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Effects of Well Thickness on the Light Emission in InGaN/GaN and GaN/AlGaN Multiple Quantum Wells

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Summary

Picosecond time-resolved photoluminescence (TRPL) has been employed to study the effects of well thickness on the light emission properties and recombination dynamics in $In_xGa_{1-x}N$/GaN and GaN/$Al_xGa_{1-x}N$ multiple quantum wells (MQWs) grown both by metal-organic chemical vapor deposition (MOCVD) and reactive molecular beam epitaxy (MBE). In this work we present results from a set of MOCVD grown $In_xGa_{1-x}N$/GaN and a set of MBE grown GaN/$Al_xGa_{1-x}N$ MQW samples with well thicknesses varying from 20 to 90 Å. Results from these MQW samples are compared with each other and also to InGaN and GaN epilayers to extrapolate the mechanisms and quantum efficiency of the optical emission in these structures. The implications of these results on device applications, in particular for blue LEDs and laser diodes will be discussed.

1. $In_xGa_{1-x}N$/GaN MQW. The MQW sample with 25 Å well thickness showed only intrinsic localized exciton emission from the well region at low temperatures with recombination lifetimes in the sub-nanosecond scale, demonstrating high crystalline quality of the MQW structures. The MQW sample with 45 Å well thickness showed emission lines from both the well and barrier regions. For the MQW sample with 90 Å well thickness, an impurity related transition was observed to be dominant in its emission lines. In summary, our results have revealed that (i) the optical transitions in both the 25 Å and 45 Å well MQW samples were blue

shifted with respect to the $In_xGa_{1-x}N$ epilayer, however, no such blue shift was evident for the 90 Å well MQW sample, (ii) radiative recombination is dominant at low temperatures for the 25 Å well and 45 Å well MQW samples, and (iii) in 45 Å well MQW, the carrier transfer rate from the barrier to the well is strongly temperature and excitation intensity dependent.

2. GaN/$Al_xGa_{1-x}N$ MQW. In GaN/AlGaN MQWs, the dominant emission lines always resulted from the well region. In MQWs with well thicknesses of 20 and 25 Å, the emission lines at low temperatures were due to localized excitons. On the other hand, the band-to-impurity recombination dominated at low temperatures in MQWs with well thicknesses larger than 50 Å. In summary, our results have revealed that (i) the optical transitions in both the 20 Å and 25 Å well MQW samples were blue shifted with respect to the GaN epilayer, however, no such blue shift was evident for the MQW samples with well thicknesses greater than 50 Å, (ii) the localized exciton recombination lifetimes in MQWs of narrow well thicknesses increased linearly with temperature up to 60 K, which was a hallmark of radiative recombination in MQWs, and (iii) impurity related transitions, most likely the band-to-impurity transitions, were the dominant emission lines in MQWs of large well thicknesses (> 50 Å).

All of these results can be explained by the concepts of the critical thickness of the MQWs. For both InGaN/GaN and GaN/AlGaN MQWs, below the critical thickness (e.g., in MQWs with 20 - 30 Å well thicknesses), intrinsic localized exciton transitions with expected quantum confinement (or blue shift) were observed. Above the critical thickness, structural defects and spatial nonuniformity were introduced, which caused impurity related transitions to be dominant with no evident of blue shift.

In terms of device applications, these results suggest that the better configuration for LED and laser diodes is to use multiple quantum wells of narrow well widths. The quantum efficiency is expected to be reduced dramatically when the well thickness becomes larger than a certain value since the band-to-impurity transition is less efficient compared with that of the excitonic transitions.