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CONCLUSIONS

In this dissertation, the growth and characterization of GaN and $Al_xGa_{1-x}N$ epilayers have been systematically studied. The AlGaN/GaN HEMTs with different doping layer and spacer were also demonstrated. Low temperature PL spectra were used to study the near-band-edge emissions of GaN and 2-DEG related emissions of AlGaN/GaN HEMTs. The etching techniques involving the ICP dry etch and PEC wet etch were also optimized in our systems. We reveal gate recessing of GaN-based FET by PEC wet etch. The WN_x T-gate AlGaN/GaN HEMTs for high temperature operation were also demonstrated. The primary results obtained in this dissertation are summarized below:

(1) The growth and studies of GaN and AlGaN films by buffer layer optimization were made such that we could growth high quality AlGaN/GaN HEMT structures. The near-band-edge emissions of u-GaN were studied at low temperatures that showed that the exciton emissions could be explained by the fine structures of valence band after electron-spin coupling. We also demonstrated the 2-DEG subband emissions at low temperatures that were never clearly resolved before. It showed that the stress has less effect on the subband emissions rather that on the bulk of GaN. The Coulombic interaction between the ionized dopants and the 2-DEG was also observed in the PL spectra, Hall measurement and *C-V* measurement.

(2) The effects of the ICP dry etch, and PEC wet etch and the hybrid ICP/PEC etch on GaN-based materials were studied. In summary, when the ICP power is higher than 600 W, the etch rates for nitrides show a relationship of AlGaN > GaN > InGaN for Cl_2/N_2-based ICP etch and the etch rates increase with the ICP power up to 1200

W. As for the PEC wet etch, the etch rate of AlGaN is higher than that of GaN, and due to the diffusion limit mechanism, the etch rate increases with the $KOH_{(aq)}$ concentration under 100 mW/cm^2 of UV exposure. The calculated Gibb's free energy for the ICP etch and the PEC wet etch matches the experimental results. Based on the DC characteristics of the Schottky diodes after ICP etch, the depth of the damages caused by the ICP etch was at least 150 Å under our experiment conditions. This study shows that a nearly damage-free surface can be obtained under hybrid dry ICP etch and wet PEC etch; this could be a very practical technique for the fabrication of electronic devices such as gate recess in the HEMTs.

(3) The electrical characteristics and the materials aspects of the refractory $TiWN_x$ and WN_x films as the Schottky contacts on n-type GaN were studied. From the low angle X-ray diffraction data, the WN_x film formed β-W_2N phase and the $TiWN_x$ film formed TiW_2N solid solution with Ti atoms dissolved in the β-W_2N lattice after deposition. Lattice parameter measurement on the WN_x films indicated a β-W_2N unit cell with lattice parameter larger than the reported data, which is due to the incorporation of excessive nitrogen atoms in the β-W_2N lattice. The lattice parameter of the β-W_2N phase and the TiW_2N solid solution decreased with increasing annealing temperature, which is believed to be due to the out diffusion of the N atom from the β-W_2N and the TiW_2N lattices. The WN_x Schottky contact to n-GaN was thermally stable up to 850℃, and the ideality factor and the barrier height remained at 1.10 and 0.80 eV, respectively after 850℃ annealing. The Schottky characteristics of the $TiWN_x$/n-GaN contact remained stable up to 650℃ annealing with the ideality factor and the barrier height remained at 1.14 and 0.76 eV, respectively. The contact degraded after 750℃ annealing and become Ohmic-like behavior after 850℃ annealing. This degradation of the diode was due to the atomic inter-diffusion between $TiWN_x$ and GaN that occurred at higher temperatures as

indicated by the SIMS analysis.

(4) We demonstrated the high temperature durable WN_x T-gate AlGaN/GaN HEMTs with operation temperatures up to 330℃. The WN_x T-gate was fabricated by sputtering and etch-lift-off processing that was proven to work well at high temperatures. The gate recessing by PEC wet etch was also demonstrated which showed it’s a promising method in fabricating damage-free gate. DC characteristics for various recessed-gate showed that PEC wet etch was a very practical technique in AlGaN/GaN HEMT fabrication. Ti/Al/Pt/Au also worked well at high temperatures. The low transconductance and current collapse showed that there were still a lot to improve in epitaxial film quality, especially in AlGaN material. Although the DC properties of the WN_x-gate HEMT needs further improvement, the etch techniques developed here, the metallization of the Ohmic and the Schottky contact were proven promising.