Oral Defense of Doctoral Dissertation

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ABSTRACT

OPTICAL CHARACTERIZATION OF WIDE-BAND GAP BULK CRYSTALS AND EPITAXIAL LAYERS

This dissertation describes the non-destructive optical characterization of undoped/doped GaN and SiC bulk crystals/epitaxial layers. These materials have applications for optoelectronic devices that are operational in the UV to green regions of the spectrum and also for devices operating at high-temperature, high-frequency and high-power. The primary tool used for the characterization of GaN is low temperature photoluminescence (PL) spectroscopy and for the characterization of SiC is photoluminescence imaging. Non-optical characterization techniques such as secondary ion mass spectrometry (SIMS), X-ray diffraction, Raman spectroscopy, etc., were also used to support the results obtained from optical characterization techniques.

In this thesis work, bulk GaN substrates: (1) grown by hydride vapor phase epitaxy (HVPE) method and (2) grown from solution at moderate temperature and pressure (SMTP) were used. Thick iron doped GaN substrate grown by HVPE showed no evident degradation in material properties due to iron doping, when compared to the thick unintentionally doped GaN substrate grown by the same method. Low temperature PL measurements performed on GaN crystals grown by SMTP at 800 ^{0}C and 0.25 MPa showed relatively sharp and intense exciton peaks, indicating good crystalline quality. Also good crystalline quality and relatively low free carrier concentration of these GaN crystals was verified using room temperature X-Ray diffraction and Raman spectroscopic measurements.

Low-temperature PL studies were also carried out on unintentionally doped and Si-doped homoepitaxial films grown by molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD) methods, respectively, to confirm the identification of O and Si as the dominant shallow donors in GaN films. Based on the PL spectroscopy, the intense peaks at 3.4716 eV and 3.4723 eV are associated with the neutral O and Si donors, respectively. Also the chemical nature of these background impurities and dopants were verified using high sensitivity secondary ion mass spectrometry.

High-resolution PL at 5K on a series of MBE grown Mg-doped (10^{17} – 10^{20} cm^{-3}) GaN homoepitaxial layers revealed intense bandedge emission with narrow linewidth (0.2-0.4 meV), attributed to annihilation of excitons bound to shallow Mg acceptors. Optically detected magnetic resonance study on this emission from a sample doped with [Mg] of 10^{17} cm^{-3} revealed the first evidence of highly anisotropic *g*-tensor ($g_{\|}$ ~2.19, $g_{\perp}$ ~0) for Mg shallow acceptors in wurtzite GaN.

PL characterization was performed on in-situ (Mg and Be) doped and Mg ion-implantation doped GaN films subjected to microwave annealing in the temperature range of 1300 ^{0}C - 1600 ^{0}C, for a duration of 5s/15s, using different caps (AlN and MgO) for protecting the GaN surface during annealing. In case of in-situ Mg doped GaN, AlN caps were more effective compared to the MgO caps. Low temperature

PL spectra and Hall measurements performed on the Mg in-situ doped or Mg ion-implanted GaN samples indicated that the 5-15s duration microwave annealing at 1500 ^{0}C is more effective in activating Mg acceptors than the 1300 ^{0}C microwave annealing. The microwave annealing performed on in-situ Be doped GaN samples showed pronounced Be out- and in- diffusion with increasing annealing temperature.

Real color (Red Green Blue) / monochromatic PL imaging was performed on 4H-SiC wafers to investigate the potential of PL imaging in identifying the sub-micron and microscopic defects in wafers. Results are compared with grazing-incidence synchrotron white beam X-ray topography (SWBXT), secondary electron microscopy in combination with electron beam induced current, and color cathodoluminescence. PL images of low angle grain boundaries correlate well with SWBXT images. This validation indicates that the PL imaging provides a rapid way of imaging low angle grain boundary structures in large-scale SiC wafers. The PL imaging was also performed on device structures to correlate device current-voltage characteristics with defects in the device area.