p-GaN층에 따른 InGaN/GaN 다중 양자우물 발광 다이오드의 전기 · 광학적 특성

최락준, 한윤봉*
전북대학교 화학공학부

Effects of p-GaN Layer on Electrical and Optical Properties of InGaN/GaN Multiple Quantum Well Light-Emitting Diodes

R. J. Choi and Y. B. Hahn*
School of Chemical Engineering and Technology, Semiconductor Physics Research Center, Chonbuk National University, Chonju 561-756, Korea

Ⅰ. INTRODUCTION

In recent years, there has been significant progress for the commercial production of light-emitting diodes (LEDs) and laser diodes (LDs) by utilizing wide band gap Ⅲ-nitride semiconductors.[1-4] In spite of the rapid development, many problems still exist which many impediment to further progress in this field. Especially there are problems to be solved such as the high resistivity and low hole concentration of p-type GaN:Mg required for fabricating the high efficiency device operating at low voltage and for decreasing the contact resistance between the metal/p-type semiconductor. But, as well known, the carrier concentration of Mg-doped GaN has been limited by the deep nature of the Mg acceptor in GaN. In other words, it is difficulty to obtain the highly conductive p-type GaN which is necessary for carrier and optical confinement of Nitride-based devices. Therefore, a more detailed study on the Mg-doped GaN including growth technique and activation treatment is needed to optimise the efficiency of devices which are fabricated by Nitride-based devices.

In this paper, we report the effect of p-GaN:Mg layers which were grown with various Cp_2Mg flow rate and growth temperature on the electrical and optical properties of InGaN/GaN multiple quantum well (MQW) LEDs.

Ⅱ. EXPERIMENTAL

The samples were grown on c-plane sapphire substrates by low-pressure metal-organic chemical vapor deposition (MOCVD) system. As shown in Fig. 1, we first grew a 3-μm-thick n-GaN layer at 1130 ℃ on a GaN nucleation layer grown at 560 ℃, and then grew a five-periods of $In_xGa_{1-x}N$

* Author for all correspondence; electronic mail: ybhahn@moak.chonbuk.ac.kr

(25 Å)/GaN(80 Å) MQWs with an x value of average 0.25 at 795 ℃. The source materials were trimethylgalluim (TMGa), trimethylindium (TMIn), and ammonia (NH_3). A 0.25-μm-thick Mg-doped p-GaN layer was grown finally as a function of Cp_2Mg flow rates and growth temperature on the top of MQWs.

The dopant source was cyclopentadienyl-magnesium (Cp_2Mg).

For fabrication of the InGaN/GaN MQW LED chips, the processing procedures were summarized as: 1) SiO_2 film was deposited by PECVD onto the epi-wafer as the etch mask before ICP mesa etching, 2) inductively coupled plasma (ICP) etching with Cl_2/Ar was carried out to form a mesa structure, 3) Au(6 nm)/Ni(6 nm) bi-layer for transparent layer was deposited on the p-GaN by e-beam evaporation and lift-off, 4) Ti(30 nm)/Al(70 nm) bilayer for n-type contact was deposited and patterned by lift-off, and 5) A Ni/Au (30 nm/ 100 nm) bilayer was deposited as the p-type electrode. These metal contacts were annealed at 500 ℃ for 20 seconds under air ambient. The size of LED chip was $320 \times 320\ \mu m^2$. Details of the ICP etching for mesa structure are available elsewhwere.[5] The output power and current-voltage *(I-V)* characteristics were measured at room temperature using an HP 4155A semiconductor parameter analyzer.

Ⅲ. RESULTS AND DISCUSSION

Figure 2 shows the current-voltage (*I-V*) characteristics at room temperature of the InGaN/GaN MQW LEDs as a function of Cp_2Mg flow rate (left) and growth temperature (right) of p-GaN layer, respectively. As the Cp_2Mg flow rate increased from 0.72 to 2.13 μmol/min at keeping growth temperature of 1090 ℃, an operation voltage decreased from 5.18 to 4.34 V at 20 mA injection current. Also, the ***I-V*** characteristics as a function of the growth temperature ranged from 1000 to 1090 ℃ at a Cp_2Mg flow rate of 2.13 μmol/min showed the operation voltage decreased with increasing growth temperature. Although not shown, from the Hall measurement on p-GaN:Mg epilayers with various Cp_2Mg flow rate, we obtained the highest hole concentration at a Cp_2Mg flow rate of 0.72 μmol/min (hole concentration: 5.4×10^{17} cm^{-3}, mobility: 12.6 cm2/V•s), thereafter the hole concentration decreased with increasing Cp_2Mg flow rate. Also, electrical properties with growth temperature of p-GaN:Mg epilayers, when relatively low growth temperature showed a higher the hole concentration in low Cp_2Mg flow rate. But, In high Cp_2Mg flow rate, the hole concentration showed independent of growth temperature of p-GaN:Mg epilayers. In general, the *I-V* characteristic of p-n junction diodes depends on the hole concentration which is related to the resistivity of p-GaN layer. Therefore, if electrical properties (e.g. hole concentration and mobility) is similar between p-GaN:Mg epilayers and p-n junction LEDs fabricated by p-GaN:Mg layer, the abnormal dependence of *I-V* on hole concentration may be explained by predominant current flow at the p-pad/p-GaN interface through a deep level defect band rather than the valence band.

Figure 3 shows the output power characteristics measured as a function of injection current at room temperature with varying the Cp_2Mg flow rate (left) and the growth temperature (right) of p-GaN layer, respectively. We obtained the highest light output power value when the Cp_2Mg flow rate was 1.06 μmol/min at constant growth temperature of 1090 ℃ (left). Also, the output power characteristics as a function of the growth temperature of p-GaN layer showed the highest light output power when the growth temperature was 1050 ℃ at constant Cp_2Mg flow rate of 2.13 μmol/min.

When the output power-current-voltage characteristics consider with Cp_2Mg flow rate and growth temperature of p-GaN layer, optimum condition showed that Cp_2Mg flow rate is 2.13 μmol/min and growth temperature of 1050 ℃. Also, We believe that the light output power is more sensitive to growth temperature than Cp_2Mg flow rates in a certain growth condition range of p-GaN:Mg layer. However, to further elucidate the properties of relation between p-GaN: Mg epilayers and p-n junction LEDs fabricated by p-GaN:Mg layer, more detailed analyses are required.

Ⅳ. CONCLUSIONS

In summary, the effect of p-GaN layer with Cp_2Mg flow rate and growth temperature on electrical and optical properties of InGaN/GaN MQW LED structures were investigated. As the Cp_2Mg flow rate increased at constant growth temperature, an operation voltage decreased from 5.18 to 4.34 V at 20 mA injection current. However, the output power characteristics measured as a function of injection current at room temperature showed the highest light output power at Cp_2Mg flow rate of 1.06 μmol/min. Also, the current-voltage characteristics at room temperature as a function of the growth temperature of p-GaN layer, an operation voltage decreased with increasing growth temperature. The output power characteristics measured as a function of injection current at room temperature achieved the highest light output power value at growth temperature of 1050 ℃. When the output power-current-voltage characteristics consider with Cp_2Mg flow rate and growth temperature of p-GaN layer, optimum condition showed that Cp_2Mg flow rate is 2.13 μmol/min and growth temperature of 1050 ℃. Also, We believe that the light output power is more sensitive to growth temperature than Cp_2Mg flow rates in a certain growth condition range of p-GaN:Mg layer.

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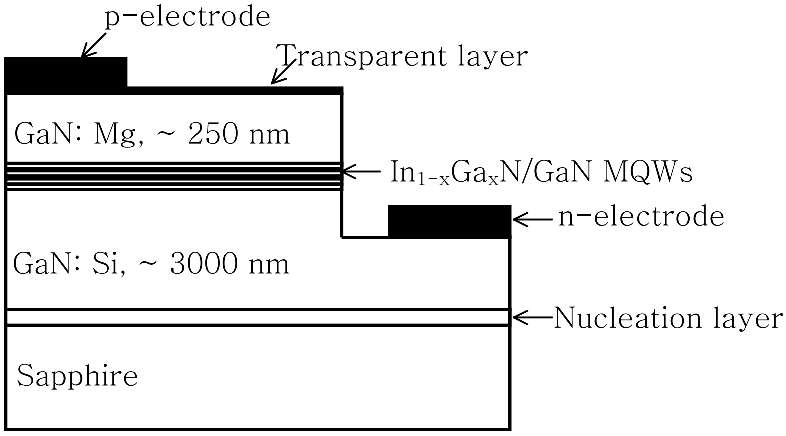

Figure 1. Schematic diagram of InGaN/GaN MQW LED structure.

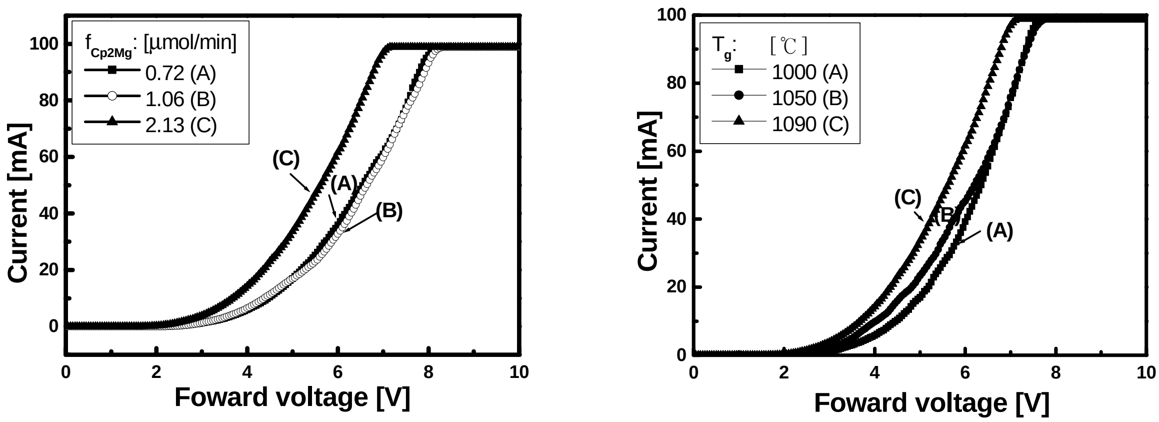

Figure 2. Typical I-V characteristics of InGaN/GaN MQW LED structures at room temperature with the various Cp_2Mg flow rates(left) and growth temperature(right) of p-GaN layer.

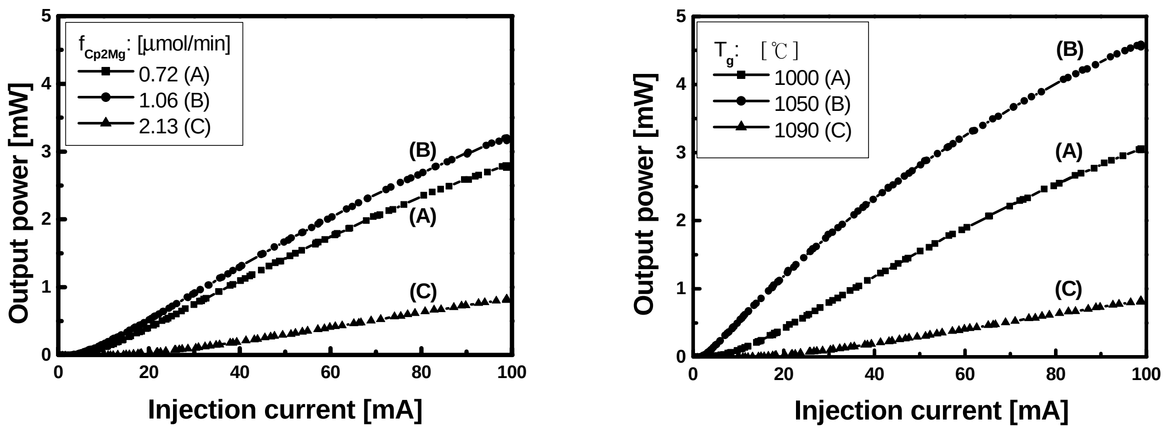

Figure 3. The output power of InGaN/GaN MQW LED structures as a function of injection current at room temperature with various Cp2Mg flow rates(left) and growth temperature(right) of p-GaN.