

Introduction to the Special Issue on “Simulation of GaN-based Light-Emitting Diodes”

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The Nobel Prize in Physics 2014 was awarded jointly to I. Akasaki, H. Amano and S. Nakamura “for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources”. Their invention of GaN-based LEDs has generated intense worldwide research and development activities, not only for general lighting applications, but also in many other areas, such as displays, sensing, biotechnology, and medical instrumentation.

Growing efforts are currently directed towards modeling and simulation of these devices. To a large extent, these efforts are driven by a mysterious phenomenon, the so-called efficiency droop. The expected high energy efficiency of GaN-based LEDs is only observed at low injection current and low light power. With rising current, injected electron-hole pairs disappear increasingly in non-radiative recombination processes, thereby reducing the fraction that delivers photons (internal quantum efficiency). Still unclear is the specific non-radiative mechanism that dominates this efficiency droop. The two leading explanations are Auger recombination and electron leakage, respectively, in possible combination with other effects. However, very few direct measurements of either mechanism are published thus far, none of which establishes a dominating magnitude. Thus, many publications on the efficiency droop base their quantitative claims on the modeling and simulation of efficiency measurements. Several contradicting models have been shown to reproduce the same type of measured efficiency characteristics. But in any given case, only one such model, if any, can be correct. This dilemma represents a severe but valuable challenge to the computational electronics community.

The present Special Issue intends to address this challenge by giving leading groups the chance to explain their recent results in detail. Most authors express the Auger process by the simple coefficient C since a realistic microscopic theory for Auger recombination in InGaN quantum wells is still not available. Some authors follow my suggestion to apply their theory to the same experimental LED structure, which enables a more direct comparison. The difference between modeling approaches is mainly found in the carrier transport models, including the common drift-diffusion concept, the Monte-Carlo method (Kivisaari et al.), the non-equilibrium Green's function (Auf der Maur), non-local transport (Li), and percolation transport considering random alloy fluctuations (Wu et al.). Hader et al. present an alternative explanation for the recently claimed direct measurement of Auger recombination in InGaN quantum wells. Kisin and El-Ghoroury investigate the non-equilibrium carrier distribution inside multi-quantum well active regions. Mandurrino et al. model trap-assisted tunneling in GaN-based LEDs. Roemer and Witzigmann describe an advanced acceptor activation model. Last but not least, Marquardt et al. study the electronic properties of InGaN nano-structures inside GaN nano-wires.

This collection of invited papers presents an instructive snapshot of current models and a valuable basis for the further exploration of the sophisticated physical processes inside GaN-based LEDs. I sincerely thank all authors for their contribution to this Special Issue.

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