Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 652-653

P-7-10

Effects of Transparent Conductive Layers on Characteristics of InGaN-Based Green Resonant-Cavity Light-Emitting Diodes

Shih-Yung Huang[1], Ray-Hua Horng[2,*]
Wei-Kai Wang[1], Ting-En Yu[1], Po-Rung Lin[1] and Dong-Sing Wuu[1,3]

[1]Department of Materials Engineering, National Chung Hsing University, Taichung, Taiwan 402, R.O.C
[2]Institute of Precision Engineering, National Chung Hsing University, Taichung, Taiwan 402, R.O.C.
[3]Institute of Electro-Optics and Materials Engineering, National Formosa University, Huwei, Taiwan 632, R.O.C.

*Phone: +886-4-22856039; E-mail: huahorng@dragon.nchu.edu.tw

1. Introduction

GaN-based semiconductor material has gone from investigation research to commercial products [1], [2]. Recently, the concept of the resonant-cavity light-emitting diodes (RCLEDs) [3]-[5] have been demonstrated to have a narrower spectrum linewidth, superior directionality of the emitted light, larger bandwidth, better fiber-coupling efficiency and high light extraction efficiency as observed from a comparison with conventional light-emitting diodes. Conventional nitride-based RCLEDs use semi-transparent Ni/Au on p-GaN as the transparent conductive layer (TCL). However, the transmittance of such semi-transparent Ni/Au conductive layer is only around 60-75%. In this work, we have utilized transparent indium-tin oxide (ITO), instead of Ni/Au, as the TCL to increase the probability of transparent light and improve the light-extraction efficiency. This paper describes the characteristics of InGaN-based green RCLEDs on a Si substrate using a wafer bonding technique. The optical and electrical characteristics of these RCLEDs with ITO or Ni/Au TCLs will be discussed.

2. Experimental

The RCLED sample used in this research had a chip size of 356 × 356 μm^2. The electron beam evaporation of ITO and Ni/Au film onto the p-type GaN surface to form the TCL. A SiO_2 insulation layer was evaporated as a current confinement layer to define the aperture region and the mesa region. The LEDs epi-wafer was bonded to a glass carrier using an adhesive, subjected to the laser lift-off process. The lift-off process was performed using a Q-switched Nd:YAG laser. A total 10/15 (top/bottom) dielectric distributed Bragg reflectors (DBRs) layer was evaporated as the mirror to fabrication the RCLEDs device. The transmittance spectra of the evaporated films were measured by the n&k ultraviolet visible spectrometer. A schematic diagram of the RCLEDs structure with ITO and Ni/Au TCL were shown in Fig. 1. A field-emission scanning electron micrograph (FE-SEM) of 5-pairs dielectric DBRs is also illustrated.

3. Results and discussion

Fig. 2 shows the light transmittance spectra of the ITO (200 nm) and Ni (5 nm)/Au (4 nm) film after annealed. As can be seen, the transmittance of the ITO conductive layer is about 90% at the 494 nm peak wavelength. Compared to ITO conductive layer, the smaller transmittance obtained from Ni/Au conductive layer could be attributed to the more opaque property of Ni/Au layer. Fig. 3 shows the current-voltage (*I-V)* characteristics of ITO and Ni/Au contacts on p-GaN after annealed. It can be seen clearly, there was obtain a nonlinear characteristic when we deposited ITO directly onto p-GaN. However, a much more linear behavior of the *I-V* characteristics of Ni/Au can be obtained, which indicates the formation of a superior ohmic contact. We are also measurements to obtain that the specific contact resistance of the ITO contacts is 1.96×10^{-4} $\Omega\cdot cm^2$ when annealed at 550℃, which is to be close to the 1.58×10^{-4} $\Omega\cdot cm^2$ used Ni/Au contacts. Such a result suggests the *I-V* characteristic of ITO contacts on p-GaN is similar to that of the Ni/Au contacts. Therefore, the ITO also preserves high conductivity and can be used as the p-contact material of InGaN-based LEDs.

The optical properties of the InGaN RCLED with an ITO TCL were studied using electroluminescence (EL) measurements as shown in Fig. 4. The emission peak wavelength was located at 494 nm under an injection current of 20 mA. It was found that the EL spectra of the RCLEDs with ITO TCL were modulated strongly for the MQW structure to agree with stopband width of the ITO with top-DBRs and presence of four resonant cavity modes. Moreover, the mode spacing about 8 nm between 494 and 501 nm resulted in the resonant cavity formed during the top and bottom DBRs structure. In addition, the quality factor for this resonant cavity structure can be obtained, we was estimated to be approximately 120. A comparison on the RCLEDs with ITO and Ni/Au TCLs was also shown in the inset in this figure. The EL emission spectra of the RCLED with an ITO TCL structure shows superior periodically modulation than that of the RCLED with a Ni/Au TCL structure due to the high transmittance of ITO.

Fig. 5 shows the EL intensity as a function of injection current density for the RCLEDs with ITO and Ni/Au TCLs. The EL intensity of the RCLED with an ITO TCL is 1.7 times that of the RCLED with Ni/Au TCL under a forward current of 0.6 kA/cm^2. The improvement of optical output was attributed to the high transmittance of the ITO TCL. This result indicated that the Ni/Au metal layer for transparent ohmic contact decreases the EL intensity of the RCLED sample due to the small transmittance of the Ni/Au TCL.

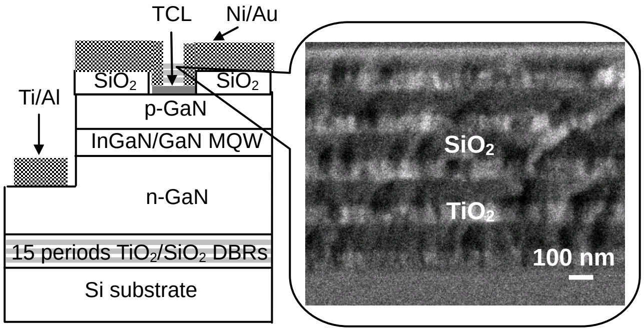

Fig. 1. Schematic diagram of RCLED structure with a cross-section FE-SEM of top-DBRs.

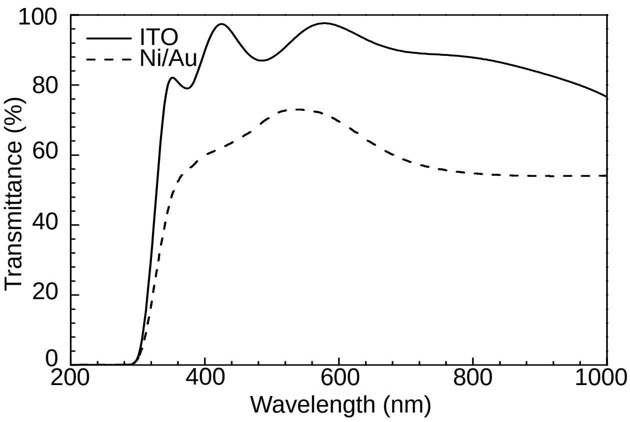

Fig. 2 Transmittance spectra of Ni(5 nm)/Au(4 nm) and ITO (200 nm) film after annealed.

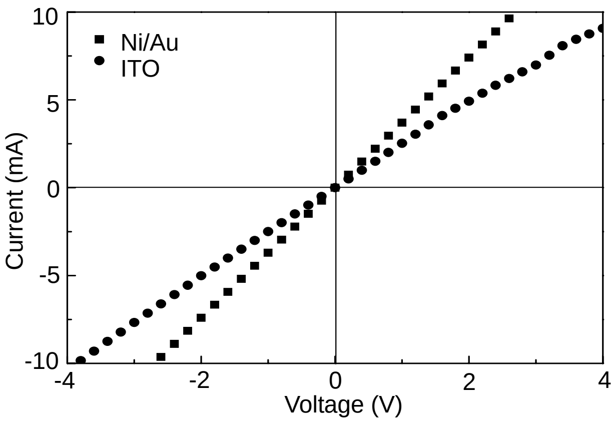

Fig. 3. *I-V* characteristics of Ni/Au and ITO contacts on p-GaN

4. Conclusion

The characteristics of the InGaN-based RCLEDs with ITO and Ni/Au TCLs fabricated on a Si substrate were reported. The ITO TCL on p-GaN shows specific contact resistance of 1.96×10^{-4} $\Omega\cdot cm^2$ with high light transmittance of about 90% at 494 nm peak wavelength. The EL intensity of the RCLEDs with an ITO TCL at 0.6 kA/cm^2 showed an enhancement by a factor of 1.7 times, as compared with that of the RCLED with a Ni/Au TCL. The quality factor of this resonant cavity structure was estimated to be approximately 120. These results indicate that the ITO can be used as a suitable TCL for the high-performance InGaN-based RCLEDs.

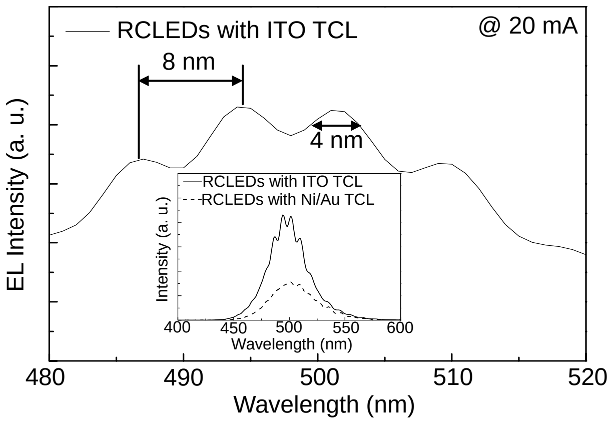

Fig. 4 Room-temperature EL spectrum of InGaN RCLED with an ITO TCL at 20-mA injection current. The inset shows EL spectra of RCLEDs with Ni/Au and ITO TCLs.

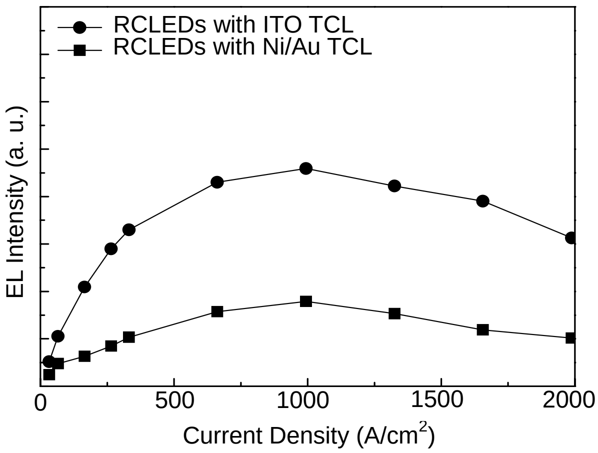

Fig. 5. EL intensity as a function of injection current density for RCLEDs with ITO and Ni/Au TCLs.

Acknowledgment

This work was supported by the National Science Council of the Republic of China under contract No. NSC-93-2615-E-005-004.

References

[1] S. Nakamura, and G. Fasol, "The Blue Laser Diode," Springer, New York, 1997.

[2] S. D. Lester, M. J. Ludowise, K.P. Killeen, B. H. Perez, J. N. Miller, and S. J.Rosner, J. Cryst. Growth, vol. 189, pp. 786, 1998.

[3] F. B. Naranjo, S. Ferna´ndez, M. A. Sa´nchez-Garcý´a, F. Calle, and E. Calleja, Appl. Phys. Lett., vol. 80, pp. 2198, 2002.

[4] P. Maaskant, M. Akhter, B. Roycroft, E. O'Carrol, and B. Corbett, Phys. Stat. Sol. (a), vol. 192, pp. 348, 2002.

[5] F. Calle, F. B. Naranjo, S. Ferna´ndez, M. A. Sa´nchez-Garcý´a, E. Callea, and E. Munoz, Phys. Stat. Sol. (a), vol. 192, pp. 277, 2002.