The evaluation of the extraction efficiency by simulation and measurement

Jin-Bock LEE, Sang-Ho YOON, Jung-Ja YANG, Min-Ho KIM, Kyeong-Ik Min

Samsung Electro-Mechanics Co.,LTD.

314, Maetan3-dong, Yeongtong-Gu, Suwon, Gyunggi-Do, Korea 443-743

I. INTRODUCTION

While remarkable progress has been made in the development of blue nitride light emitting diodes(LEDs) in recent years, many problems must still be overcome so that the high efficiency and high flux solid state light sources are to be achieved. The efficiency of GaN LEDs is not yet sufficient to satisfy costumer demands.[1-2]

There are two principal approaches for improving LED efficiency. The first is increasing the internal quantum efficiency, which is determined by crystal quality, epitaxial layer structure, and thermal dissipation. And the second is increasing light extraction efficiency. High values of internal quantum efficiency have already been reported, and so further improvements may not be readily achieved. It was reported that a typical internal quantum efficiency value for blue LEDs has reached more than 70 %.[3] However, there is much room for improvement of the light extraction efficiency.

Therefore, many methods to improve the extraction efficiency have been proposed, including altering surface texture, chip shaping and other approaches.[3-5] However, the method for evaluation of the extraction efficiency in LEDs is not reported though the light extraction analysis of LED is quite important. If the extraction efficiency can be evaluated exactly, the internal efficiency can be calculated from measurement of external efficiency. It is expected that these analyses are helpful in the design for high brightness GaN LEDs. Unfortunately, it is impossible that the extraction efficiency is measured by simple methods. Also, though the absorption plays a major role when the extraction efficiency is calculated, the values for the reported absorption coefficient are not precise enough to achieve the extraction efficiency with reasonable accuracy.[6]

In this work, the method of the evaluation for the extraction efficiency by simulation and measurement will be proposed. By the comparison of simulation and measurement on two different types of LEDs, the absorption coefficient can be obtained, from which the extraction efficiency was calculated.

II. RESULTS AND DISCUSSION

Fig.1 shows LED structure fabricated in this work. The conventional vertical structure LED can be fabricated due to conducting property of GaN substrate, which means that LEDs usually have geometry with vertical current flow layer giving rise to the possibility of a uniform current distribution and good heat dissipation in active area. Also, the light generated from MQW emit to air via substrate.

In this work, a comparison of two different LEDs was performed. They are fabricated from the same epitaxial layer grown on a GaN substrate but the different chip size. One is 500μm×500μm, the other is 900μm×900μm.

It can be believed that the current could be distributed uniformly in active region because 200 μm GaN substrate in the vertical LEDs play role of current spreading layer in two different LEDs. It means that internal efficiency is almost same under same current density regardless of chip size. However, the extraction efficiency is varied with chip size because chip volume limits the extraction efficiency. The extraction of the LED is defined by the ratio of rays escaping from the LED chip to the total number of rays generated by the active layer, and is limited by critical angles loss, Fresnel loss, reflection on backside mirror and absorption of the materials.[6] The decrease of extraction efficiency on chip size attributed to absorption coefficient.

Therefore, it can be expected that the absorption of material including GaN substrate and GaN epi layer have a major influence on the devices performance of two different LEDs. The absorption coefficient of GaN can be estimated by the comparison of LED performance on a different chip size. Also, the measurements of fabricated LEDs are performed with unpackaged devices so that the package efficiency is not considered.

To simulate the extraction efficiency under various conditions and parameters, we can use a Monte-carlo ray tracing simulation to obtain the light distribution across the whole volume of the chip. In the following simulations, it is assumed that the current spreading is uniform and the photon recycling effect is negligible.

Fig.2 shows the measured output power (P_{ext}) as a function of the devices current density for the two different LEDs. As expected, the higher output power can be obtained in 900μm×900μm chip(■) than in 500μm×500μm chip(●) because the output power increase in proportion to chip size. Also, the expected output power($P_{expected}$, ○), which was calculated from assumption that the extraction efficiency is almost same under same current density regardless of chip size, is calculated as $P_{500\times500}\times3.24$. It should be noted that the expected output power is directly proportional to chip size under the same internal efficiency briefly. However, the expected power ($P_{expected}$) is actually different from measured $P_{900\times900}$. It can be attributed to the absorption coefficient caused by chip volume and the extraction efficiency is directly influenced by the absorption coefficient. In other words, the internal efficiency would not be different under same current density if LEDs have same MQW structure. It indicates that the difference between $P_{expected}$ and $P_{900\times900}$ was caused by only difference of extraction efficiency.

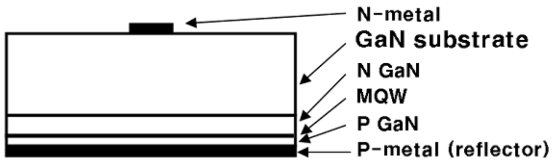

Fig.1. Schematic of fabricated LED structure

The power ratio($P_{900\times900}/P_{expected}$), which represents the difference between $P_{expected}$ and $P_{900\times900}$ in Fig.2, is shown in Fig.3. The power ratio is about 0.82 and constant at all current density range though it is expected to be 1 without absorption on chip size. It means that the power ratio is independent of current density and influenced by absorption. In other words, it can be confirmed that the power ratio reflects the difference of extraction efficiency by absorption on chip size and the extraction efficiency is not a function of current density. The ray tracing simulation was used for the estimation of the effects on the extraction efficiency by absorption coefficient in the respective LED. The following simulation results will be compared with measurement results.

Fig.4 shows the simulated extraction efficiency of LEDs as a function of the absorption coefficient. The extraction efficiency of LEDs under zero absorption is almost same with 17.5 % regardless of chip size if the refractive index is 2.5 for GaN and the reflectance of P metal is 80 %. As the absorption coefficient increase, the extraction efficiency for 900μm×900μm chip decreases more rapidly. Because the optical path of ray traced from MQW lengthen as chip size is large, the absorption coefficient has a critical effect on the extraction efficiency in the large sized chip. It is obvious that the extraction efficiency for two different sized LEDs is determined by absorption. Also, it is expected that the ratio of the extraction efficiency is equal to ratio of the output power (P_{ext}) for two different LEDs in Fig.3 because the internal power(P_{int}) generated from MQW is the same for ray tracing simulation.

Fig.5 shows the power ratio($\eta_{500\times500}/\eta_{900\times900}$ from Fig.4) on absorption coefficient. It was found that the power ratio is varied with absorption coefficient. The power ratio by absorption is about 0.82 as shown in Fig.3. It was expected that the absorption coefficient for our LEDs can be found at the point which the power ratio is 0.82 in Fig.5. The absorption coefficient is 20.33/cm at the point, which is match to power ratio of 0.82 in fig.5. Therefore, it is believed that the absorption coefficient of fabricated LEDs is 20.33/cm. From the absorption coefficient obtained from simulation and measurement, it can be estimated that the extraction efficiency is 9.05 % and 10.93 % for 900μm×900μm chip and 500μm×500μm chip in Fig.4, respectively.

III. Conclusion

In this paper, the method for evaluation of the extraction efficiency was proposed. It could be found that the absorption coefficient is 20.33/cm for fabricated LEDs. Also, the extraction efficiency was calculated from the obtained absorption coefficient. It could be confirmed that the extraction efficiency is very low, much improvement needed for high brightness LED. In future work, it is expected that the internal quantum efficiency can be evaluated from this results if the external quantum efficiency can be measured exactly.

References

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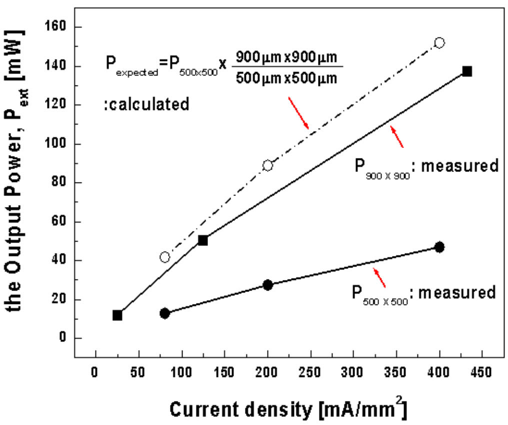

Fig.2. The output power measured from fabricated LED (●:500μm×500μm, ■:900μm×900 μm, ○: expected output power)

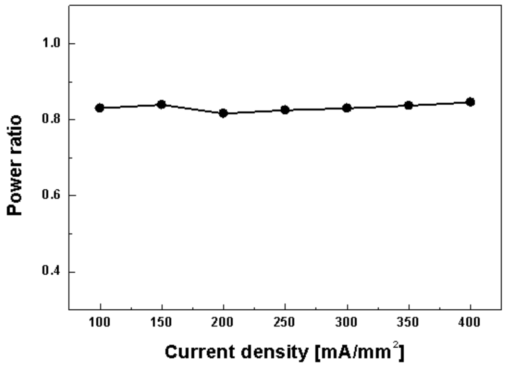

Fig.3. The power ratio ($P_{900x900}$ / $P_{expected}$) calculated from Fig.2

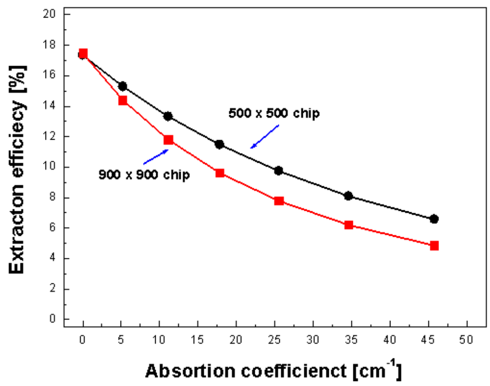

Fig.4. The simulated extraction efficiency of LEDs as a function of absorption coefficient (●:500umx500um, ■:900um x 900 um)

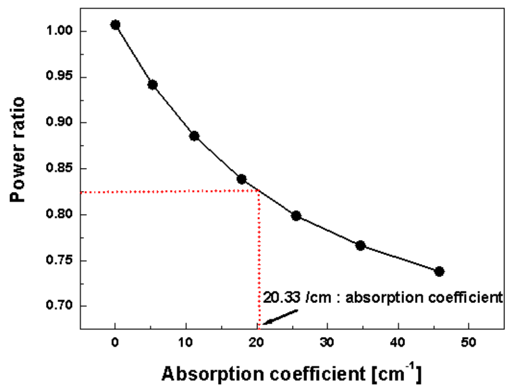

Fig.5. The power ratio($\eta_{500\times500}/\eta_{900\times900}$ from fig.4) on absorption coefficient