Determination of carrier injection efficiency and its effects on the efficiency droop in GaN light emitting diodes

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The final purpose of research on light emitting diodes can be summarized to have higher external quantum efficiency of the device. The external quantum efficiency (EQE), which is defined by the ratio of the number of photon emitted from the device to the number of electrons injected into the device and, is relatively easy to measure quantitatively. The EQE is a product of a carrier injection efficiency (CIE), a radiative efficiency (RE) and a light extraction efficiency (LEE). While EQE can be determined by relatively simple methods, separate determination of CIE, RE and LEE has been a topic of long debate in InGaN/GaN light emitting diodes (LEDs) research fields. The actual separation of these three efficiencies can give us a concrete conclusion of the questions at hand, such as the origin of the efficiency droop, the improvement of injection efficiency by structure modification, and the general understanding of device operation [1].

In this study, we suggested and demonstrated a novel method to experimentally determine the CIE quantitatively. The basic idea is to compare the necessary amount of *additional* carriers in optical and electrical excitation to reach the same intensity increase of light output. Fig 1 shows schematics of this proposed measurement. While LED was on with a certain driving current, an additional resonant laser was illuminated on the whole the device surface, which makes the luminescence output a slightly higher. CIE can be calculated by comparing how many carriers should be injected electrically to have the exact same luminescence increase as the additional resonant laser excitation. The number of carrier generated by the additional resonant excitation is carefully obtained for quantification. A 405nm laser line with various output intensities was used for the resonant excitation. Whole measurement process was automatically controlled by a PC. Various LED devices with either single quantum well or multiple quantum well were tested in order to confirm the credibility of our measurements.

While the CIE is often assumed to be constant and close to be 1, CIE is significantly lower than 1 and decreases as the current density increases in our measurements (Fig 2). Through our method, the CIE and the RE can be separately determined in a given device structure. The respective effects of CIE and RE on the resultant EQE and the efficiency droop will also be discussed.

We believe our proposed method can provide an ultimate characterization tool to determine all the LEDs efficiencies and to understand the operating mechanism without ambiguity.

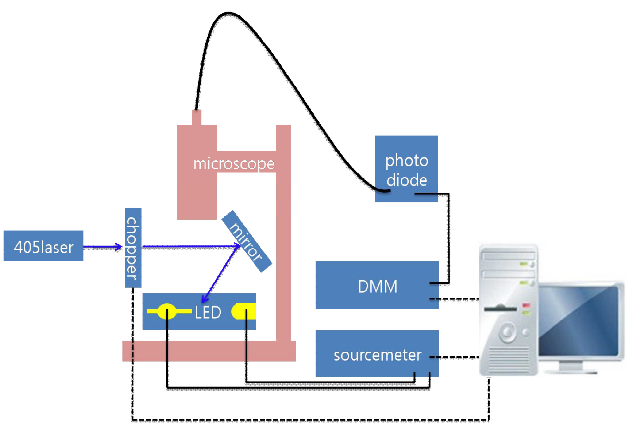

Fig. 1. Schematic diagram of experimental set up for the carrier injection efficiency

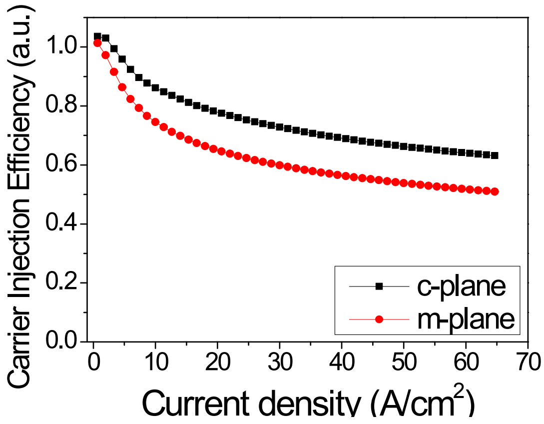

Fig. 2. Measured CIE

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