

## Heterostructure Active Area Optimization by Simulation

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Changing LED performance characteristics, depending on Indium atoms concentration and at different temperatures were simulated. It was suggested that a LED having  $p$ - $n$  junction area  $S_0$  can be considered as a sum of "SmallLEDs (SLEDs)" electrically connected in parallel, each SLED has its own In-content and its own  $p$ - $n$  junction area  $S(X)$ . Good correlation in simulation and experimental results has been obtained. It was determined that the best structure for AlGaInN NH is  $p^+GaN / p^+Al_{0.2}Ga_{0.8}N / 4(n-In_xGa_{1-x}N-n-GaN) / n^+GaN$ . The main thing is that in the NH AA there are 4QW-in two central ones there is maximum radiation and two ones at the both ends of active region are "barriers" which help to concentrate electrons / holes in active region and additionally "protect" QW from different defects.

**Keywords:** Light-emitting diode, InGaN, Simulation.

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## 1. INTRODUCTION

The last decade proved an increase the simulation usage for semiconductor devices investigation. Device simulations play an important role in device research, Winston [1]. As devices become more complex, researchers and designers turn to simulation tools.

## 2. EXPERIMENTAL PROCEDURES

In current work simulation was carried out in SimWindows 1.5 which was created by David W. Winston. The specific features of this program are: 1) the electrical, optical and thermal device properties for simulation based on system of exact physical equations; 2) the simulation possibilities with 1D approximation of various kinds of two-lead devices (diodes, photodiodes, laser and etc.) based on different materials: Si, Ge, solutions  $A^{III}B^V$ ,  $A^{II}B^VI$  and etc.; 3) the device simulation possibility with the structures containing plenty of layers including layers with quantum-mechanical properties (single and multiple quantum wells). The software extends a lot of traditional electrical models by adding effects such as quantum confinement, tunneling current, and complete Fermi-Dirac statistics. The program has an exclusive flexibility at optoelectronic semiconductor device simulation. Exact solutions of electrical, optical and heat transport phenomena in 1D case have been put into its basis. For example, drift-diffusion currents, thermoionic and tunneling currents of electrons and holes are taken into account, in recombination of charge carriers radiating spontaneous and stimulated band to band transitions and non-radiating Auger and SHR transitions are considered. For band diagram calculations Fermi-Dirac or Boltzmann statistic and full version of Poisson differential equation has been used. Poisson equation includes the impact of ionized donors and acceptors, free electrons and holes and bounds in quantum wells electrons and holes charges.

## 3. RESULTS AND DISCUSSION

InGaN active areas in heterostructures and LEDs simulation was divided into two parts. At first the opti-

imum quantum well (QW) quantity for InGaN heterostructures was determined. Secondly blue and green InGaN LEDs were simulated at different temperatures (233 K, 300 K, 398 K). For the simulation new device and material files were created. More than 25 parameters such as geometrical QW sizes, type of conduction, doping concentration, bandgap, optical absorption, thermal conduction, electron affinity, coefficient of radiation and radiationless recombination were included. One of the most important parameters of LED radiation properties is internal quantum efficiency (QE)  $\eta_{internal}$ . By the definition  $\eta_{internal}$  is the ratio of radiation recombination velocity  $U_{B-B}$  to the total recombination velocity  $U_{Tot}$ .

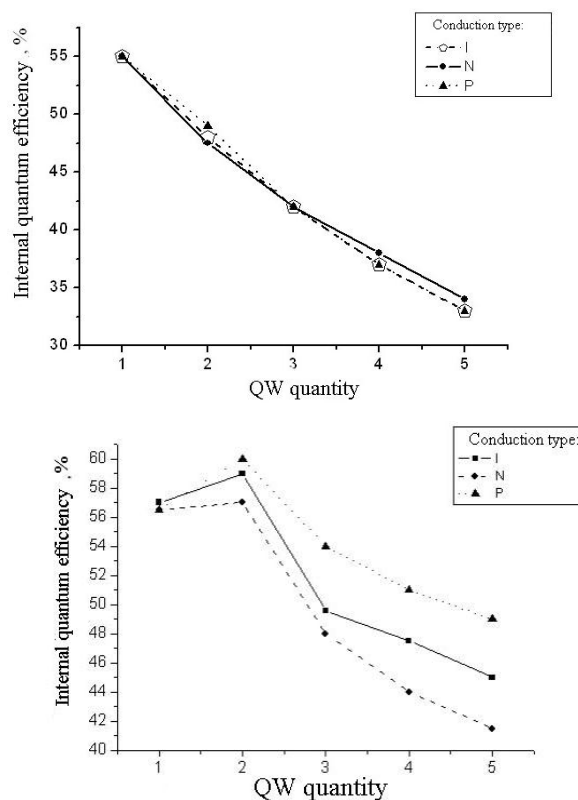


Fig. 1 – Internal quantum efficiency vs QW (QW width 2/3.5 nm) @ 100 A/cm<sup>2</sup>

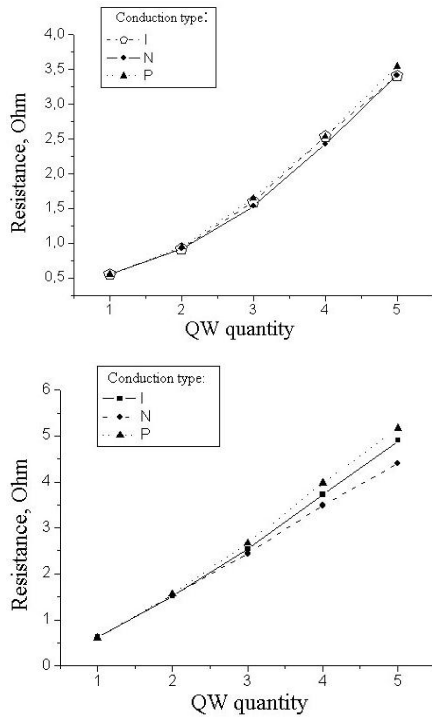


Fig. 2 – Resistance vs QW (QW width 2/3.5 nm) @ 100 A/cm<sup>2</sup>

Based on the results of the first part of InGaN active area simulation at current densities 80, 100, 900 and 1000 A/cm<sup>2</sup> and different QW width (2/3.5 nm) it can be seen that the most effective (based upon internal quantum efficiency) are heterostructures with 4 QW – mainly radiation is in the middle ones and edge are like quasisubuffers and with inject carrier current (Fig. 1-4).

With the effect of QW quantity the  $\eta_{internal}$  will decrease and resistance will increase. It can be also said

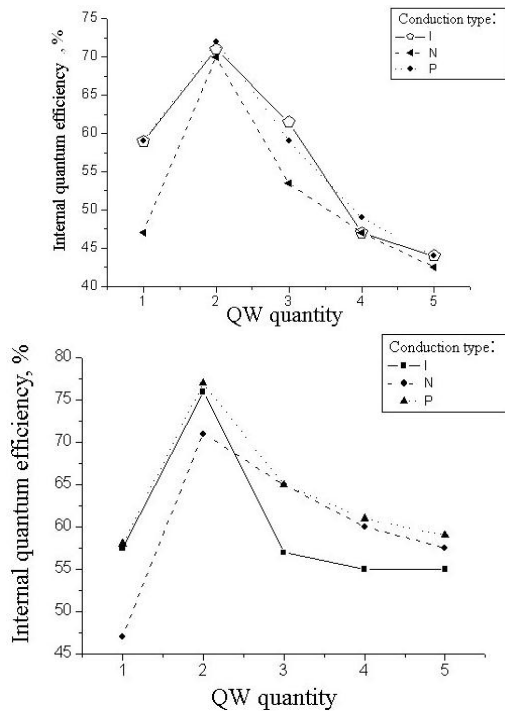


Fig. 3 – Internal quantum efficiency vs QW quantity (QW width 2/3.5 nm) @ 100 A/cm<sup>2</sup>

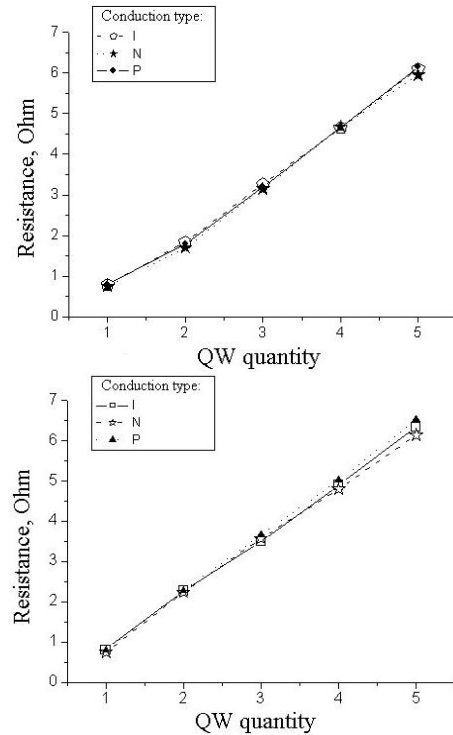


Fig. 4 – Resistance vs QW quantity (QW width 2/3.5 nm) @ 100 A/cm<sup>2</sup>

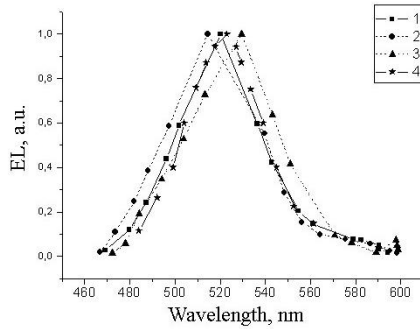
that LEDs can be used at current densities more than 100 A/cm<sup>2</sup> if there is low contact ohmic resistance.

Results of blue LED simulation are presented in the Fig. 1-2. Results of green LED simulation are presented in the Fig. 3-4.

During the second part green and blue InGaN heterostructures were simulated with different In concentration for blue  $x = 0.15-0.25$ , green  $x = 0.25-0.35$  LEDs which are continuation works [2-4]. In published experimental works it was determined that in  $In_xGa_{1-x}N$  quantum well active region of blue and green LED spatial indium content fluctuations are responsible for many peculiarities of electrical and optical characteristics of devices. In several works these peculiarities were explained by creating of additional energy state tails below  $In_xGa_{1-x}N$  band gap. In such models an average value of indium content  $X$  is defined to all coordinates of quantum well active region of LEDs. It was proposed to consider quantum well active region of blue and green LEDs as a combination of local spatially distributed regions which have their own fixed indium content. In this case a local region can be considered as a local SLED which has its own  $p-n$  junction area. In general a LED can be considered as a sum of SLEDs with the electrical parallel connection.

Spectra have asymmetric shape, in the long wavelength part of spectra radiation power is decreasing slower than in the short wavelength part of spectra. Simulation proves the spectral “blue shift” at current density increase even at quantum Stark-Keldysh effect is neglected (Fig. 5).

The most experimental dependencies of blue LED electrical and optical parameters and characteristics on current density and temperature are proved by computer simulation based on the new model of a LED quantum



**Fig. 5** – Electroluminescence spectral characteristics 1 –  $T = 300$ , 2 –  $T = 398$ , 3 –  $T = 233$ , 4 – experimental data

well active region having spatial indium content fluctuations. As it was detected the shift is due to temperature

influence and redistribution of Indium atoms in active region (multiply quantum wells). Areas with larger than average Indium atoms concentration are “crashed” and due to this “longwave tail” of spectrum reduces but at the same time areas with lower than average Indium concentration increase and based on this “shortwave tail” increases.

#### 4. SUMMARY

It was detected the optimum active region structure for blue and green red and yellow active area in heterostructures – active region should contain 4 quantum wells for InGaN. Temperature influences on LED characteristics due to redistribution of Indium atoms in quantum wells.

#### REFERENCES

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