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Removal of Sapphire Substrate for Fabrication of InGaN/GaN MQWs Vertical Blue Light-Emitting Diodes Using Laser Lift-Off Technique

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Abstract

The removal of sapphire substrate from epitaxially grown InGaN/GaN multiple quantum wells (MQWs) based blue light emitting diode structure grown on c-plane sapphire substrate using KrF excimer laser (λ = 248 nm) were investigated. The LED structure was successfully transfer to thick (~ 150 µm) electroplated copper substrate. Blue light emission was demonstrated successfully from LED structure transferred on thick electroplated copper substrate using laser lift-off process after removal of sapphire substrate.

Keywords: *GaN, light emitting diode, p-contact, laser lift-off.*

1. Introduction

Group III-nitride wide band gap materials have recently attracted due to their wide applications in optoelectronic devices such as blue-light emitting diodes (LEDs), laser diodes (LDs) and other electronic devices, which operates at high temperature and high power. In last few years, white LEDs made by GaN materials were suitable for light sources. The epitaxial layers were grown on sapphire substrate to realize LEDs due to relatively low cost compared to SiC or GaN substrates. However, due to electrically insulating and low thermal conductivity (~ 35 W/m.K) of sapphire substrate, the device process steps are relatively complicated compared to SiC and GaN. For solid state lighting application, the fabrication of high power and high efficiency GaN based light-emitting diodes are essential. In the conventional LED chip fabrication using sapphire substrate, p and n-contacts are made in the same plane due to insulating properties of sapphire substrate. Moreover, chip size is limited ~ 300 x 300 µm^2 due to current crowing, low thermal conductivity of sapphire and top p-contact etc. Also, the light emission area of conventional GaN-based LED on sapphire with p-side up configuration was reduced because a part of the area of p-GaN and multiple quantum wells (MQWs) layers required etching away to expose n-GaN layer for n-contact. Moreover, due to low hole mobility and lower electrical conductivity of p-GaN [1], the conventional LED chip design require the transparent conducting layer (TCL) on p-GaN for uniform current distribution over p-GaN for uniform light emission. However, to increase the light emission area and output power, the interdigitated mesa geometry [2-3] were reported but the light emission area was still limited due to current spreading length, and reduction in size of light emission area due to interdigitated electrodes. Though, the flip chip bonding technique for backside emission of GaN LED were reported to enhance light emission area and output power, but process for fabrication of GaN LEDs from this technique were complicated and costly. In recent years, the fabrication of GaN–based light-emitting diodes (LEDs) with p-side down and transfer to a copper substrate [5-6] using laser lift-off (LLO) have been reported and have superior performance due to excellent heat dissipation, high operating current, large emission area etc., compared to conventional LEDs on sapphire substrate.

In this paper, we report in detailed, the removal of sapphire substrate from metal-organic chemical vapor deposition (MOCVD) epi-taxially grown InGaN/GaN MQWs based LED structure on c-plane sapphire using LLO technique. Blue light emission from transferred LED structure on thick electroplated Cu substrate after removal of sapphire substrate was also demonstrated.

2. Experimental Details

The LED structure used for LLO process was grown by metal organic chemical vapor deposition on c-plane sapphire substrate. The LED structure consists of a low temperature (~ 550 ^{0}C) 20 nm thick GaN nucleation layer, 2 µm un-doped GaN buffer layer, ~ 2 µm thick n-GaN (Si-doped), a region of multiple quantum wells (MQWs) consisting of five pairs of InGaN QW (3nm) and GaN barrier (12 nm), a 20 nm AlGaN electron blocking layer (EBL) and 100 nm thick p-GaN (Mg-doped). The thickness and indium fraction in $In_xGa_{1-x}N$ QW were optimized to get emission wavelength around ~ 460 nm. After epitaxial growth of GaN layers, wafer was annealed

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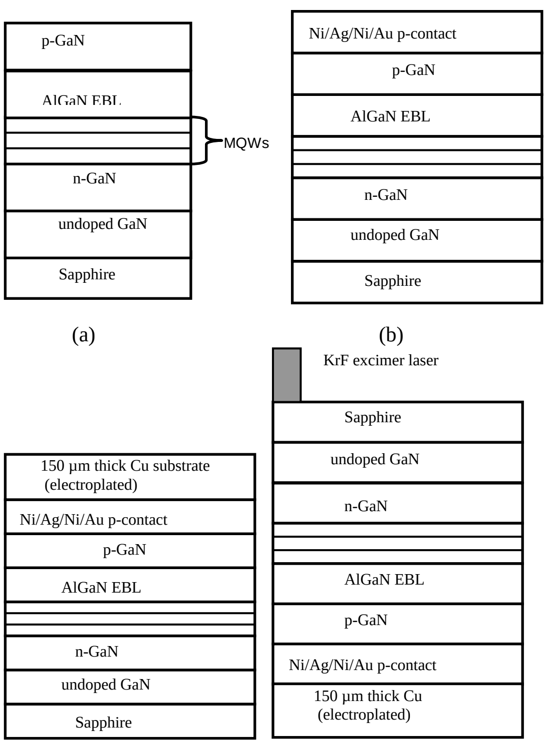
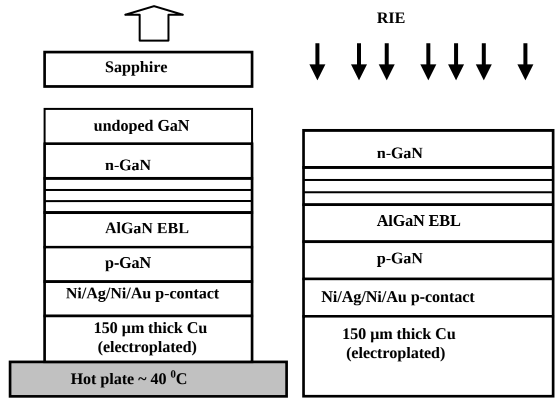
in rapid thermal annealing (RTA) to activate magnesium (Mg) and followed by backside polishing of sapphire wafer to get smooth surface for LLO. To get highly reflective p-contact with low specific contact resistance, first wafer was cleaned in aqua-regia solution for 10 min and then rinse with de-ionized (DI) water to remove the native oxide and then loaded in to chamber of electron beam system. The metal scheme Ni/Ag/Ni/Au (1.5/120/10/50 nm) was deposited. To reduce the contact resistance, wafer was annealed at 500 ^{0}C in RTA system. After annealing, a thick (~150 µm) copper electroplating was carried out. The electroplated LED wafer with backside polished sapphire substrate was diced in small pieces. The electroplated sample was subjected to LLO process. A KrF excimer laser emitting wavelength at 248 nm with a pulse width of 20 ns was used to remove sapphire substrate. The laser with a beam size of 1.0 x 1.0 mm^2 and laser flux (~806 mJ/cm^2) was incident on polished backside surface of sapphire substrate to remove the sapphire substrate. At the sapphire/GaN interface, the laser radiation is absorbed and GaN is decomposed into Ga and N_2. After the whole GaN LED sample was scanned by laser beam, the sample was placed on a hot plate at Ga melting point of about 40^0 C to separate the GaN LED structure from sapphire substrate to a copper substrate. The remaining Ga on surface was removed in hot diluted HCl solution. Finally, Indium (In) was deposited on n-GaN as n-type contact.

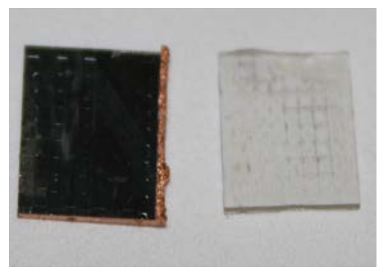


(c) (d)



(e) (f)

Fig. 1 LLO process for fabrication of GaN LEDs on Cu substrate (a) Epitaxial grown LED structure on sapphire (backside polished) (b) p-type metal deposition (c) Cu electroplating (~150 µm) (d) KrF excimer laser processing (e) removal of sapphire substrate (f) etching of GaN buffer layer using reactive ion etching



(a) (b)

Fig. 2 Photograph of LED structure transferred on electroplated Cu substrate (a) and separate sapphire substrate (b) after LLO and heat treatment (40 ^{0}C).

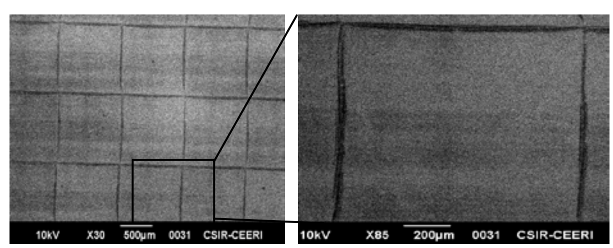


Fig. 3 The SEM images (top view) of the GaN LED structure transferred to electroplated Cu substrate. No cracks were observed on transferred LED film.

Fig. 4 Blue light emission from LED structure transferred to thick electroplated Cu substrate after LLO and reactive ion etching of un-doped n-GaN

3. Results and Discussions

Fig. 2 (a) shows the photograph of the transferred GaN LED structure on electroplated Cu substrate. Fig. 2 (b) shows removed sapphire substrate after LLO process. The GaN LED film on Cu substrate was smooth. To confirm the smoothness of surface the scanning electron microscopy (SEM) of sample carried out. Fig. 3 shows the scanning electron microscope (SEM) image of the transferred GaN LED film on Cu substrate. From fig. 3 it is clear that film is smooth without peeling or cracks even the large difference in the thermal expansion coefficients of GaN (4.4 x 10^{-6}/K) and Cu ((16.9 x 10^{-6}/K). It is also clear (fig. 3 a) that no bending of sample was occurred which means thickness of electroplated Cu substrate has sufficient strength for fabrication of vertical LEDs. Fig. 4 shows the photograph of blue light emission from LED structure transferred on electroplated Cu substrate.

4. Conclusions

In conclusion, we demonstrate the laser lift-off process for removal of sapphire substrate from InGaN/GaN MQWs blue LEDs structure on c-plane sapphire for fabrication of high brightness vertical light emitting. The LED structure was successfully transferred to electroplated thick ~ 150 µm Cu substrate. The un-doped GaN layer was etched using reactive ion etching. The chlorine chemistry (BCl_3 and Cl_2) was used to etch un-doped GaN layer. The blue light emission was successfully demonstration after LLO and removal of un-doped GaN layer. For electrical connection the indium was deposited on n-GaN. Thus, LLO-LEDs on electroplated Cu substrate may be suitable for fabrication of low cost high brightness vertical GaN LEDs.

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References

[1] Nakamura and G. Fahsol: The Blue Laser Diode (Springer, Berlin, 1977).

[2] X. Guo, Y-L. Li and E. F. Schubert, “Efficiency of GaN/InGaN light-emitting diodes with interdigitated mesa geometry,” Applied Physics Letter vol. 79, 2001, pp. 1936-1938.

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[3] X. Song, X. Zeng, J. Zhang, Y. Jin and X. Meng, “Optoelectronic properties of GaN-based light-emitting diodes with different mesa structures,” Material Sciences and Applications, vol. 3, 2012, pp. 838-842.

[4] J. J. Wierer, D. A. Steigerwald, M. R. Krames, J. J. O’Shea, M. J. Ludowise, G. Christenson, Y-C. Shen, C. Lowery, P. S. Martin, S. Subramanya, W. Gotz, N. F. Gardner, R. S. Kern and S. A. Stockman, “High-power AlGaInN flip-chip light-emitting diodes,” Applied Physics Letter vol. 78, no. 22, 2001, pp. 3379-3381.

[5] J. J. Chu, H. C Kuo, C. C Kao, H.W. Huang, C. F. Chu, C. F. Lin and S. C. Wang, “Fabrication of p-side down GaN vertical light emitting diodes on Copper substrates by laser lift-off,” Phys. Stat. Sol. Vol. 1, No. 10, 2004, pp. 2413- 2416.

[6] C. F. Chu, F-I Lai, J-Tang Chu, C-Chang Yu, C-Feng Lin, H-Chung Kuo and S. C. Wang, “Study of GaN light-emitting diodes fabricated by laser lift-off technique,” Journal of Applied Physics, vol. 95, no. 8, 2004, pp. 3916-3921.

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