

Degradation of InGaN/GaN LEDs under Forward-bias Operations in Salty Water Vapor

Hsiang Chen^{1,*}, Kun Min Hsieh¹, Yun Yang He¹, Li Chen Chu², Ming Ling Lee² and Kow Ming Chang²

¹Department of Applied Material and Optoelectronic Engineering, National Chi Nan University, 54561, Puli, Taiwan, R.O.C.

²Department of Electronic Engineering, National Chiao Tung University, Hsin-Chu, 30010, Taiwan, R.O.C.

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Abstract: Forward-bias stress in salty water vapor can quickly degrade the InGaN/GaN LEDs. To examine the weakness of the device, electrical, optical, and material analyses and characterizations were performed to investigate the failure mechanism. Corrosion of the electrode and Au atom diffusion might result in damages of the device. Results indicate that forward-bias stress in salty water vapor can quickly influence the material properties, optical behaviors, and electrical characteristics of the LED device.

Keywords: Green InGaN/GaN LED, Salty Water Vapor, Forward-bias, Corrosion, Au diffusion

1. INTRODUCTION

Over the past decade, the reliability of InGaN-based light emitting diode has attracted growing attention. However, it takes around 10000 h to degrade the LED under normal forward-bias operations and investigate the reliability problems. Therefore, considerable studies have been conducted to examine the reliability issues for the LED under reverse-bias operations because stressing the device in the reverse-bias mode can shorten the device degradation time and screen the LED failure mechanisms as the researchers report [2-4]. Still, under reverse-bias operations, the LEDs are biased at high reverse-bias voltage but low reverse-bias leakage current may not be fully unfold the real forward-bias operation mode since the LEDs are biased at high band-to-band recombination current but low forward-bias voltage. On the other hand, researchers have also examined the reliability issues for the LEDs biased in forward-bias operations in water vapor ambient [5, 6]. Incorporation of LED working environment can examine the robustness for device and quickly screen the device quality [7]. In addition to water vapor environment, salty water vapor can also degrade the LED performance rapidly. Furthermore, salt mist tests have been applied to examine the reliability for semiconductor devices in industrial field although the detailed physics for LEDs operated in salty water ambient have not been clearly studied.

In contrast to traditional LED reliability test reported in academic field, we stressed AlGaIn/GaN LEDs under normal forward-bias operations in salty water ambient.

2. EXPERIMENTAL METHODS

To analyze the degradation caused by the salty water vapor for LEDs under normal forward-bias operations, electrical measurements, optical observations (forward-bias and reverse-bias electro-

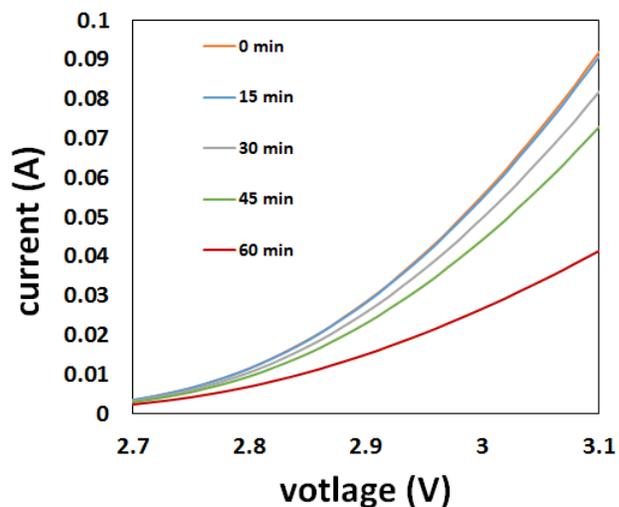


Figure 1. (a) Forward-bias I-V characteristics for the stressed green LED (b) Reverse-bias I-V characteristics for the stressed green LED.

*To whom correspondence should be addressed: Email: hchen@ncnu.edu.tw
Phone: +886-49-2910960 fax: +886-49-291-0960

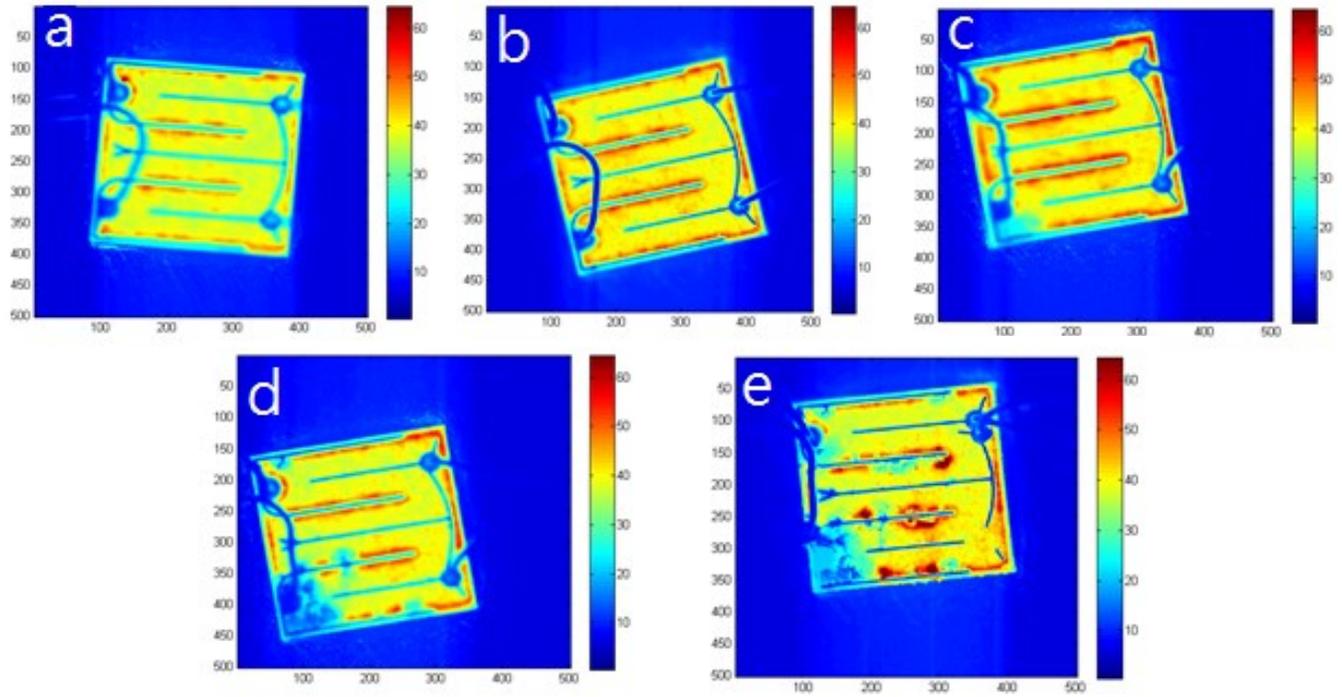


Figure 2. Forward-bias EL images for the device stressed for (a) 0 min (b) 15 min (c) 30 min (d) 45 min (e) 60 min.

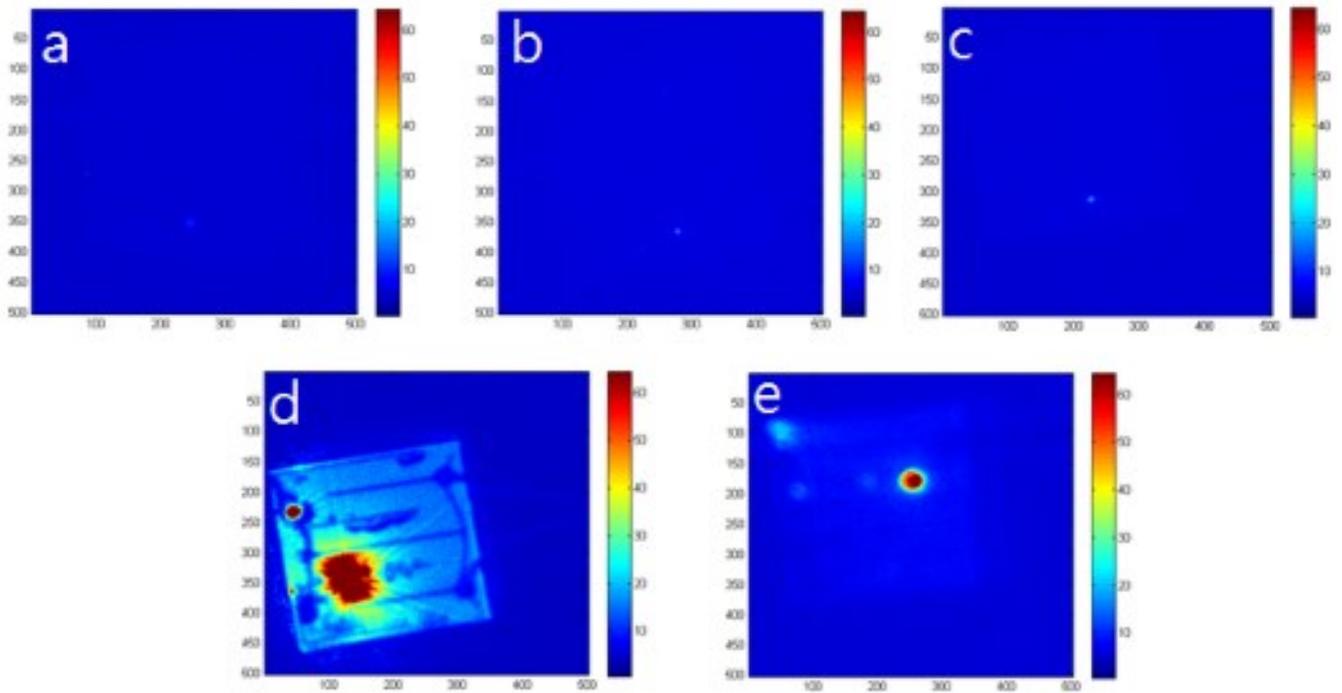


Figure 3. Reverse-bias EL images for the device stressed for (a) 0 min (b) 15 min (c) 30 min (d) 45 min (e) 60 min.

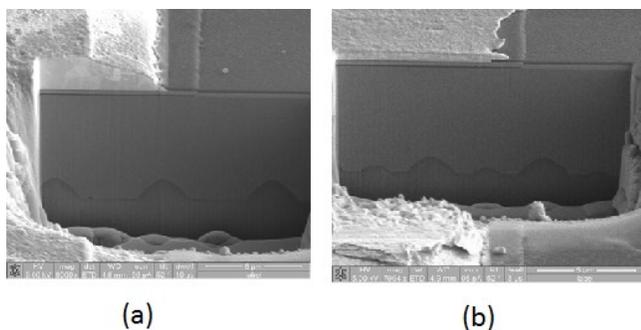


Figure 4. SEM images of the cross section for (a) the fresh device and (b) the stressed device around the metal contact.

luminescence (EL)), and multiple material analyses including focus ion beam (FIB), scanning electron microscope (SEM), energy dispersive X-ray spectroscopy (EDX) were conducted. Moreover, CIE and EL spectra were taken to investigate the luminescence wavelength. The experimental results reveal that LEDs in normal forward-bias mode could be degraded rapidly in salty water vapor. The LED degraded under forward-bias operations around 1 hour in salty water vapor compared degradation after 10000 hours in dry air. Furthermore, according to multiple material analyses, metal contact corrosion and Au diffusion downward into the device might cause the failure of the device.

3. RESULTS AND DISCUSSION

The InGaN/GaN MQW green LEDs were deposited by metal organic chemical vapor deposition (MOCVD) on a c-face 2-inch sapphire (0001) substrate. The LED structure was composed of a 30 nm GaN nucleation layer, a Si-doped n-type GaN buffer layer, a Mg-doped electron blocking layer, and a Mg-doped p-GaN layer. Between the p-type GaN and the n-type GaN layers InGaN/GaN quantum well-barrier pairs were stacked. After the deposited sample was partially etched down to n+ layer, a surface indium-tin oxide (ITO) layer was grown on the surface functioning as the transparent contact layer (TCL). In addition, Ti/Al/Ti/Au contact was evaporated on top of the n-type GaN layer functioning as the n-type electrode. To measure the forward-bias and reverse-bias electrical properties, forward-bias and reverse-bias I-V curves were taken by HP 4155 C. Forward-bias and reverse-bias EL images were captured by iXon electron multiplying charge coupled device (EMCCD) camera. The exposure time to capture the forward-bias images was 5 μ s and the exposure time to capture the reverse-bias images was 25 s. Since the reverse-bias EL intensity is weak, the electron multiplying (EM) gain was 1024 when the reverse-bias images were taken. The model for the FIB/SEM/EDX system was FEI Nova 200. The EL spectra and CIE chromaticity diagram were taken by Optimum optoelectronics LM-ISP-50.

To study the green LED degradation trend caused by forward-bias stress in salty water ambient, the forward-bias I-V and the reverse-bias I-V curves were measured by as shown in Fig. 1(a) and (b) for the fresh device, and the device stressed at 0, 15, 30, 45 min and 60 min, respectively. Obviously, the forward-bias turn-on current kept decreasing as shown in Fig. 1(a). However, the reverse-bias current did not follow the same trend as the forward-bias

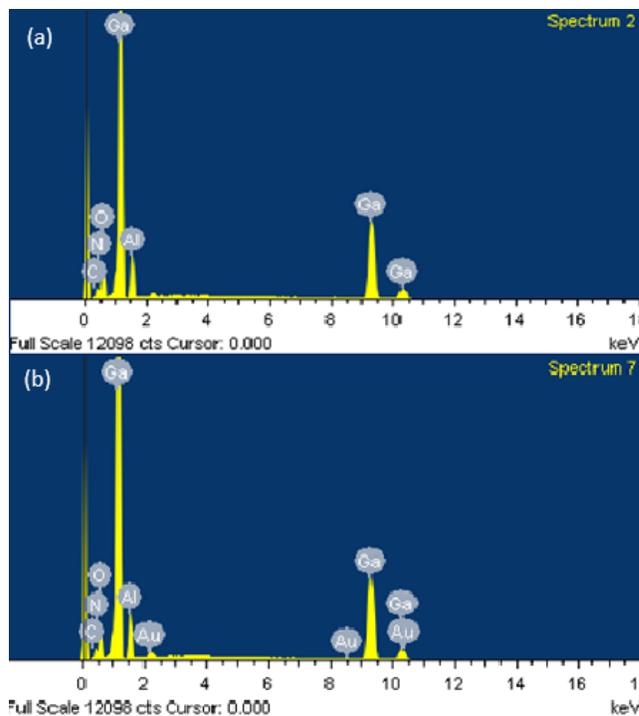


Figure 5. EDX analyses for the area on bottom of the metal contact for (a) the fresh device (b) the stressed device.

current did as shown in Fig. 1(b). The reverse-bias current increased drastically as the stress time increased from 0 min to 45 min but decreased as the stress time increased from 45 to 60 min.

To further understand the degradation trend of the green LEDs, the forward-bias and reverse-bias electroluminescence (EL) images processed by MATLAB from the LEDs were taken by EMCCD as shown in Fig. 2 (a)-(e) and 3 (a)-(e). As shown in Fig.2 (a), (b), (c), (d), and (e), the forward-bias EL images captured by the EMCCD from the fresh LED and the LED stressed for 15 min, 30 min, 45 min, and 60 min are juxtaposed. Some dark area on the bottom-left corner emerged after the device was stressed for 30 min. As the stress time increased from 30 min to 60 min, the dark area on the bottom-left corner enlarged and more dark areas appeared on the chip. The forward-bias emission intensity increased in certain areas, which might be because of the surface leakage current. To reveal the changes of the LED chip, the reverse-bias EL images at the stressed time of 0 min, 15 min, 30 min, 45 min, and 60 min are shown in Fig. 3 (a), (b), (c), (d), and (e). According to the reverse-bias EL images, a tiny reverse-bias EL spot can be seen on the images for the device stressed shorter 30 min. As the LED further stressed for 45 min under forward-bias operations in salty water ambient, two large reverse-bias EL spots emerged. The reverse-bias areas were distributed near the contact edge, which might be attributed to hot electron-induced emission because of high electric field [8]. Moreover, by comparing the forward-bias and reverse-bias images, the reverse-bias EL areas are dark on the forward-bias images. The results indicate that the reverse-bias EL areas might be damaged areas for the green LEDs. Finally, as the LED stressed for 60 min, the reverse-bias EL spots became dim again. Consistent

with the reverse-bias I-V curves, the reverse-bias current increased drastically after the device stressed for 45 min. At the same time, the two strong reverse-bias spots emerged. As the stress time further increased to 60 min, the reverse-bias EL and current both became smaller. In addition, the forward-bias current decreased drastically. The emergence of the reverse-bias EL spot might be related to the device degradation.

To gain insight to the change of the electrical and optical properties, FIB was used to dissect the LED and analyze the cross section. Furthermore, SEM and EDX were conducted to observe the cross section for the fresh device and the stressed device. As shown in Fig. 4 (a) and (b), SEM images for the cross section image reveal that the electrode was corroded seriously. Since high electric field might occur near the deformed electrode, the reverse-bias EL might appear near the corroded electrode. Furthermore, we performed the EDX analysis on bottom of the electrode for the fresh device and the stressed device as shown in Fig. 5(a) and (b). EDX analysis indicate that the Au element concentration increased was stressed. Diffusion of Au during stress in salty water vapor might increase the leakage current and cause high electric field areas [9].

4. CONCLUSION

In this study, we perform reliability test for the green LED under forward-bias operations in salty water vapor. Forward-bias stress in salty water vapor could degrade the device rapidly. The forward-bias and reverse-bias I-V curves, EL images spectra, and CIE show the degradation trend of the device. In addition, material analyses of SEM/EDX reveals that corrosion of electrode and diffusion of Au might cause the device degradation around 1 hours. The reliability stress test in this study is promising for screening the LED quality quickly.

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