Abstract

Gallium Nitride (GaN) with its large bandgap, high electron saturation velocity, and critical electric field has been widely applied in the fabrication of illumination, high frequency, and high-power devices. In addition, GaN has also been used for various sensing applications such as UV and gas detectors, etc. Another sensing application for GaN is in radiation sensing. This is because the Displacement Energy (E_D) of GaN is 20 eV which is much higher as compared to other semiconductors such as GaAs and Si. Up till now, different research groups have successfully fabricated GaN Schottky Barrier Diodes (SBD) and tested them for alpha particle detection. While SBDs with thin epitaxial layers (<12 µm) could only detect low energy alpha particles (<4.5 MeV) at -120 V, SBDs on bulk GaN substrate required very high voltage (-550V) to detect higher energies (5.48 MeV). However, both bulk GaN SBDs and SBDs with thin epitaxial layers show extremely poor performance at low voltages. The poor performance of GaN-based radiation detector is due to the high Threading Dislocation Density (TDD) and limited Depletion Width (DW). While high TDD increases leakage current (I_R), thus reducing the sensitivity of the detector, thin DW restricts the maximum energy which can be detected by a GaN detector.

In this thesis, the focus is to reduce I_R and increase DW by reducing TDD, Charge Carrier Density (CCD), and increasing Drift Layer Thickness (DLT). While TDD was successfully reduced (~3 orders) by employing a GaN-on-GaN structure, CCD was reduced by compensating the un-intentionally doped n-type (Si) dopants with p-type (Mg) dopants. In addition, multiple Drift Layers (DL) of different thicknesses were grown to improve the SBD performance further. Finally, the fabricated SBDs were then tested as radiation detectors to detect higher energy (5.48 MeV) alpha particles.

In this study, SBDs were fabricated on GaN-on-GaN wafers with 15 µm compensated DL. Compensation of DL reduced CCD by ~2 orders resulting in 3-order reduction of I_R (3 pA) and ~3 times improvement in Breakdown Voltage (V_{BD}) (1480 V) while having minimal impact on the forward current characteristics. To further increase DW and understand the effect of change in DW on diode characteristics, multiple SBDs were fabricated on GaN-on-GaN wafers with different Drift Layer Thicknesses (DLT) (2 µm, 5 µm, 15 µm, and 30 µm). Increase in DLT increases DW resulting in 1-order reduction in I_R. A linear increase in V_{BD} from 560 V to 2400 V was observed with an increase in DLT. The measured V_{BD} of 2400 V on SBDs with 30 µm DLT is the highest reported value to date.

To further enhance the understanding of the physical causes for the reduction in I_R and increase in V_{BD}, Conduction Mechanism (CM) and Activation energy (E_a) was extracted from the IVT characteristics of the SBDs. It was found that the CM changed from barrier modified Thermionic Field Emission (TFE) in conventional SBDs to regular TFE in compensated SBDs with 15 µm DL due to lower CCD and increased DW. Similarly, increasing DLT of SBD changed the CM from TFE to TE due to the reduced probability of electron tunneling through thicker DW. E_a of ~0.4 eV was extracted from IVT characteristics, which corresponds to activation of Mg-ions used to compensate the n-type (Si) dopants. CM and E_a together provide a clear understanding of the effect of compensation and change in DLT on the DW, thereby I_R and V_{BD}.

Finally, SBDs with compensated DLT of 15 µm and 30 µm were tested for radiation sensing applications by exposing them to Am-241 alpha particle source, which releases a 5.48 MeV alpha particle. These SBDs exhibited a near-ideal Charge Collection Efficiency (CCE) at 96.7% at -300 V (in 15 µm SBDs) and at -750 V (in 30 µm SBDs). The detectors with 15 µm DL also exhibited a CCE of 65% at a low biasing voltage of -20V. The measured CCE is 30% higher in comparison with other reported GaN radiation detectors. Furthermore, they exhibit 5 times lower variation of CCE with a change in applied voltages from -20V to -80V. The dramatic reduction in CCE variation with applied voltage and improvement in CCE is a result of the reduced

CCD due to the compensation by Mg in the grown GaN DL, which resulted in the increased of DW for the fabricated GaN SBDs.

In summary, high energy detection at low voltages have been realized by reducing TDD, CCD, and increasing DW. The designed GaN detectors function with high efficiency even at low voltages. These enhanced performances will help to realize a radiation detector with high efficiency, smaller form factor, and increased portability.