

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

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ABSTRACT: Vertical GaN blue light-emitting diodes (VLEDs) on thick electroplated copper substrate were realized and characterized at wafer level. To realize vertical LED, the sapphire substrate from epitaxially grown LED structure was removed using KrF excimer laser ($\lambda=248$ nm). The Ti/Al/Ni/Au metal scheme was used n-contact. The current-voltage (I-V) and electroluminescence (EL) were measured. The turn on voltage was ~ 2.8 V.

KEYWORDS: GaN, light-emitting diode (LED), laser lift-off (LLO), reactive ion etching (RIE).

I. INTRODUCTION

In recent years, GaN-based light-emitting diodes (LEDs) are the most promising candidate for development of more efficient and highly reliable light source for replacement of low efficient (~ 5 -10%) incandescent bulb, compact fluorescence lamp (CFL) etc. Though, CFL has much energy efficient compare to incandescent bulb but due to contains of mercury, it has health and environmental related issues such as disposal and toxicity. Other important issue with CFL is its low life time (~ 2000 -7000 hrs) compare to LED ($\sim 50,000$ -100000 hrs).

For development of efficient and reliable solid-state light source, vertical-injection GaN-based light-emitting diodes (LEDs) [1-3] have been identified the most promising candidates for production of high power LEDs. However, to fabricate vertical LED structure, removal of sapphire substrate using laser lift-off [1-4] is essential. Moreover, vertical LED structure has various advantages such as better current injection, large emission area, efficient thermal dissipation due to high thermal conductivity of copper, over to conventional LED structure. The conventional LED structure suffers current crowding [5], less emission area due to n- and p-contacts in the same plane, less heat dissipation due low conductivity of sapphire (~ 35 W/m.K).

In this paper, we report the detailed growth, fabrication and characterization of GaN blue vertical light emitting diode.

II. FABRICATION OF GAN VERTICAL LEDs

The LED samples used in this work were grown by metal organic chemical vapour deposition (MOCVD). The LED structure consists of ~ 20 nm thick low temperature (550 °C) GaN nucleation layer, 2 μm thick undoped GaN buffer layer, ~ 2 μm n-GaN (Si-doped), an active region with five periods InGaN-GaN multiple quantum well (MQW) layer, ~ 20 nm thick Magnesium (Mg) doped AlGaIn electron blocking layer (EBL) and a 150 nm thick Mg-doped p-GaN

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on c-plane sapphire substrate. The thicknesses of InGaN QW and GaN barrier were ~ 3 nm and 10 nm respectively. The fraction of indium (In) in InGaN QW and thickness were optimized to obtain the dominant wavelength ~ 460 nm. To fabricate vertical GaN blue LED, first a metal layer composed of Ni/Ag/Ni/Au was deposited on p-GaN by electron beam evaporation. Before depositing Ni/Ag/Ni/Au, p-GaN surface was treated in aqua-regia solution to remove native oxide. This metal layer serves as p-contact, a highly reflective mirror layer and an adhesive layer to subsequent electroplated copper layer. The p-contact was annealed at 500°C for 5 min in N_2+O_2 atmosphere in rapid thermal annealing system. The thickness of electroplated copper was ~ 150 μm . Before, laser lift-off (LLO) process, the backside of the LED sample (sapphire) was polished for getting smooth surface to avoid the scattering of laser light. After polishing of sapphire substrate, LLO process was executed using KrF excimer laser emitting at 248 nm. The laser beam was directed through the back of polished sapphire substrate. The details of LLO process was published elsewhere [4]. The sapphire substrate was removed when sample was heated at $\sim 40^{\circ}\text{C}$. After removal of sapphire, gallium (Ga) particles remaining on the undoped GaN layer. The GaN particles were removed in HCl: H_2O (1:1) solution. After removal of Ga particles, n-contact pattern were formed using conventional UV photolithography. Shipley -1818 photoresist was used as masking layer for etching of undoped GaN layers. After patterning, undoped GaN layer was etched in reactive ion etching system using BCl_3 and Cl_2 chemistry. After etching of undoped GaN layers, Ti/Al/Ni/Au metal were deposited by electron beam evaporation system and followed by lift-off. The metal scheme Ti/Al/Ni/Au serves as n-contact.

III. RESULTS AND DISCUSSIONS

Fig. 1 shows the photograph of fabricated vertical blue LED on electroplated thick copper substrate. The chip size of vertical blue LED was ~ 1.0 mm x 1.0 mm. Since thermal annealing play important role in electrical and optical properties of LED. Therefore, to analyse the effect of thermal annealing on LED film, scanning electron microscopy (SEM) images of the samples were taken. Fig. 2 shows SEM images of LED samples without annealed (a) and annealed at 330°C (2 b), 400°C (2c) and 830°C (2d). From fig. 2 (a), it is clear that there were no cracks in sample without annealing. Moreover, it is clear that film was cracked when annealed at 330°C , 400°C and 830°C , respectively. The cracks in LED film increases as annealing temperature increases. It is clear that cracks in LED films were largest when sample was annealed at 830°C and cracks decreases when annealing temperature was decreases. The cracks in film may be due large difference in the thermal expansion coefficients of GaN ($4.4 \times 10^{-6}/\text{K}$) and Cu ($16.9 \times 10^{-6}/\text{K}$). Fig. 3 shows the photograph of blue light emission from fabricated vertical blue LED chip at 4.0 V. To check the emission wavelength as per our design, the electroluminescence (EL) of LED sample was taken. For measurement of EL, LED chip was biased at 4.0V and the emitted blue light was collected in integrated sphere. The fig. 4(a) shows the electroluminescence spectra of fabricated blue VLED at 5V. The peak wavelength was ~ 461 nm. Fig. 4 (b) shows the measured current-voltage (I-V) of fabricated InGaN/GaN MQWs blue VLED on copper substrate. The turn on voltage was ~ 2.8 V. The increase in current after threshold limit was not sharp. This may be due higher resistance of the device because n-contacts were not annealed at higher temperature.

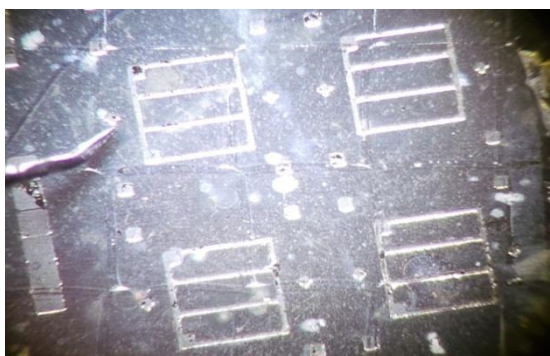


Fig. 1 Shows the photograph of fabricated InGaN/GaN MQWs vertical blue LED on electroplated copper substrate.

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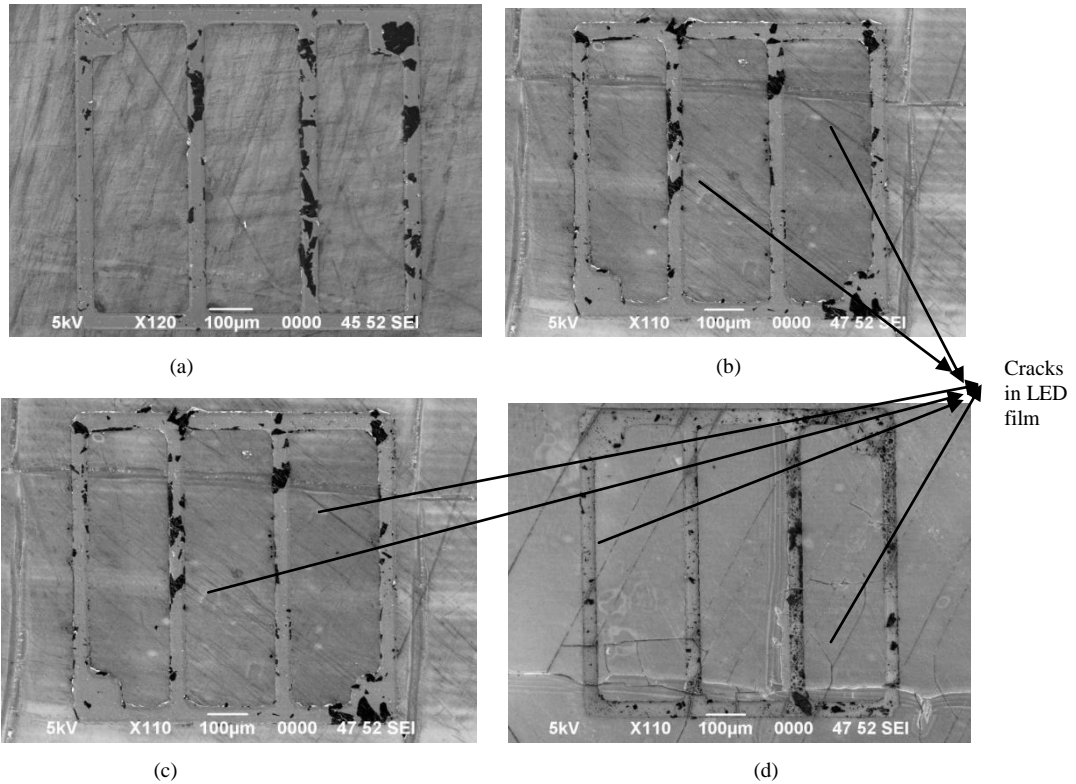


Fig. 2 Shows SEM photograph of fabricated InGaN/GaN MQWs blue LED on electroplated copper substrate with different annealing temperatures (a) without annealing (b) annealed at 330 °C for 30 sec (c) 400 °C (d) 830 °C.

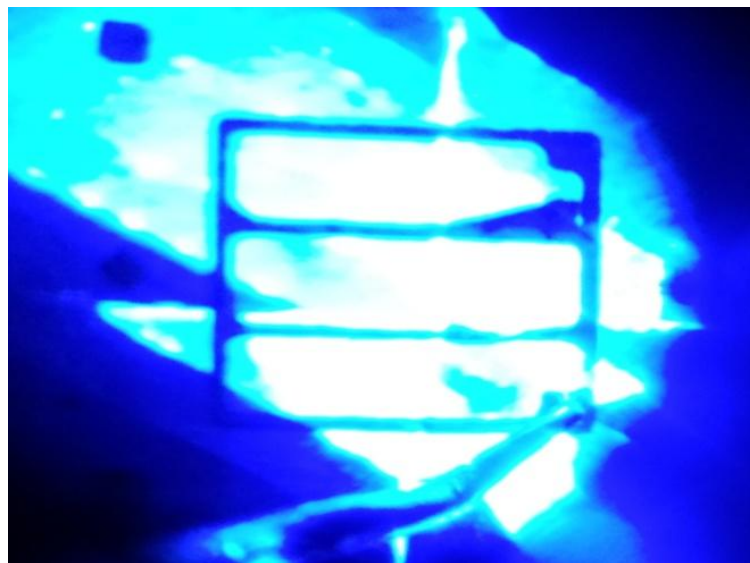


Fig. 3 Shows the photograph of blue light emission from InGaN/GaN MQWs vertical blue LED on electroplated Cu substrate at 4.0 V.

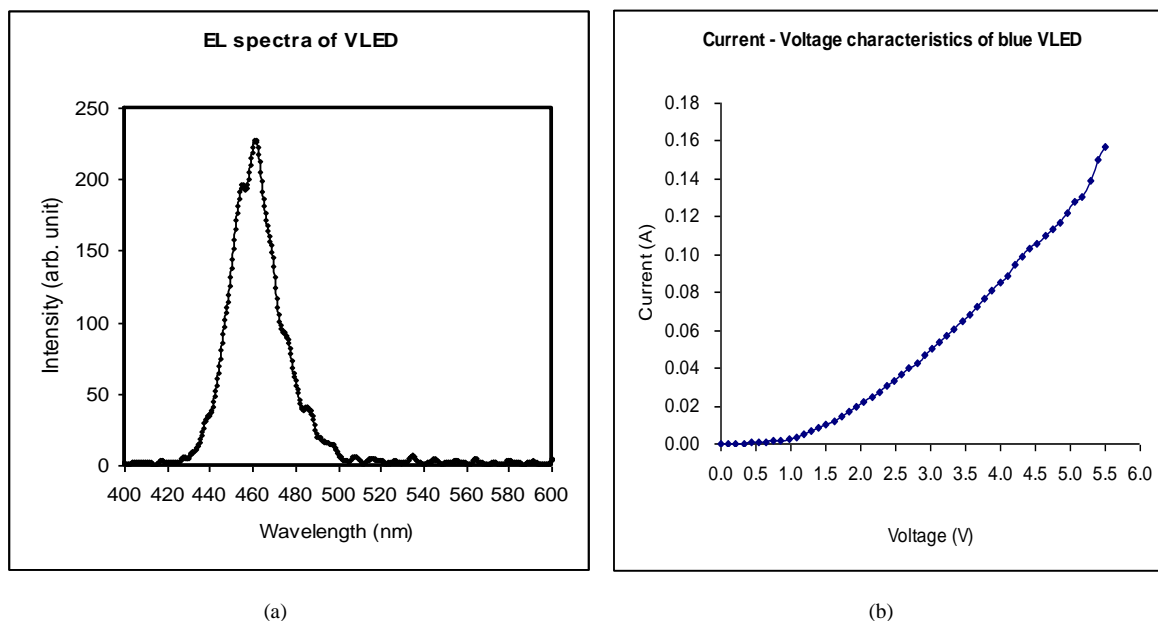


Fig. 4 (a) shows the electroluminescence spectra of fabricated VLED at 5.0V (b) the current-voltage characteristics of VLED at wafer level.

IV. CONCLUSION

In conclusion, we have successfully demonstrated the InGaN/GaN MQWs vertical blue LEDs on electroplated thick copper substrate using laser lift-off process. The effect of thermal annealing on LED film was carried out after LLO and formation of n-contact (Ti/Al/Ni/Au). It is observed that due to large difference in thermal expansion coefficients of Cu and GaN material, the film was cracked after thermal annealing. At higher temperature thermal annealing, the cracks in LED structure were large while, LED structure annealed at lower temperature, cracks were small. Since thermal annealing in N_2 ambient is necessary for getting low contact resistance for n-contact ((Ti/Al/Ni/Au) because this metal scheme has low contact resistance when they are annealed in temperature range 750-850 $^{\circ}C$. Therefore, stress in LED structure should be optimized for fabrication of high brightness blue LED.

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