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Carrier transport, polarization matching, and efficiency droop in GaN-based visible LEDs

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Transport of electrons and holes in GaInN/GaN LEDs is known to be largely asymmetric, due to differences in carrier mobility and the ionization energy for donors and acceptors. Sheet charges at heterointerfaces of devices grown in the c-direction, which arise due to mismatch in spontaneous and piezoelectric polarization, further hinder transport by increasing barriers for carrier injection into quantum wells. The effect of these sheet charges upon capture of carriers by quantum wells is analyzed with a quantum-mechanical calculation of the dwell time of electrons and holes over quantum wells. Wavefunctions and dwell times are calculated using the k.p quantum transmitting boundary method with the wurtzite 8-band Hamiltonian with Burt-Foreman operator ordering. The effect of quantum well width upon dwell time is also considered. It is shown that both reduction of sheet charges by polarization matching and the increase of well width result in substantially longer dwell times, and therefore higher probability of capture. Experimental results of LEDs with polarization-matched active regions are presented. Such LEDs are shown to have improved efficiency throughout the entire range of forward currents. This indicates that a reduction in carrier density is not solely responsible for the improved efficiency, since reduced carrier density would also lead to a higher Shockley-Reed-Hall rate at low currents. The implications of this result are discussed in detail. Further, experimental results of LEDs with varying doping in the active region are presented. It is shown that a reduction in doping – which has the effect of slowing electron transport – results in an increase in efficiency at large forward currents. This result is explained in detail using modeling results.