Temperature Dependence of the Radiative Recombination zone in GaN/InGaN Multiple-Quantum-Well Light Emitting Diodes

Jia-Ming Lee, Chang-Cheng Chuo, Jing-Fu Dai, Xian-Fa Zheng, and Jen-Inn Chyi

Department of Electrical Engineering, National Central University
Chung-Li, Taiwan 32054, R.O.C.
Tel:+886-3-4258241, Fax:+886-3-4255830, E-mail:chyi@ee.ncu.edu.tw

The radiative recombination process in GaN based light-emitting diodes (LEDs) is a subject of much interest because of their roles in full-color display and white light generation. Through the studies on the temperature dependence of the radiative recombination zones in GaN/InGaN MQW LED, the effects of Mg doping and electron scattering are observed.

The LED studied in this work was grown on c-face sapphire by low-pressure metal-organic chemical vapor deposition in a horizontal reactor. It consists of a 4 μm-thick n-type GaN buffer, five pairs of InGaN well (3 nm) and GaN barrier (10 nm) multiple quantum well active region, and a 0.5 μm-thick p-type GaN.

The electroluminescence (EL) spectra of the GaN/InGaN MQW LED operated at 20 mA were measured between 25 and 300 K. There are two peaks at about 400 nm (P1) and 460 nm (P2), which can be attributed to Mg-related and quantum well transitions, respectively. At room temperature, P2 is the dominant peak. As the temperature is decreased from 300 K to 25 K, P1 appears and its integrated intensity increases almost monotonically. But the behavior of P2 is different markedly. The integrated intensity of P2 increases with decreasing temperature and reaches a maximum value at 175K. Then it decreases with decreasing temperature. For the regime above 175 K, the increased intensity of P2 with decreasing temperature is attributed to the improved quantum efficiency of the radiative recombination due to less thermal scattering. As temperature is decreased further, the recombination zone shifts to the p-type GaN region because the hole concentration decreases due to the high activation energy of Mg in GaN. The radiative recombination in the quantum well is therefore reduced while the recombination at the p-type region increases correspondingly. Since the radiative recombination is limited by the holes available, the recombination processes in GaN/InGAN MQW LED can be modeled based on the following rate equations.

$$dP_{Mg}/dt = I/e - P_{Mg}/\tau_1 - P_{Mg}/\tau_2 \qquad (1)$$
$$dP_{Well}/dt = P_{Mg}/\tau_2 - P_{Well}/\tau_3 \qquad (2)$$

where P_{Mg} and P_{well} are the hole concentrations in the p-type GaN and quantum-well, respectively. I is the injection current, e is the electronic charge, τ_1 is the recombination lifetime in the p-type region, τ_2 is transit time of hole from the p-type region to quantum well, and τ_3 is the recombination lifetime in quantum-well. In the steady state, $dP_{Mg}/dt = dP_{Well}/dt = 0$, equation (2) gives the relation $P_{Well}/P_{Mg} = \tau_3/\tau_2$. Since τ_2 is directly proportional to the depletion width at p-type region, which increases inversely with the square root of hole concentration, we can thus expect that τ_2 is proportional to exp(Ea/2kT), where Ea is the activation energy of Mg in GaN. Compared to τ_2, τ_3 is much small so that we can consider it as a constant. Consequently, it can be concluded that P_{Well}/P_{Mg} is proportional to exp(-Ea/2kT). From the intensity ratio of P2 to P1 as a function of temperature, the Ea od Mg in GaN is estimated to be 126 meV. This value is in good agreement to the results of Hall measurement, C-V measurement and temperature-dependent PL measurement by several researchers.

For temperature regime above 200 K, the effect of Mg activation is not as obvious. The recombination process is dominated by the electron scattering rate in quantum well. From the Arrhenius plot of the integrated EL intensity of P2 between 200 and 300 K, the activation energy of electrons escaping from the well is deduced to be 136 meV.

In conclusion, we present the EL spectra of GaN/InGaN MQW LED as function of temperature. There are two peaks, which are associated with the transitions in the p-type and the quantum well region, respectively. The activation energies for the Mg in GaN and the electrons escaping from the well is deduced to be 126 meV and 136 meV, respectively. This work demonstrates the effects of p-type doping concentration on the electroluminescence of GaN/InGaN LEDs.

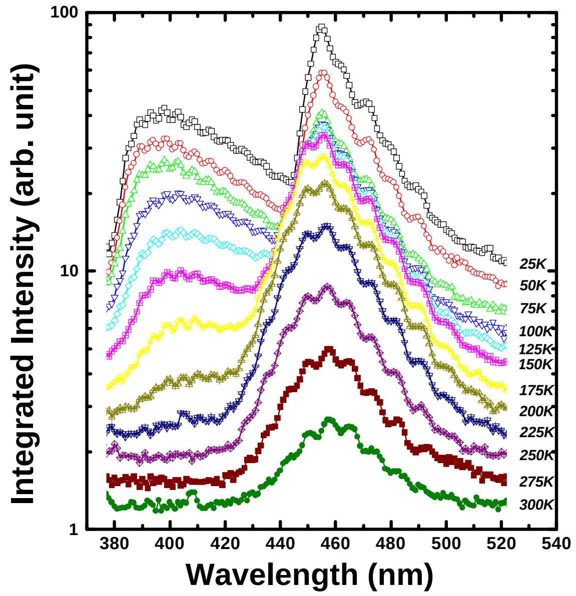

Fig 1. Electroluminescence spectra of a GaN/ InGaN multiple-quantum-well light emitting diode measured between 25 and 300 K.

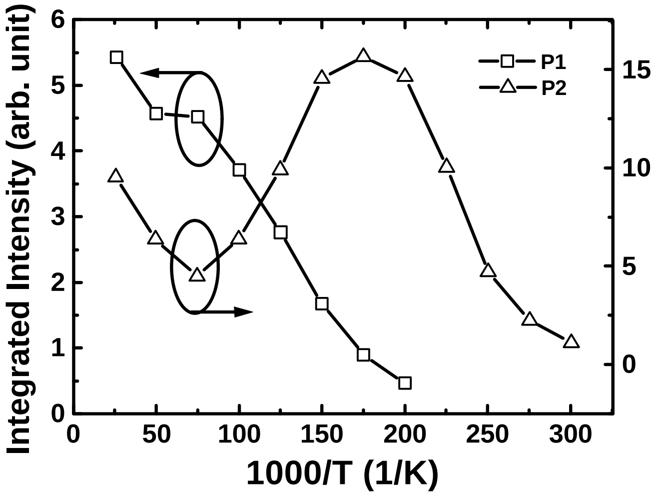

Fig 2. The integrated EL intensity of P1 and P2 peaks at various temperatures.

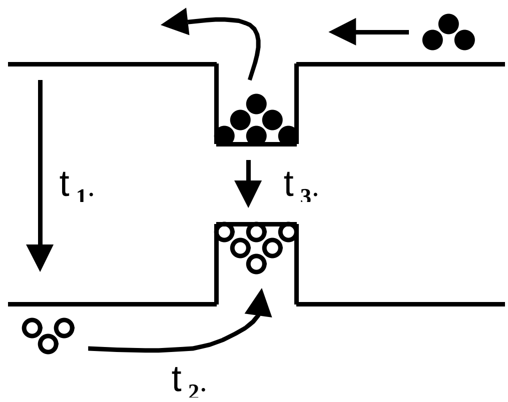

Fig 3. Schematic diagram of the recombination processes.

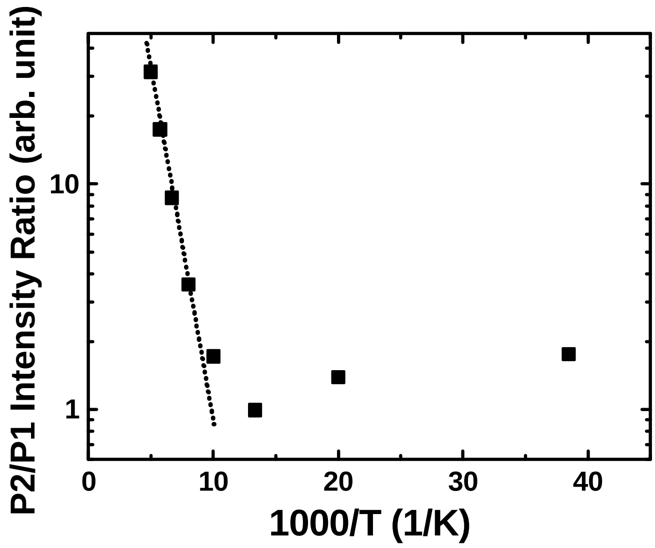

Fig 4. Arrhenius plot of the Intensity ratio of P2 to P1. The activation energy of Mg in GaN is deduced to be 126 meV.

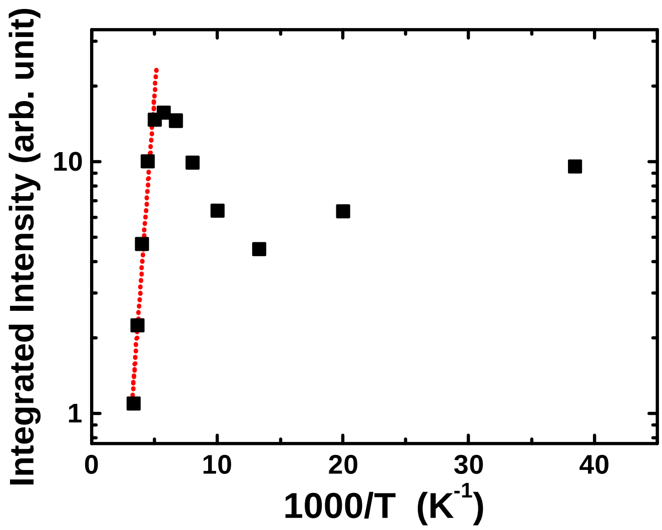

Fig 5. Arrhenius plot of the integrated EL intensity from quantum well (P2). The activation energy for electrons to escape from the well is deduced to be 136 meV