Thermal characteristics of InGaN/GaN MQW blue LEDs

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1. Introduction

Light emitting diodes (LEDs), which have many advantages of low power consumption, long lifetime, and environmental protection, have received great attention as a potential light source. Recently, there is significant improvement in device performance, thus it has become possible to make a variety of applications such as full color displays, traffic signals, backlights, and solid state lightings [1]. Despite many performance breakthroughs, however, the power conversion efficiency of LEDs is still indicating the low values between 20% and 40%. In addition, for practical and industrial applications, the LEDs should be driven by high driving power more than 10 or 100 times compared to the conventional devices. This causes an increase in junction temperature because a large portion of electrical power is dissipated as heat inside the device. Generally, the properties of LEDs are directly affected by the junction temperature. As the junction temperature is increased, the output power and conversion efficiency are degraded, and the operating voltage and emitted wavelength are also changed. Furthermore, GaN-based LEDs are generally grown on sapphire (Al₂O₃) substrate that has a relatively low thermal conductivity compared to Si substrate. Thus, the buildup of heat generated from the active region can reduce device efficiency. To analyze the thermal characteristics of LEDs, the junction temperature measurements and theoretical calculations should be carried out.

In this work, we analyzed the thermal characteristics of GaN-based LEDs with different device sizes. The junction temperature was measured as function of injection current. For comparison, the device structure was simulated by the three dimensional (3D) finite element method (FEM) model using the COMSOL. From the simulated results, temperature distribution and the thermal resistance (R_{th}) of the devices were theoretically analyzed.

2. Measurement and thermal modeling

Fig. 1 shows the schematic diagram of blue LED with InGaN/GaN multi-quantum well (MQW) structure at $\lambda \sim 470$ nm. The devices were grown on sapphire substrate with the thickness of ~ 445 µm by metal organic chemical vapor deposition. The junction temperature was measured by the forward voltage method [2]. First, we measured the k-factors (i.e., k= $\Delta V_{f}/\Delta T$) by pulsed injection current with 0.1 % duty cycle. The measured k-factors indicated -2.48 mV/K, -2.49 mV/K, and -2.49 mV/K for LEDs with

 $400 \times 400 \ \mu m^2$, $350 \times 350 \ \mu m^2$ and $300 \times 300 \ \mu m^2$, respectively. The junction temperature is given by [2]

$$T_{j} = T_{o} + \frac{V_{FT} - V_{FO}}{k}, \qquad (1)$$

where T_j is the junction temperature, T_o is the ambient (oven) temperature, and k is the k-factor. Also, V_{FT} and V_{FO} are the constant forward voltage in equilibrium and the instant voltage.



Fig. 1. Schematic diagram of blue LED with InGaN/GaN MQW structure at $\lambda {\sim}$ 470 nm.

From the experimentally measured L-I-V data, the GaNbased LED structures were simulated. The junction temperature, temperature distribution, and thermal resistance were obtained using a steady-state 3D heat dissipation model. The steady-state heat transfer equations are represented as [3]

$$Q = -\nabla \cdot (k \nabla T)$$
 and $k \nabla T = h(T_{inf} - T)$, (2)

where T is the temperature, Q is heat source density, h is the heat transfer coefficient (h= $20 \text{ W/m}^2\text{-K}$ for natural convection), T_{inf} is the ambient temperature, and k is the thermal conductivity. The isotropic thermal conductivity was assumed for all materials consisting of GaN-based LED structure. Table I shows the isotropic thermal conductivities of various materials used in this simulation at 300 K.

Table I. Isotropic thermal conductivities of various materials used in this simulation at 300 K [4,5]

Materials	Thermal conductivity (W/m-K)
Al _{0.15} Ga _{0.85} N	6.3
In _{0.25} Ga _{0.75} N	6
In _{0.03} Ga _{0.97} N	90
GaN	160
Al_2O_3	35
Ti	21.9
In	81.6
Au	315
Ni	90.7
ITO	8.2
Cu	398

3. Results and Discussions

The junction temperature was measured at room temperature (T= 298 K) for 30 min by using the forward voltage method. Fig. 2 shows the measured and calculated junction temperatures as a function of injection current for GaN-based LEDs. The junction temperature was almost linearly raised with increasing the injection current due to the increase in internal heat generation, and it was increased as the chip size became smaller. Under the injection current of 100 mA, the junction temperature increased from 346 K for 400×400 μ m² LED to 373 K for 300×300 μ m² LED. As shown in Fig 2, the simulation results agreed fairly well with the experimentally measured data. As a result, we estimated that the junction temperature is increased to 412 K for 400×400 μ m² LED at 200 mA.



Fig. 2. Measured and calculated junction temperatures as a function of injection current for GaN-based LEDs.

Fig. 3 shows the thermal resistance as a function of injection current for GaN-based LEDs. For the measured junction temperature, the thermal resistance, R_{th} , can be extracted by [5]

$$T_{th} = \frac{\Delta T}{Q_{heat}},\tag{3}$$

where ΔT is the temperature difference between the copper heatsink and the active region, Q_{heat} is the power dissipated as heat. As shown in Fig. 3, the thermal resistance remains nearly constant due to the linear relationship between junction temperature and injection forward current. For the larger LED chip size, the thermal resistance was reduced. For 400×400 µm² LED, the thermal resistance below 100 K/W was obtained.



Fig. 3. Thermal resistance as a function of injection current for GaN-based LEDs.

4. Conclusions

The thermal characteristics of GaN-based LEDs were studied by the experimental measurement and the theoretical simulation. From the measured L-I-V data, the junction temperature and thermal resistance were obtained by using a steady-state three dimensional (3D) heat dissipation model and the simulation results was compared with the experimental data. The junction temperature was decreased with device size, indicating the lower thermal resistance. As a result, the thermal resistance below 100 K/W was obtained for 400×400 μ m² LED.

References

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Abstract

We investigated the thermal characteristics of GaN-based Light emitting diodes (LEDs) with different device sizes for efficient heat dissipation. The junction temperature (T_j) was experimentally measured by the forward voltage method, in comparison with theoretical results calculated using a steady-state three dimensional heat dissipation model. The T_j was raised almost linearly with the increase of injection current. From the measured T_j and L-I-V data the thermal resistance was estimated experimentally, indicating a good agreement with the calculated result. The T_j was reduced as the device size was increased, resulting in the lower thermal resistance. The thermal resistance below 100 K/W was obtained for 400×400 μm² LED.