# Multidimensional Numerical Modeling on the Influence of Random Alloy Fluctuation in InGaN Quantum Well LED to the Transport Behavior

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The efficiency droop issue of nitride based light emitting diode(LED) has been a critical problem for lighting, where the efficiency drops as the current density increases. The major reason is the quantum confined stark effect (QCSE) induced by the piezoelectric and spontaneous polarization field at InGaN/GaN interface due to the strong strain induced by lattice mismatch. This also induces stronger random alloy indium fluctuation in the quantum well(QW) and observed by atom probe tomography. The influences of random alloy to the emission spectrum broadening and shift have been studied through atomistic model by many researchers but the influences to carrier transport were less reported.In addition, the traditional 1D Poisson and drift-diffusion solver failed to predict the I-V behavior due to the induced large piezoelectric field, where a much larger voltage is predicted. However, this is not the case in commercial LED[1]. Therefore, we modeled the influence of the random indium fluctuation in the QWs on the carrier transport with our 2D and 3D FEM Poisson and drift-diffusion solver[1, 2] with a dense mesh and found that the I-V curve can be fitted much better. The efficiency droop behaviors are also explained well. Most commercial grade LED observed a droop behavior at a small voltage ( 2.9V-3.0) and we found that this can only be fitted by considering Auger effects because it has not reached the flat band condition where overflow is relative much weaker. Especially due to the high localized carrier density, the Auger recombination is enhanced at low current density where a smaller Auger coefficient ($\sim 2-5\times10^{-31}$ cm$^6$/s) is needed and this value is more close to theoretical prediction. This effect is never expected before we included the fluctuation model into the carrier transport. To further improve our work, recently we also developed a 3-D finite element method for the strain calculation and analyzed the local strain relaxation to make the calculation more accurate. In the future work, we start to work on 3D potential landscape model[3] to include the quantum effect without losing calculation speeds too much and we will discuss the progress on this work.

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## References

[1] Yuh-Renn Wu, Ravi Shivaraman, Kuang-Chung Wang, and James S. Speck, Analyzing the physical properties of InGaN multiple quantum well light emitting diodes from nano scale structure, *Appl. Phys. Lett.* **101** (2012), p083505.

[2] Tsung-Jui Yang, Ravi Shivaraman , James S. Speck, and Yuh-Renn Wu, The Influence of Random Indium Alloy fluctuations in Indium Gallium Nitride Quantum Wells on the Device Behavior, 116, 113104, 2014. *J. Appl. Phys.* **116** (2014), p113104.

[3] M. Filoche and S. Mayboroda, Universal mechanism for Anderson and weak localization,*Proc. Natl. Acad. Sci. USA*, **109**, (2012), pp14761-14766.