Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 668-669

P-7-18

High electrical stress influence on reliability characteristics of polarization-induced GaN-InGaN MQW LEDs

Ja-Soon Jang[1] and Hyun Hwi Lee[2]

[1]Korea University, Research Institute of Engineering and Technology
Seoul 136-713, Korea
Phone: +82-62-970-2346 E-mail: jjscontact@yahoo.co.kr
[2]Pohang Accelerator Laboratory (PAL), POSTECH, Pohang 790-784, Korea

1. Introduction

High-performance GaN-based light emitting diodes (LEDs) with excellent operation performance and high reliability are of technological importance for applications in traffic signal, full color display, and solid state lighting.[1] In order to achieve high efficient LED, the enhancement of output power, and the reduction of the turn-on voltage and series resistance of LEDs are essential. However, it is known that GaN-based LEDs with a lateral current path suffer from current crowding and high series resistance due to the high resistivity of *p*-type ohmic contacts.[2] In addition, the electrical properties of transparent current spreading electrode are severely affected by the high resistivity of *p*-GaN, resulting in the high turn-on voltage of LEDs.[3] Recently, polarization-induced InGaN/GaN superlattice, AlGaN/GaN superlattice, and InGaN strained layer have been successfully demonstrated to reduce the series resistance and the turn-on voltage.[4-5]. Although a few of investigations for the device reliability of the normal LED have been reported,[6] however, the high stress dependence on the operation performance and the reliability of the polarization-induced LED (PI-LED) has not been fully carried out.

In this work, we have investigated the electrical stress dependence on the LED reliability characteristics as well as LED performance behaviors for the PI-LED having different transparent ohmic electrodes such as Ni/Au and ITO schemes.

2. Experiment

A metalorganic chemical vapour deposition (MOCVD) system was used to grow InGaN/GaN multiple quantum well (MQW) LED structures (having a peak wavelength of around 455 nm) on c-face sapphire substrates. The PI-LED structure consists of a 30 nm-thick GaN nucleation layer grown on the sapphire substrate, a 2 μm-thick unintentionally doped GaN layer, a 1.5 μm-thick Si-doped GaN *n*-contact layer (N_d ~3.5×10^{18} cm^{-3}), an active region with five periods of InGaN/GaN MQWs, a 0.12 μm-thick Mg-doped GaN layer (N_a ~$3\text{x}10^{17}$ cm^{-3} from Hall measurement). Finally, a 5 nm-thick Mg-doped $In_{0.15}Ga_{0.85}N$ strained layer was grown on *p*-GaN. The Mg concentration of both *p*-GaN and *p*-InGaN, which were determined by secondary ion mass spectroscopy (SIMS), were measured to be 1.5×10^{19} cm^{-3}. After the surface cleaning of the PI-LED, LEDs (330×350 μm^2) were fabricated using photolithography patterning and inductive coupled plasma (ICP) etching to a depth of 0.6 μm. E-beam evaporated Ni/Au (5/5 nm) and sputtered ITO (220 nm) layers were used as transparent ohmic electrodes for the PI-LEDs. The samples were rapid-thermal-annealed at 500 °C for 0.5 min in a flowing N_2/O_2 (4:1) ambient to form ohmic contact. For the N- and PI-LEDs, Ti/Al/Pd/Au (20/50/30/300 nm) (as a *n*-ohmic electrode) was deposited on the *n*-GaN surface and Cr/Al/Ni/Au (20/30/50/300 nm) (as a *p*-ohmic bonding pad) was deposited on the surface of the transparent ohmic electrode. These contact samples were subsequently rapid-thermal- annealed at 500 °C for 30 sec in a flowing N_2 ambient. Current-voltage (*I*-*V*) data were measured using a semiconductor parameter analyzer (HP4155A). Electroluminescence and optical power were obtained using an optical spectrometer and a photodiode detector.

Table I. Summary of the electrical and optical properties of the Au/Ni/*p*-InGaN/*p*-GaN and the ITO/*p*-InGaN/*p*-GaN

	NiAu contact	ITO contact
Light-transmittance @ 450~470 nm [%]	82~87	89~93
Contact resistance [Ωcm^2]	$6.8(\pm0.3)\times10^{-6}$	$4.2(\pm0.4)\times10^{-5}$

3. Results and Discussion

Table I shows summary for the light-transmittance (LT) and the specific contact resistance (R_{sc}) of the Ni/Au and the ITO contacts on strained *p*-InGaN/*p*-GaN. It is shown that R_{sc} of the Ni/Au contact is much lower than that of the ITO contact by more than one order magnitude. On the contrary, it is also shown that the LT of the Ni/Au sample is lower than that of the ITO one. If considering these results, it can be well expected that the electrical properties of the NiAu_PI-LED is better than that of the ITO_PI-LED, while optical output power of the ITO_PI-LED is superior to that of the NiAu_PI-LED. It is also revealed that low contact resistance of both contacts is due to the combinational effects of an increase of the polarization charges and the effective reduction of the Schottky barrier height.[7]

Figure 1 shows the output power (P_o) of the NiAu_PI-LED and the ITO_PI-LED as a function of applied current density. The measurement time of the output power was within 1 sec. It is shown that Po of the ITO_PI-LED increases at a current density of 0.4 kA/cm^2

while that of NiAu_PI-LED decreases at a current density range of more than 0.24 kA/cm^2. This indicates that at a region of less than 0.24 kA both LEDs are electrically and optically stable. Therefore, in this work, we have investigated the applied time dependence on the reliability characteristics as well as electro-optical (E-O) properties at 0.22 and 0.4 kA/cm^2, respectively. In the measurements at a relatively high stress of 0.22 kA/cm^2, we did not find any difference for the E-O and the reliability characteristics of both LEDs, although there was a very slight deviation for the LED device properties of both samples, which is in good agreement with our previous expectations.

On the contrary to the measurement results at 0.22 kA/cm^2, it seems to observe the obvious differences for both LEDs under the high stress of 0.4 kA/cm^2. Figure 2 shows the *I*-*V* characteristics of the NiAu_PI-LED and the ITO_PI-LED as a function of stress time. As for the NiAu_PI-LED, the forward leakage current gradually increases until a stress time of 24 min and then catastrophically degraded at a time of more than 30 min. This behavior was the same as the characteristic of reverse leakage current. It is noted that an increase of forward and reverse leakage current may be associated with various types of defects such as dislocation and point defects and current crowding effect of *p*-ohmic electrode.[3,6,8] On the other hand, the I-V characteristics of the ITO_PI-LED were gradually degraded but remain alive even for more than 60 min, indicating that the ITO_PI-LED shows excellent reliability characteristic as compared to the NiAu_PI-LED. Figure 3 shows the degradation rate of P_o for both NiAu and ITO PI-LED under the electrical stress of 0.4 kA/cm^2. The output power of Po can be expressed by

$$P_o = P_{o,initial} \cdot \exp(-\alpha t) \quad (1)$$

where α and t are the degradation rate and operating time. It is shown that the optical degradation rate of the NiAu_PI-LED is much more rapid than that of the ITO_PI-LED. Based on the electrical and optical degradation behaviors, it should be stressed that the reliability characteristics of the ITO_PI-LED is much better than that of the NiAu_PI-LED.

More detailed results for the temperature dependence on the reliability characteristics and their degradation mechanisms will be described and discussed later.

4. Conclusions

We have investigated the electrical stress dependence on the LED reliability characteristics as well as LED performance behaviors for the PI-LED having different transparent ohmic electrodes such as Ni/Au and ITO schemes. Based on the applied stress and the stress time dependence on the E-O and the reliability characteristics of both LEDs, the ITO_PI-LED is a promising device structure for the realization of the LED having the excellent reliability characteristics as compared to the NiAu-based PI-LED.

Acknowledgements

Authors would like to thank Prof. T-Y. Seong for the discussion.

References

[1] S. Nakamura, S. Senoh, N. Hwasa, and S. Nagahama, Jpn. J. Appl. Phys. **34**, L797 (1995).
[2] Y. Nakano and T. Jimbo, J. Appl. Phys. **92**, 5590 (2002).
[3] X. Guo and E. F. Schubert, Appl. Phys. Lett. **78**, 3337 (2001).
[4] S. J. Chang, C. S. Chang, Y. K. Sheu, R. W. Chuang, W. C. Lai, C. H. Kuo, Y. P. Hsu, Y. C. Lin, S. C. Shei, H. M. Lo, J. C. Ke, and J. K. Sheu, IEEE Photon. Technol. Lett. **16**, 1002 (2004).
[5] J.-S. Jang, D. H. Kim, and T.-Y. Seong, IEEE Photon. Technol. Lett. (in press).
[6] X. A. Cao, E. B. Stokes, P. M. Sandvik, S. F. LeBoeuf, J. Kretchmer, and D. Walker, IEEE Electron. Dev. Lett. **23**, 535 (2002).
[7] J.-S. Jang, S.-J. Sohn, D. H. Kim, and T.-Y. Seong, Semicond. Sci. and Technol. **21**, L37 (2006).
[8] C.-Y. Hsu, W.-H. Lan, and Y. S. Wu, Appl. Phys. Lett. **83**, 2447 (2003).

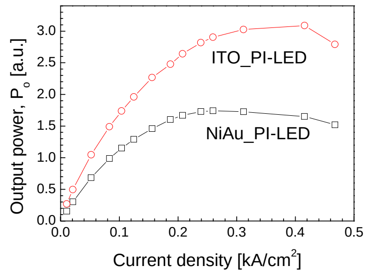

Fig 1. The output power (P_o) of the NiAu_PI-LED and the ITO_PI-LED as a function of applied current density.

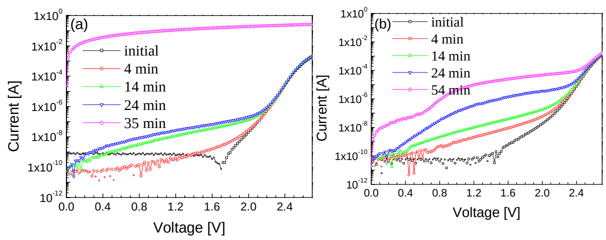

Fig. 2. The *I*-*V* characteristics of (a) the NiAu_PI-LED and (b) the ITO_PI-LED as a function of stress time

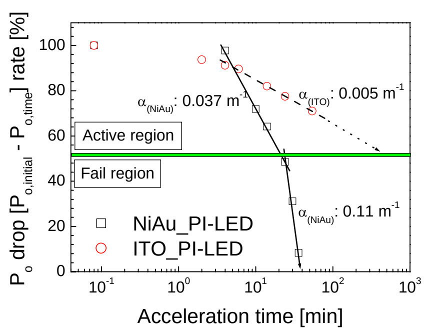

Fig. 3. The degradation rate of P_o for both NiAu and ITO PI-LED under the electrical stress of 0.4 kA/cm^2.