Radiative and non-radiative processes in green InGaN/GaN quantum wells

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Abstract The optical properties and carrier dynamics of green-emitting InGaN/GaN quantum wells with different thicknesses were investigated by (time-resolved) photoluminescence. Thick samples show very long lifetimes in their low energy tail

Introduction

Multiple approaches for white LEDs with a high CRI exist. On one hand, a blue (or UV) LED can be combined with a (e.g. phosphorous) conversion layer. This however inherently limits the efficacy of such devices. On the other hand, a CRI>95 can be obtained by mixing blue, green (both InGaN) and red LED (InGaAlP) (1). Here, the efficacy is currently limited by the green component, which performs poorly compared with the other two. State-of-the-art green LEDs employ an InGaN/GaN MQW active region grown on c-plane sapphire with large GaN buffers. Using c-plane substrates, while comparably cheap, means that the active region is grown along the polar c-axis of the wurtzite structure. Therefore, strong pyro- and piezoelectric fields are present in the active region. The resulting band bending in the active region causes a reduction in the emission energy and an increased separation of electrons and holes in the QWs (this is called the Quantum Confined Stark Effect (QCSE)) (2). As the QW thickness increases, so does the QCSE. While this allows to alter the emission wavelength to match the preferred 530nm, it also inceases the radiative lifetimes and is thought to decrease the internal quantum efficiency. To avoid this problem, it is generally preferable to control the emission wavelength by the In composition of the QWs. Growth of high In composition InGaN is however challenging (3). Therefore a deeper understanding of the underlying phenomena limiting the efficiency of thick c-plane InGaN-QWs is necessary.

Samples

The investigated structures were grown by MOCVD and feature five $In_{0.22}Ga_{0.78}N$ QWs each, which are separated by 27nm GaN barriers to rule out interactions between QWs. The QW thickness is varied between 2.2nm and 3.8nm. The active layer is grown on c-plane sapphire with a thick (~3µm) GaN buffer and capped by an AlGaN EBL and 80nm GaN.

Photoluminescence Properties

The samples emit in the green range, from around 490nm for the 2.2nm thick QWs to 550nm for the 3.8nm thick QWs. Photoluminescence excitation spectroscopy show very similar absorption edges, indicating that the samples indeed feature identical In composition. A huge Stokes shift of more than 500meV is observed for the thickest sample. In power dependent PL measurements, the emission blue shifts due to partial screening of internal fields, with higher shift rates for thicker QWs. This confirms the origin of the thickness dependence of the emission energy to be the QCSE. As the temperature is increased (Fig. 2) the 3.8nm sample performs more than an order of magnitude worse than the 2.2nm and the intermediate 3.0nm sample. These much higher non-radiative losses could be caused by longer radiative lifetimes in this sample (due to the QCSE-induced electron-hole separation) or by an increased incorporation of defects during the (more challenging) growth of the thicker QWs.

Time-resolved Photoluminescence (TRPL)

Room temperature TRPL shows very similar bi-exponential decays for thin and thick QWs (Fig. 3), with two rather

long (4) components of around 70ns and 300ns, respectively. Notably, the decay time in the peak of the PL emission does not increase with QW thickness, suggesting that the QCSE is not the primary cause of the performance degradation. The longer decay component does, however, dominate and increases to 500ns in the low energy tail of the thick sample's luminescence. Measurements in superfluid Helium (Fig 4.) yield drastically increased decay times of up to 8µs for this region, while the thin sample's dynamics are relatively unchanged. This suggest the presence of localized states in the thick sample, which can be activated at room temperature and are probably caused by defects.

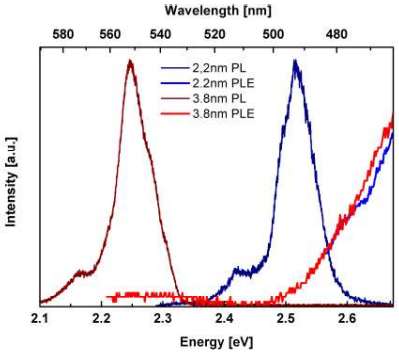

Fig. 1 Normalized PL intensity (dark) and PLE spectra (light) of the 2.2nm (blue) and 3.8nm (red) samples.

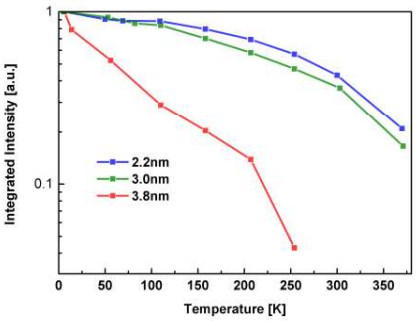

Fig. 2 Temperature dependence of the integrated PL intensity of the 2.2nm (blue), 3.0nm (green) and 3.8nm (red) samples.

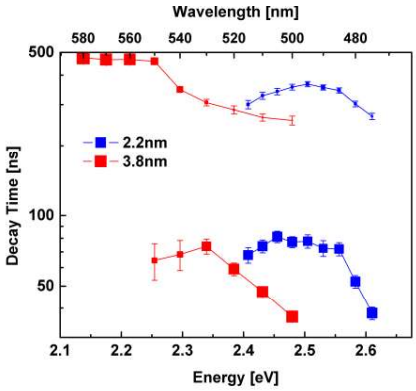

Fig. 3 Decay times and intensities (dot size) of the observed bi-exponential decay at room temperature.

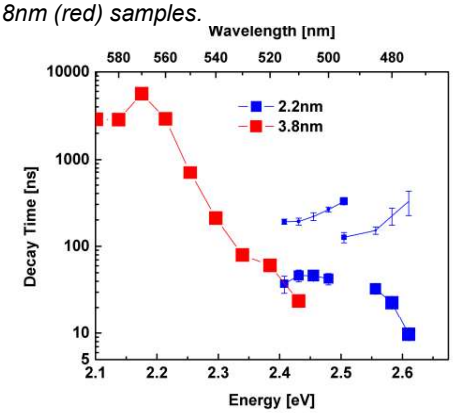

Fig. 4 Same as Fig. 3, at 2K. (Note change of scale)

Conclusions

While the samples show a strong influence of the QCSE, the efficiency decrease towards thick QWs is mostly governed by increased defect generation leading to long-lived localized tail states at QW thicknesses above 3nm.

References

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Felix Nippert received his Diploma degree in Physics from Technische Universität Berlin in 2012.