Measurements of Various Light-Emitting-Diode Efficiencies at Room Temperature

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1. Introduction

We present a method of measuring the internal quantum efficiency (IQE) of light-emitting diodes (LEDs) just at room temperature, the so-called *room-temperature reference-point method* (RTRM) that utilizes only experimentally measurable quantities of radiant power and current without assuming any physical parameters. Once the IQE is known, various LED efficiencies can be measured separately and quantitatively. The RTRM is applied to InGaN-based blue LEDs in order to elucidate operational mechanisms and improve the device performances.

2. The IQE measurement

For LEDs, various efficiencies can be defined as measures of different conversion processes [1]. The overall efficiency of an LED chip can be characterized by the power efficiency (PE), also known as the wall-plug efficiency. The PE is defined as the ratio of the radiant power to the electrical power. There are many factors that can affect the PE: these factors are characterized by other efficiency parameters such as the voltage efficiency (VE), the external quantum efficiency (EQE), the light-extraction efficiency (LEE), the IQE, the radiative efficiency (RE), and the injection efficiency (IE). The VE represents the ratio of the average photon energy emitted from the LED to the average electron energy supplied by the power source. In summary, the overall PE can be rewritten as follows: PE = VE·EQE = VE·(LEE·IQE) = VE·LEE·(IE·RE). The PE, the VE, and the EQE are quantitatively measurable by using experimental data of current, voltage, radiant power, and spectra. To separate the efficiencies further, the IQE as a function of current is required.

The IQE is a key parameter that represents the quality of epitaxial layers and contains essential information on operational mechanisms. For reliable and accurate IQE measurements, it is desirable to use easily measurable physical quantities such as current and radiant power *without* assuming any physical parameters, e.g., the chip size, carrier recombination rates, and complex refractive indices. Moreover, it is necessary to identify the RE and the IE separately and quantitatively because of IQE= IE·RE.

For the IQE estimation at room temperature (RT), the temperature-dependent electroluminescence (TDEL) has been utilized most popularly, in which IE = RE = 100% at the EQE peak is assumed under cryogenic temperatures. The TDEL is very time-consuming, which hinders the method from being applied in real industrial applications. There exist an alternative set of methods based on the AB(C)-model. In these methods, it is assumed that the IE is 100% and that the recombination coefficients A, B, and C are independent from the carrier density N. Then the RE is obtained by fitting or analyzing the EQE curve as a function of current. However, the curve fitting based on the ABC-model often shows a significant deviation from the measured EQE at low and/or high currents away from the maximum EQE. We believe that these discrepancies mainly result from the assumption of IE = 100% over wide current ranges.

We have developed an IQE measurement method as a function of current just at RT, called RTRM, to overcome the technical hurdles of conventional constant AB(C)-models [2]. We find a reference current I_{ref} firstly at which the IE is most probably taken as 100%. Then, the RE at I_{ref} is calculated from the experimental EQE curve. Once IQE at I_{ref} is exactly known, the IQE at any other current is obtained from $IQE(I)/IEQ(I_{ref}) = EQE(I)/EQE(I_{ref})$. The basic idea and calculation procedure of the RTRM is almost identical to the TDEL except that the RE is not 100% at RT. The RTRM has been applied to InGaN-based blue LEDs and comparison with the results by the TDEL shows excellent agreements.

Many realistic LEDs usually show a certain amount of leakage currents in the low-current region even far below the maximum EQE. The surface current and the defect-related tunneling current are considered as possible leakage currents. In the symposium, we present some techniques to identify such leakage currents from the experimental data of current, voltage, and radiant power.

3. Conclusion

A simple and accurate IQE measurement method at an arbitrary temperature is possible. We believe that the proposed method should serve as a very useful tool in measuring the IQE and characterizing the leakage currents of various LED devices.

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References

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