Recombination dynamics in Si-doped AlGaN and ultraviolet light-emitting diodes grown on sapphire and bulk AlN substrates by metal-organic vapor-phase epitaxy

by

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ABSTRACT

In this dissertation, Si-doped AlGaN and AlGaN based ultraviolet light-emitting diodes (UV LEDs) have been grown by using an Aixtron 200/4 RF-S metal-organic vapor-phase epitaxy (MOVPE) system. The dissertation includes (i) the growth and characterization of AlN and AlGaN on sapphire and bulk AlN substrates; (ii) the investigation of parasitic luminescence in Si-doped AlGaN and (iii) the analysis of recombination dynamics in UV LEDs.

Two different methods, namely the two-step growth method and the flow-modulation high-temperature (FMHT) AlN method, are investigated for the development of high quality AlN epilayers on *c*-plane sapphire substrates. In the optimization of the two-step growth of AlN epilayers, several different parameters are investigated and varied, which include the growth time, growth temperature, growth pressure, thickness, TMAl and NH_3 flow rate of nucleation layer. On the other hand, the pulse duration, the number of pulses, and flow-modulation interruption times are investigated for the optimization of FMHT-AlN epilayers.

In order to find out the origin of the parasitic blue luminescence in AlGaN, the effect of ammonia, Si doping, and dislocations on the electrical and optical properties of AlGaN is investigated. The UV-to-blue luminescence ratio in n-type $Al_{0.3}Ga_{0.7}N$ grown by MOVPE is investigated as a function of silane flow rate. Experimental results show that in the high doping regime, the UV-to-blue ratio is almost unchanged even though the silane flow rate changes over more than one order of magnitude. However, when the silane flow rate is lower than 1.13×10^{-9} mol/min, the UV-to-blue ratio increases rapidly as the silane flow rate decreases. A theoretical model is developed, which suggests that the parasitic blue emission originates from acceptor-like compensating native defects. It is also found that both free carrier concentration and mobility decrease with increasing edge dislocation densities. The acceptor-like traps formed by the dangling bonds along the edge dislocation lines can act as Coulomb scattering centers and also compensate the Si dopant. The energy level of these compensating native defects becomes deeper in AlGaN as the Al composition increases. The edge dislocations also act as non-radiative recombination centers, which are inferred from a decreasing photoluminescence

intensity versus edge dislocation density. The UV-to-blue ratio is found to be independent of the edge dislocation density, but strongly dependent on the Si doping concentration.

After the growth and fabrication of UV LEDs, the electroluminescence intensities of the UV and parasitic green emission of AlGaN UV LEDs are studied as a function of the injection current. For samples grown on AlN substrate, the UV luminescence peak intensity increases linearly with the injection current, while the green luminescence peak intensity increases sub-linearly. On the contrary, the samples grown on sapphire substrates show a supra-linear and linear dependence on the injection currents for the UV and green luminescence, respectively. A theoretical model is proposed to explain the relationship between the peak intensities and the injection current. The results obtained from the model are in excellent agreement with the experimental results. The model provides a method to evaluate the dominant recombination process by measuring the exponent of the above-mentioned power-law dependence.