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Degradation of AlGaN/GaN Light Emitting Diodes caused by Carbon Contamination with Reverse-bias Stress Test in Water Vapor

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Abstract: *Resolving failure origins of AlGaN/GaN light emitting diodes (LED) has received intensive study recently. In this study, formation of $GaCO_3$ caused by carbon contamination may result in deformation of the electrode near the surface and degrade the device. The electrochemical reactions may cause device damages. Degradation in electrical properties is observed in I-V characteristics. Forward-bias and reverse-bias EL images are used to trace the damaged areas. Furthermore, focus ion beam (FIB), scanning electron microscope (SEM), energy dispersive X-ray diffraction (EDX) are applied to examine the damaged areas. Results indicate that formation of $GaCO_3$ may deform the electrode, generate the reverse-bias EL and cause the degradation.*

Keywords: AlGaN/GaN, light emitting diodes, electrochemical reaction, carbon contamination, energy dispersive X-ray diffraction

1. INTRODUCTION

Reverse-bias stress test in water vapour has been used to screen AlGaN/GaN light emitting diode (LED) quality and investigate long-term LED failure mechanisms [1-2]. Deformation of electrodes caused by atom diffusion has been reported as one of the degradation origins [3-4]. In this study, carbon contamination and formation of $GaCO_3$ can be observed for the LED after reverse-bias stress test in water vapour. I-V characteristics are used to examine the increase and decrease of the forward-bias and reverse-bias leakage current. Electroluminescence (EL) images are used to examine the damaged areas. Moreover, focus ion beam (FIB), scanning electron microscope (SEM), energy dispersive X-ray diffraction (EDX) are also applied to examine the damaged areas. Results indicate that formation of $GaCO_3$ may deform the electrode, generate the reverse-bias EL and cause the degradation.

2. EXPERIMENTAL

Blue GaN LEDs were deposited on a sapphire substrate, region barrier layers and a 50 nm Mg-doped p-$Al_{0.15}Ga_{0.85}N$ were deposited by metal-organic chemical vapor deposition. A reverse-bias test was conducted in water vapor to accelerate the device degradation and screen the failure.

3. RESULTS AND DISCUSSION

To observe the degradation of the device, I-V curves are taken to examine the change of the leakage current. Forward-bias and reverse-bias I-V curves as shown in Fig. 1(a) and (b) reveal that the leakage current increases and then decreases in the degradation process, which is similar with our previous study [5]. To further understand the failure origins, forward-bias and reverse-bias images as shown in Fig. 2(a) and (b) are taken to trace the degraded areas. The reverse-bias EL areas, which may result from high electric field and deformation of the electrode. Moreover, reverse-bias EL areas are forward-bias dark areas by comparing Fig. 2(a) and (b). To further investigate the reverse-bias EL areas (the degraded areas.

FIB is used to cut the areas and SEM is used to examine the cross section. Consistent with previous studies, deformation of the electrode can be observed by the cross section SEM image. To study the deformed object of the device (as pointed by a red arrow in the SEM image in Fig. 3), EDX analysis and mapping is used to investigate the composition of the deformed part. The Ga, O, and C mapping and EDX analysis indicate that the formation of

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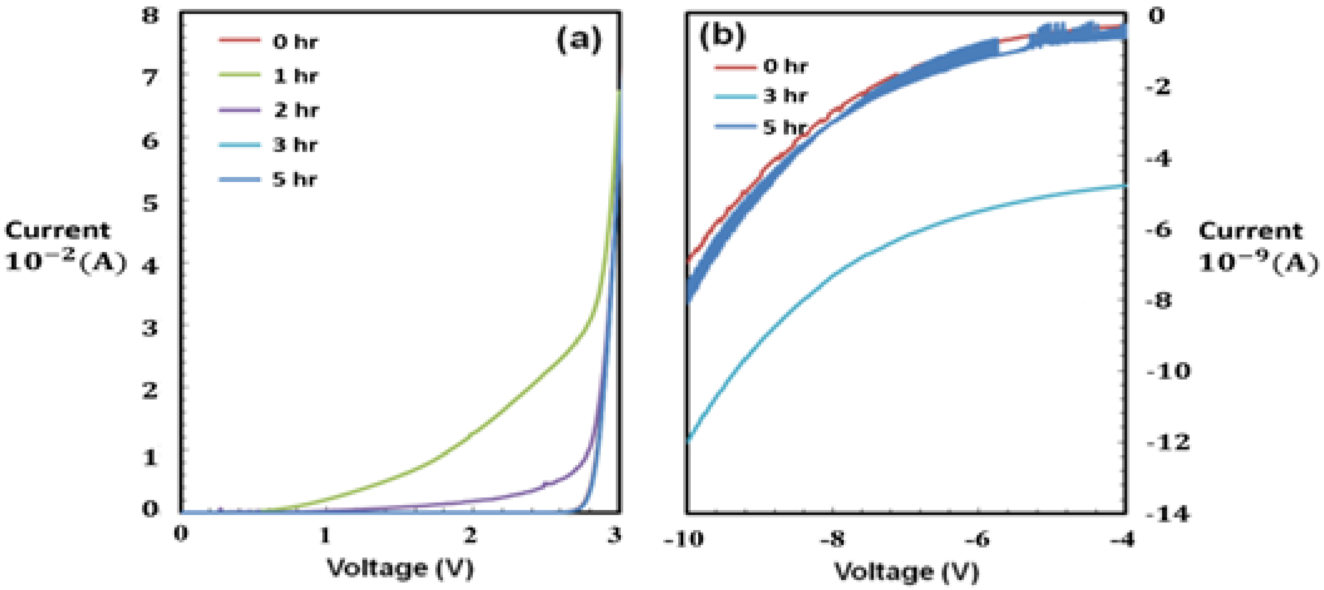
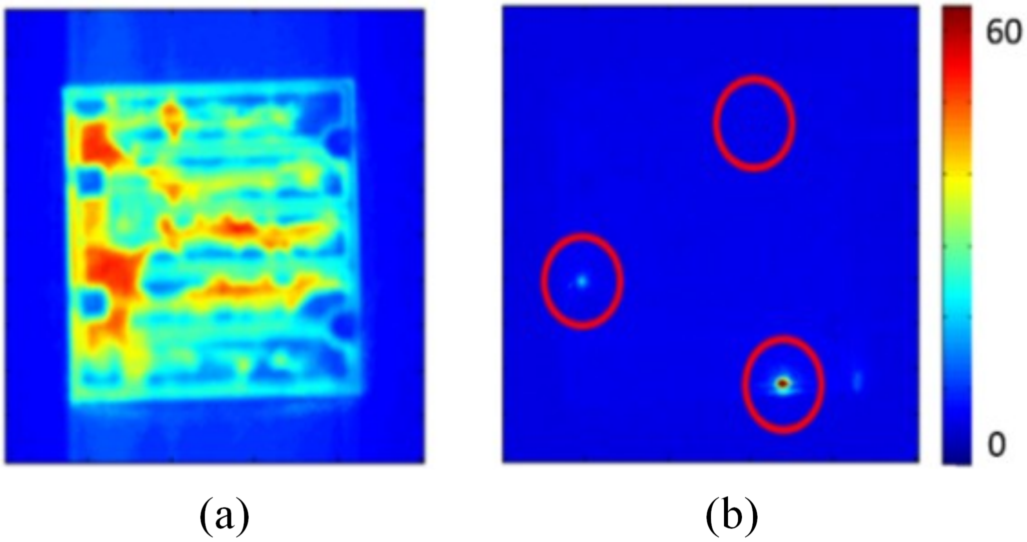


Figure 1. I-V curves after stressed water vapor conditions, a. In the forward-bias condition (0, 3 and 5 hr are overlapped), b. In thereverse-bias condition



(a) (b)

Figure 2. EL images for the device after water vapor stress, a. Forward-bias images, b. Reverse-bias images

$GaCO_3$ may cause the deformation and strong electric field in the reverse-bias test. (The deformed object can be observed in Ga, O, and C EDX mapping). Since carbon-related organic solution may be used to clean or deposit during the fabrication process. Residues of carbon may be present on the surface of LED. During the stress process, the surface is heated up and $GaCO_3$ may be formed due to the high temperature. The electrochemical reactions may occur during the reverse-bias operations of the LEDs. Therefore, the $GaCO_3$ may be formed near the electrode and cause strong electric field reverse-bias EL. High temperature areas may be around the electrode. Therefore, $GaCO_3$ objects can be generated near the electrode area and deform the normal electrode and strong reverse-bias EL can be observed around the deformed electrode.

4. CONCLUSION

Degradation of LEDs caused by carbon contamination has been observed. Formation of $GaCO_3$ objects may deform the electrode, generate the reverse-bias EL and accelerate the device degradation. The finding of carbon contamination may be useful in screening the LED quality in future LED industry.

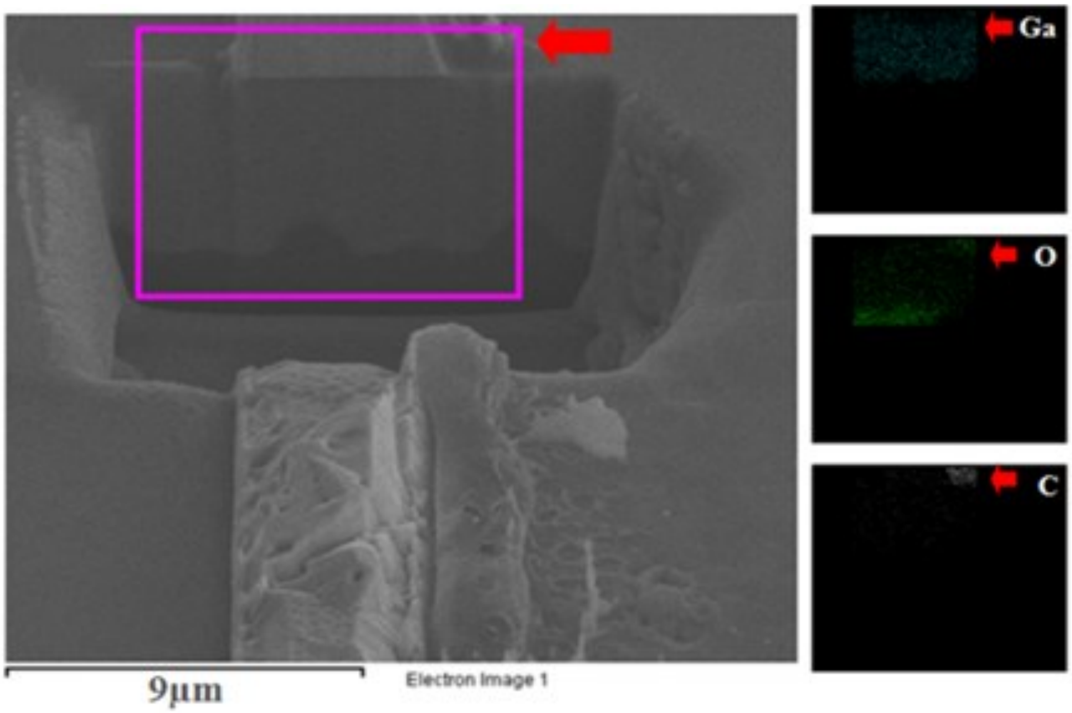


Figure 3. A SEM image and EDX analysis for the stressed device

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