3-Dimensional Current Flow Analysis in InGaN Light Emitting Diodes Grown on Sapphire Substrate

Jong-In Shim
Dept. of Electrical and Computer Engineering
Hanyang University
1271 Sa-dong, Sangnok-gu, Ansan, Kyungki-do, 426-791, Korea
jishim@giga.hanyang.ac.kr

Abstract—**In order to analyze current spreading 3-dimensionally in an InGaN/GaN multiple quantum well (MQW) light emitting diode (LED), we successfully developed a method of modeling a LED as an electrical circuit consisting of resistances and intrinsic diodes. The main advantage of this method is its simple algorithm and fast calculation time.**

I. Introduction

Recently, GaN-based light-emitting diodes (LEDs) have attracted much attention due to their great applications of solid-state lighting. Typical GaN-based LEDs grown on the sapphire substrate has an etched mesa shape and a side-by-side contact configuration due to the insulating substrate. These diodes grown on an insulating sapphire substrate employ a lateral as well as a vertical current flow. In particular, the lateral current flow can lead to the non-uniform current spreading which directly influence on LED performance as well as its reliability [1]-[4].

In this paper, we present a method based on the 3-dimensional circuit modeling. Each circuit element is modeled by experimentally measurable parameters like structure dimensions. Thus, a 3-dimensional current flow can be obtained according to material and geometric parameters of layers by the method. It is also shown that the current crowding is closely related to the improvements in series resistance, saturation of light output power, leakage current with operational time, and endurance of electrostatic discharge. Among many design parameters, the electrode pattern is found to be the most effective one to achieve both performance and reliability simultaneously.

II. Resutls And Discussions

Fig. 1 shows a schematic structure of a InGaN/GaN LED and its equivalent circuit model, respectively. Usually applications of LEDs require a maximum modulation speed of less than a few tens of kHz. Therefore, LED can be modeled electrically by only using the resistances and the intrinsic diode.

A structure consists of the n-GaN buffer layer, active layers with InGaN/GaN multiple quantum well, and p-GaN clad layer grown on an insulating sapphire substrate. The multiple active region and thin layers are electrically modeled by an intrinsic diode and 3-D resistance circuits, respectively. We can experimentally extract these circuit parameters from fabricated LED chips by preparing the transmission line model (TLM) patterns and measuring the current-voltage (I-V) curves. Here, we explain the structural influences on current spreading by using fabricated LED chips of 320×320 μm^2 in [3].

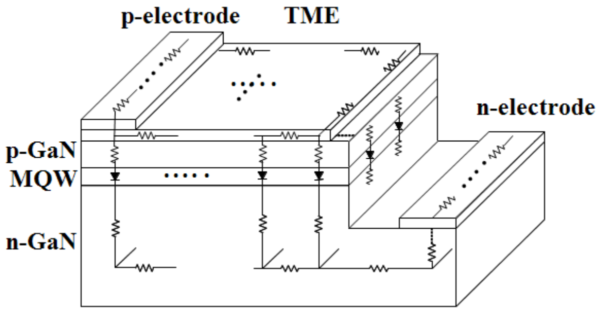

Fig. 1. Schematic views of a GaN/InGaN blue LED structure and its 3-dimensional circuit model

3-D current flow pattern in a LED chip depends on the variation of the sheet resistance of n-GaN or TME film, and p-contact resistivity (ρ_c). It is necessary for the lateral current flows at both the TME and the n-GaN layer to be the same for good light uniformity. Since the sheet resistance of n-GaN ($R_{sh,n\text{-}GaN}$) is usually larger than that of TME ($R_{sh,TME}$), it is desirable to decrease $R_{sh,n\text{-}GaN}$ and to increase ρ_c in a view of uniform current spreading. However, each method accompanies with some degradations in other performances such as operating voltage, light absorption, and crystal quality. Thus, there is little room to improve current uniformity by adjusting aforementioned parameters. Therefore, the geometric pattern of electrodes is especially important to improve current spreading without degradation of other performances.

Fig. 2(a) and Fig. 2(b) show theoretical and experimental current flow patterns in the active region, respectively, for an electrode pattern where the p-metal electrode is located at the opposite side of the n-metal electrode. Therefore, the distance between two electrode pads are always far away. Thus, small resistance mismatch among stacked layers could bring very large current non-uniformity. Light intensity around p-electrode is much weaker than those of other regions. This is due to the higher sheet resistance of n-GaN layer than those of TME layer. In Fig. 2(c) and Fig. 2(d), the p-type electrode surrounds the n-type electrode. The bright area is observed around the n-electrode and the dark area is found at the corner

978-1-4244-4180-8/09/$25.00 ©2009 IEEE

of p-electrode in both figures. But the light uniformity is a little improved compared to Fig. 2(a) and Fig. 2(b). Fig. 2(e) and Fig. 2(f) show a carefully designed electrode pattern for uniform current injection. Electrodes are arranged to keep distant between n- and p-electrodes being equal in the circuit model. Much improved light uniformity can be clearly seen, which indicates that the electrode pattern has a significant influence on the current uniformity even for the same epitaxial layered structure. All simulation results show excellently good agreements with the experimental ones. This indicates that our software is very helpful to find an optimum LED structure with negligible current crowding.

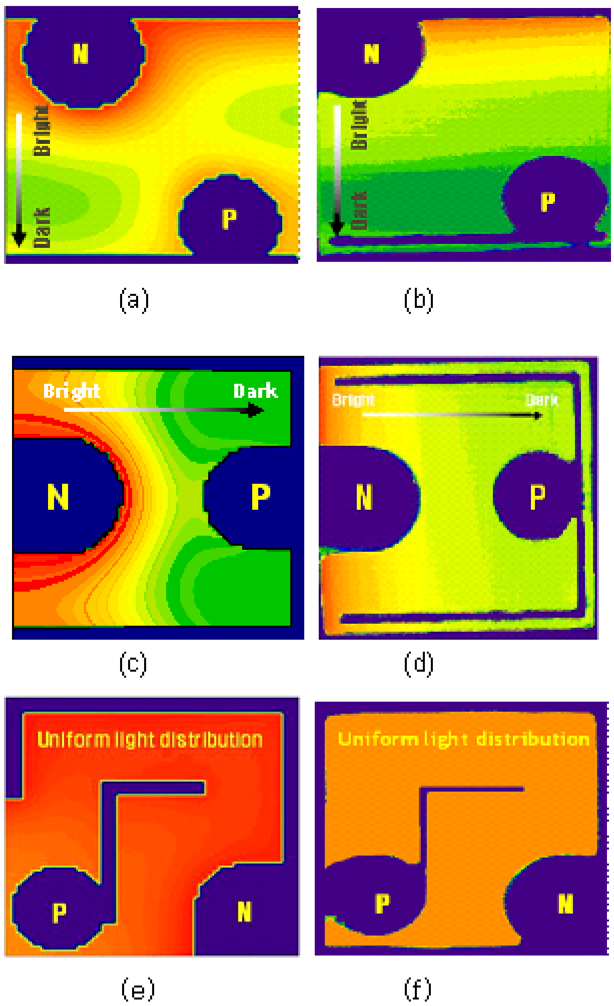

Fig. 2. Light emission patterns; (a), (c), and (e) are the calculated results. (b), (d), and (f) are their measured numeric data, respectively. The chips are InGaN/GaN blue LEDs whose size is $320 \times 320\ \mu m^2$.

Fig. 3 shows measured power-current (L-I) characteristics for three different electrode patterns. The sample of Fig. 2(f) shows the highest output power among three patterns with the lowest series resistance in the measured I-V curve. We believe that these superior characteristics result from the small local Joule heating due to the uniform current spreading.

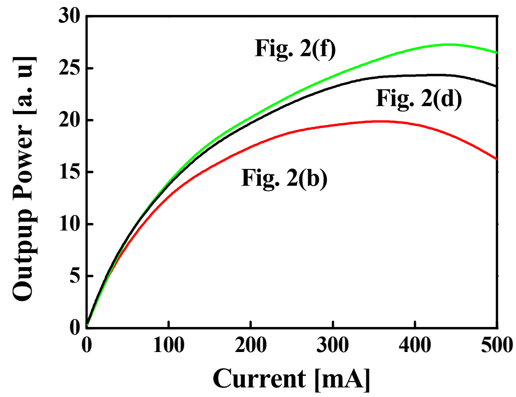

Fig. 3. Measured power-current (L-I) characteristics for three different electrode patterns shown in Fig. 2.

III. Conclusions

We demonstrated a simple and fast method analyzing 3-dimensional current spreading in a complicate LED chip and developed a design software tool. The proposed method utilizes 3-dimesnsional circuit modeling and its analysis of a LED which consists of intrinsic diodes and different kinds of resistances reflecting metallic films and epitaxial layers. The method was applied to top-surface emitting-type LEDs of $320 \times 320\ \mu m^2$ size. It was found that the electrode pattern significantly influence on current spreading and light intensity distribution. We believe that our method of 3-dimenisonal current analysis is very useful to field engineers due to its fast calculation time.

Acknowledgment

This work was supported by the Korea Science and Engineering Foundation (KOSEF) funded by Korea government (MOST) (No. R01-2007-000-20048-0-2008).

References

[1] S. R. Jeon, M. S. Cho, M.A. Yu and G. M. Yang, "GaN-based light-emitting diodes using tunnel junctions," IEEE J. of Selected Topics in Quantum Electron., Vol. 8, No. 4, pp. 739-743, 2002.

[2] X. Guo and E.F. Schubert, "Current crowding in GaN/InGaN light emitting diodes on insulating substrates," J. Appl. Phys., Vol. 90, No. 8, pp. 4191-4195, 2001.

[3] S. Hwang, J. –I. Shim, "A method for current spreading analysis and electrode pattern design in light-emitting diodes," IEEE Trans. Electron. Dev., Vol. 55, No. 5, pp. 1123-1128, 2008.

[4] S. Hwang, J. –I. Shim, "Improved ESD voltage by inserting floating metal ring in GaN-based light emitting diodes," IEE Electron. Lett., Vol. 44, No. 9, pp. 590-591, 2008.