Carrier Dynamics in III-Nitride Semiconductors

by

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ABSTRACT

In the past decade, III-nitride semiconductors had a considerable impact in solid state lighting and high speed high power electronics. As technology develops, high Al content III- nitride semiconductors lead the edge of research. It opens the door to many applications especially portable ones: from homeland security, bio-analytical, medical diagnostic, air and water disinfection, sterilization, chemical sensing systems, non-line-of-sight (NLOS) communications, to high-density optical data storage. In this thesis, we first study GaN epilayers, as well as more complicate high Al content AlGaN/AlGaN MQW structures used as active media for deep UV LEDs.

We theoretically study the photoluminescence (PL) dynamics in high quality GaN epilayers by establishing a new decay model. In our model, surface recombination, diffusion, and re-absorption are taken into account. Our model is in excellent agreement with experimental data obtained by time-resolved PL. Our results show that the carrier diffusion and surface recombination play key roles in the PL decay.

For high Al content AlGaN/AlGaN MQW structures, we first present the investigation of built-in electric fields in $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ MQWs embedded into *p-i-n* structure by using photoluminescence experiments. By comparison of the Stark shifts induced by the *p-i-n* structure and by photo-excited free carrier screening, we evaluate the intrinsic electric field induced by piezoelectric and spontaneous polarizations. Furthermore we investigate carrier dynamics in sets of identically grown $Al_{0.35}Ga_{0.65}N/Al_{0.49}Ga_{0.51}N$ MQW structures with well widths varying from 1.65 to 5.0 nm by TR-PL and LITG techniques. We observed screening of the built-in electric field by free non-equilibrium carriers and localization governed PL kinetics at different

decay stages. A decrease of carrier lifetime with increasing well width is observed and attributed to the carrier localization occurring due to well width fluctuations of the quantum well.

An extremely low decrease of the emission intensity with temperature increasing from 10 K to 300 K was observed in deep UV LED structure with emission at 285 nm. Room temperature IQE for such structures as high as 70 % was estimated under the optimal rate of carrier generation. Carrier lifetimes of 1 ns were observed in the TRPL experiments, they are considerably longer than those reported before for high aluminum content AlGaN MQW structures. The temperature and excitation power density dependences of the quasi-steady-state PL characteristics and our TR-PL study demonstrate a strong carrier (exciton) localization in such structures emitting at 285 nm. No dependence of the lifetime on the energy of the localized excitons was observed. Ray-tracing simulation demonstrates a great potential for improvement of the external quantum efficiency of deep UV LED devices by optimization of light extraction efficiency.