTs. The second part of the thesis reports on the current dispersion effects of AlGaN/GaN HEMTs from the perspective of threading dislocations, line defects that are ubiquitous in heteroepitaxial nitride growths. A methodology was developed for modulating dislocation density of heterostructures grown on the same substrate. Deep level traps were spatially quantified by characterizing ms quasi-pulsed I-V with changing duty cycle and pulse periods as well as by extracting signature time constants from single temperature detrapping transients. Correlating response to pulse drives, characterizing location specific transient response, and also evaluating normalized trap intensity for particular traps, a definite proportionate relationship was established between dislocations and current collapse. Next, the influences of dislocation induced off-state gate current were investigated in devices with dislocation density and leakage current orders apart. Initially, the current collapse was scrutinized for different combinations of the gate and drain quiescent bias. Then, three terminal off-state leakage current in all of the HEMTs were investigated as a function of field and temperature to conclude on the underlying mechanisms. A two trap (deep levels induced by surface states and dislocations) model was postulated that successfully explained both gate leakage and current collapse in off-states. Finally, simultaneous electrical, physical, and chemical analyses were conducted on electrically degraded unpassivated AlGaN/GaN HEMTs. Permanent degradation of the gate and the drain current were found to share different origins. For the latter, gradual consumption of the barrier in the form of electrochemical oxidation was responsible for the progressive increase in access resistance and consequent reduction in drain current. Also, the enhanced trapping activity and current collapse after bias stress were attributed to newly generated traps at the oxide-semiconductor interface. However, on the basis of almost unchanged gate current in the investigated devices even after -80V gate stress, the often observed leakage degradation in passivated devices was proposed to be solely correlated with the passivation layer.