Determination of Junction Temperature of GaN-based Light Emitting Diodes by Electroluminescence and Micro-Raman Spectroscopy

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Keywords: GaN, LED, Electroluminescence, Raman spectroscopy

Abstract

Rise of junction temperature during operation can greatly affect performance and reliability of Light-emitting diodes (LED). Unfortunately, the junction temperature of the LED can not be measured directly. In this report, non-contact methods using Electro-luminescence (EL) and Micro-Raman spectroscopy were employed to estimate the junction temperature of GaN-based LED.

Introduction

LED based solid-state lighting offers many advantages such as high efficiency, long lifetime and color versatility over traditional incandescent and fluorescence lamps. White light LED is predicted to attain luminous efficacy of 200 lm/W and lifetime of 100,000 hours in the foreseeable future [1]. However, to achieve this goal, heat generation must be minimized in as much as the lifetime and emission intensity of the LED decreases with increasing junction temperature [2]. Increasing junction temperature can also cause peak width broadening which degrades the monochromaticity of Laser Diodes (LDs). As a result, it is very important to determine the junction temperature of the LED during operation. Since junction temperature can not be measured directly, non-contact junction temperature measurement methods such as electroluminescence and Raman spectroscopy are preferred.

Experiment

Commercial packaged LED chips and bare LED chips were used in this measurement. Current-Voltage measurement was carried out for the packaged LED chip. Electroluminescence and Micro-Raman spectra were then collected separately for the packaged LED chip and the bare LED chip by Jobin-Yvon's spectroscopy system, consisting of a Kimmon Electric's He-Cd laser, a Zeiss optical microscope, a TRIAX 550 Monochromator and a thermo-electric cooled CCD camera (Symphony).

Result s and Discussion

Current-Voltage measurement for packaged LED is carried out first. Turn-on voltage of the LED was measured as 2.8V. Current increased from 5mA to 100mA in 5mA increment. Figure 1 shows the junction power-voltage and EL intensity-voltage characteristic of the packaged LED chip. As Forward voltage increases, the EL intensity of LED drops dramatically after a maximum value is reached, while power dissipated at the junction due to non-radiative recombination and Joule heating keeps increasing which could cause an elevation of junction temperature.

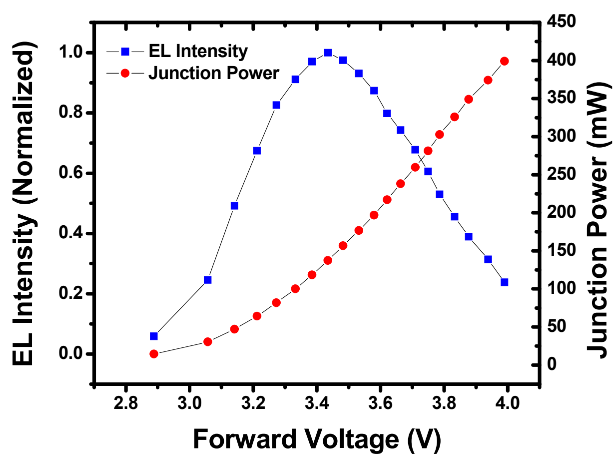

Figure 1: Voltage dependent EL intensity and Junction Power

Figure 2 demonstrates the relationship between the junction current and electroluminescence spectra. Junction temperature could be extracted from EL spectra *via* two approaches. Peak emission wavelength method based on comparison of emission peak and calibration data collected in a temperature controlled oven [3], and high-energy slope method, which is used in this study.

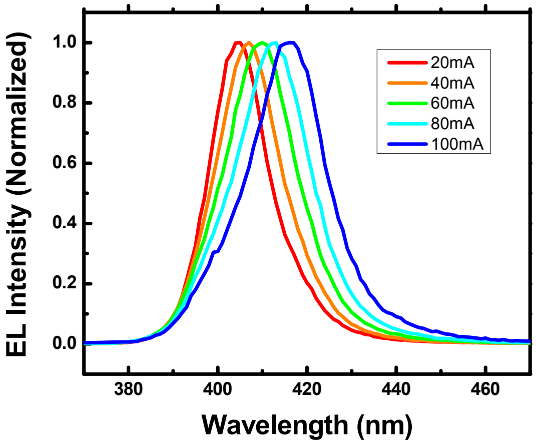

Figure 2: LED electroluminescence spectra

Photons emitted with energy much high than $k_B T_c$, where T_c is carrier temperature, approximately satisfy Boltzmann distribution.

$$I \propto \exp\left(-h\nu/k_B T_c\right)$$

where I is emission intensity and hv is energy of emitted photons. According to Vaitonis *et al.* [4], actual shape may be deviated from exponential decay. Generally, carrier temperature could be obtained by high energy slope:

$$T_c = \left[-k_B \frac{\partial(\ln I)}{\partial(h\nu)}\right]^{-1}$$

by fitting EL spectra using formula given above. Carrier temperature is considered to be the upper limit of the junction temperature [2] and thus gives a rough estimate of the junction temperature.

For junction temperature measurement using EL, what is actually measured is the average junction temperature. However, to improve the design of LED device structure and packaging, it is necessary to determine the junction temperature profile. Junction temperature profile measurement utilizing Micro-Raman spectroscopy could be exploited by focusing laser beam on different locations of the LED chip. Figure 4 shows a focused laser dot illuminated on the current spreading layer of a GaN LED chip which has a circular anode contact pad with a diameter of 100 μm.

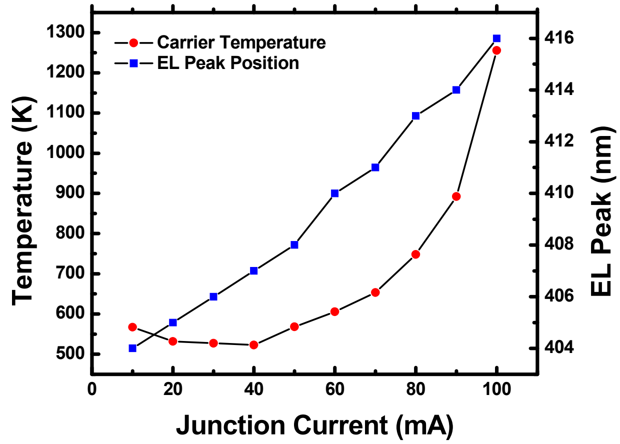

Figure 3: Junction Current dependent carrier temperature and EL peak

Figure 4: Focused laser on LED chip

Raman spectrum of GaN was well studied. Figure 4 shows Raman spectrum of GaN bare LED chip at room temperature. Among all modes allowed by Raman selection rule, E_2 mode has most intense peak at room temperature and thus is preferred in this measurement. As shown in Figure 5 an E_2 mode peak is observed at 568 cm^{-1}.

Temperature dependence of Raman peak shift is reported by Cui *et al.* [6],

$$\omega = \omega_0 - \frac{\alpha}{e^{\beta\hbar\omega_0/k_B T} - 1}$$

where α and β are fitting parameters and ω_0 is the Raman shift at 0K. Full width at half maximum (FWHM) is also a function of temperature with the relation stated below [7]:

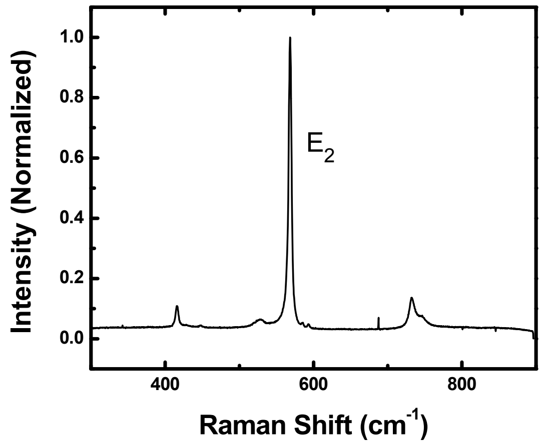

Figure 5: Raman spectrum of LED chip at RT

$$\Gamma(T) = \Gamma_0\left[1 + \frac{2}{e^{\hbar\omega_0/2k_BT} - 1}\right]$$

A reference Raman peak shift and FWHM broadening measurement is carried out qualitatively. A Fisher Scientific hot plate is used to heat LED chip to a specific temperature which is stabilized for 10min. Raman spectra was measured and Lorentzian fitting was used to attain shift position and FWHM of Raman E_2 mode peak. Figure 6 shows as temperature increases, shift of Raman peak to lower wave number and broadening of FWHM are observed, which is in good agreement with formulae given above.

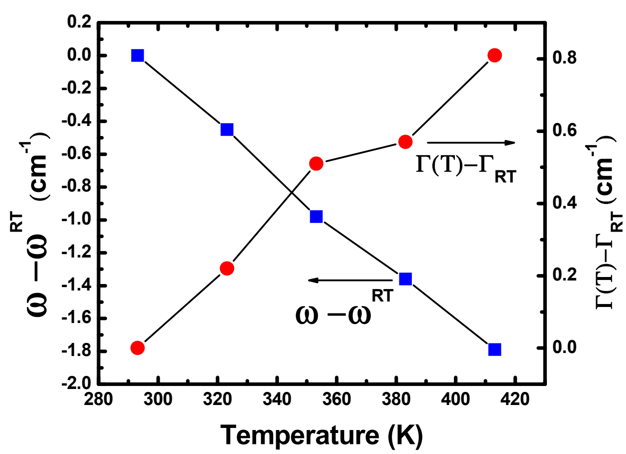

Figure 6: Temperature dependent Raman E_2 and FWHM

Future Work

In future work, packaging and wire bonding are planned for bare LED chips. *In-situ* characterization of the LED device temperature will be performed using micro-Raman spectroscopy.

Conclusions

Electroluminescence and micro-Raman spectra of packaged and bare GaN LED chips were collected. Junction temperature was quantitatively determined in packaged LED chip using EL spectra and a qualitative estimated in LED bare chip using micro-Raman spectra.

Acknowledgements

The authors would like to thank Mr. Fillmer at NRMDI for financial support.

References

[1] J. Tsao, IEEE Circuits Devices Mag. **20**, 28 (2004).

[2] E. Fred Schubert, *Light-Emitting Diodes*, 2nd ed. (Cambridge University Press, Cambridge, 2006), pp. 98, 101.

[3] Y. Xi, J.-Q. Xi, Th. Gessmann, J. M. Shah, J. K. Kim, E. F. Schubert, A. J. Fischer, M. H. Crawford, K. H. A. Bogart, and A. A. Allerman, Appl. Phys. Lett. **86**, 031907 (2005).

[4] Z. Vaitonis, P. Vitta, and A. Žukauskas, J. Appl. Phys. **103**, 093110 (2008).

[5] *Properties of Advanced Semiconductor Materials GaN, AlN, InN, BN, SiC, SiGe*, edited by M. R. Levinshtein, S. L. Rumyantsev, and M. S. Shur, (John Wiley & Sons, New York, 2001); GaN: pp 1–30 (V. Bourgrov et al.).

[6] J. B. Cui, K. Amtmann, J. Ristein, and L. Ley. J. Appl Phys **83**, 7929 (1998).

[7] M. S. Liu, L. A. Bursill, S. Prawer, K. W. Nugent, Y. Z. Tong and G. Y. Zhang. Appl. Phys. Lett. **74**, 3125 (1999).

Acronyms

EL: Electroluminescence
FWHM: Full width at half maximum