Electrical and Cathodoluminescence Studies on the Efficiency of GaInN/GaN Light Emitting Diodes

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ABSTRACT

In this dissertation, several characterization methods, mainly electrical and cathodoluminescence methods, are performed to enable the development of high efficiency light emitting diodes.

The first part of the dissertation is a charge profiling investigation of green LED dies by means of capacitance-voltage measurements. Under reverse bias conditions, three distinctive steps were found in the C-V data. Those steps were associated to the stepwise depletion of electrons in the three QWs closest to the *p*-side of the LED. To the best of our knowledge, this is the first time individual QWs can be identified by C-V measurement in group-III nitride LED-type structures. Furthermore, this C-V methodology was expanded to explore the *p*-layer side. A step-by-step depletion model was proposed according to the different doping levels of different layers. The thickness of the active region and the approximate thickness of the electron blocking layer can be determined by this model. A close correlation was found for the comparison between the layer thickness data derived in standard C-V measurement and from x-ray diffraction measurements. Furthermore, the frequency dependence of C-V data reveals a characteristic time constant of 1 μs for the ionization process of the fixed charges. We identify charge densities directly correspond to the polarization charge densities of the polarization dipoles at the hetero-polarization structure of the $Ga_{1-x}In_xN$/GaN interface. It is demonstrated that this C-V charge profiling provides a most suitable handle for the fast and reliable LED device characterization and optimization.

The second part of this dissertation explores the possibility to enhance LED light output performance by inserting a GaInN underlayer between the *n*-type region and the MQW light emission region. The first step is to explore blue emitting SQW samples with and without ULs. We found that the insertion of such UL can generate a lot of full-grown V-defects which seem to act as a minority carrier separation layer between the active region and the TDs. The layer can prevent non-radiative recombination at the TDs. Apparently such a controlled decoration of TDs with V-defects can be used to substantially enhance the luminescence efficiency. Encouraged by such results, we explored the possibility to implement the UL technique in green emitting LEDs. In

several MOVPE growth iterations, similar green emitting LED structures with different InN content in the GaInN unerlayer were developed and fabricated to full LED structure in our group. We characterized the results by means of PL intensity, internal quantum efficiency, and EL light output power and found that the 530nm LED EL light output power can be increased by as much as 85 % in a structure containing a x = 6.3 % $Ga_{1-x}In_xN$ underlayer when compared to the standard reference sample without such UL. The IQE value was determined by the temperature dependence of PL. It reaches as high as 66 % compared to 32 % in the reference sample without UL. This correlates well with the previous EL data. As the In content reaches 8.8 % in the UL, the sample EL performance becomes even worse than the reference sample without UL. From cathodoluminescence depth profiling results we propose that the UL here can catch excess carriers and prevents their recombination through radiative and non-radiative DAP transitions. By inserting of an UL with suitable alloy composition the LED performance can substantially be enhanced, about doubling the light out power even in the 530 nm green spectral region.

The last part of this thesis explores one of the possible origins of efficiency droop of LEDs with increasing driving current. Readers of this thesis are reminded of their honorable duty not to interfere with the priority rights of such work. In various measurements, a 255 – 260 nm luminescence peak was found on c-plane bulk GaN and MQW on sapphire in CL at low temperature. Low-temperature EL spectra also show a similar peak near 267 nm. The peak's intensity increases with LED drive current. This peak possibly comes from the radiative Auger recombination process. It may originate in a higher order transition involving higher states of the conduction band, possibly populated by means of the Auger effect.