CHAPTER 6

Summary

In summary, in this dissertation we have studied the low-dimensional structure of GaN-based materials and devices, including their fabrication, growth and quantum optical phenomena. GaN-based low-dimensional GaN-based semiconductors offer a fascinating field of research for both fundamental physics and for device design. The breaking of parity has strong impact of the strength and mechanisms that rule the light-matter interaction in these materials. In the case of two-dimensional structure, the enhancement in light output of the InGaN/GaN MQWs microhole array LEDs from conventional broad area (BA) LEDs were simultaneously examined with the TracePro simulation. The electrical characteristics of the devices are similar to those of conventional BA LEDs. The light output from the micro-hole array LEDs was over 36% grater than that from conventional BA LEDs with the same device areas. However, the light output declined as increased further, perhaps because of the combination of the enhancement in extraction efficiency caused by the large surface areas provided by the sidewalls and the decrease in area of light generation by holes in the microhole array LEDs. The findings indicate that an optimal design can improve the light output efficiently of the microhole array LEDs.

In the case of one-dimensional structure, the fabrication and characterization of InGaN/GaN MQWs embedded within nanorods with diameters of about 60 to 100 nm were investigated. Two fabrication technologies of the nanorods were presented, including directly ICP etching and ICP etching with the self-assembled Ni nanomasks. Their optical properties showed that sharp and narrow optical emission spectra from the InGaN/GaN MQWs nanorods, observed by micro-photoluminescence measurement at 4K, reveal a large blueshift of about 90 meV and over 17 times enhancement in photoluminescence intensity-density compared with that of the as-grown wafer under the same excitation power density. Partial released piezoelectric field in the etched InGaN/GaN MQWs nanorods was considered to be one of the origins of the blueshift in the photoluminescence spectra. The excitons of InGaN/GaN MQWs are strongly confined in quantum dots-like region or localization centers, which are observed in the one-dimensional structure of nanorods.

In the case of zero-dimensional structure, the growth and optical properties of the InGaN quantum dots (QDs) grown on SiN nanoholes were studied. The average lateral size and height of the InGaN QDs are estimated to be about 33.2 nm and 0.64 nm. As increasing the duration of the SiN treatment, the QD sizes become larger up to 35.7 nm of lateral size and

2.4 nm of height. The QDs densities were estimated to be increased approximately from 2.1×10^{11} cm^{-2} to 2.9×10^{11} cm^{-2}. In the optical properties, the redshift in photoluminescence spectra as the duration of the SiN treatment increased was observed, which could be attributed to the increasing in the height of the InGaN QDs (or nano-islands) due to quantum effects. Moreover, the thermal annealing effects on the optical properties of the InGaN QDs grown on SiN nanoholes were also explored. About 57 meV blueshifts of the PL peak positions and a decrease on the activation energy of 19 meV were observed from the InGaN QDs after 950^{o}C annealing, which may be due to In /Ga inter-diffusion and variation on the QDs size by post-grown thermal annealing.

Additionally, the effects of δ-TMIn-flow process with an initial f_{TMIn} of 400 sccm during the well layer growth on the optical properties of InGaN/GaN MQWs were investigated and compared with the conventional LEDs. The light output of the GaN LEDs with the δ-TMIn-flow process is increased up to 24% without obvious deterioration of interfacial abruptness, which were supported by the improvement on the localization effects and the activation energy of the LEDs with the δ-TMIn-flow process. These results suggest that the composition fluctuations or QDs-like regions formed by using δ-TMIn-flow process can provide the necessary confinement for an improved recombination rate. This paves the way for improved GaN-based optoelectronic devices grown by MOCVD.