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Improvement in GaN-based light-emitting diodes by surface texturization with natural lithography

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1. Introduction

GaN-based technology has gone from an exploratory research to a commercial product [1]. It has been applied to fabricate optoelectronic devices such as blue light emitting diodes (LEDs) and laser diodes. However, in conventional LEDs, the external efficiency is limited by total internal reflection as the semiconductor-air interface due to the different refractive index between the semiconductor-air. So, the internal light is difficulty to escape to the air from semiconductor. Therefore, much research has focused on improving the external quantum efficiency. One method is roughening the surface of LED sample and has been applied to GaAs-based LED successfully previously [2-4]. Recently, it has been shown that roughening the LED surface can increase the light extraction efficiency of nitride-based LEDs. The textured surfaces were directly obtained by plasma etching on the top epilayer. However, the etching often destroys a large part of the junction reducing the area which light generated [5]. Besides, the thickness of top layer p-GaN cladding is very thin in conventional LED structure. So, it is not desirable to directly etch the p-GaN layer due to the difficulty in controlling the dry etching depth and the plasma damage of p-GaN during dry etching process [6]. In this paper, two types of the surface-textured GaN-based LEDs were developed. In order to avoid any damage in the thin p-GaN layer, we use indium-tin-oxide (ITO) and SiO_2 as the roughened layers. After completing the traditional planer GaN LED, the LED surface is textured by natural lithography, where a monolayer of randomly deposited polystyrene spheres was distributed as a natural mask for dry etching. Details of processes and data will be described.

2. Experimental details

The GaN LED epi-wafers used in this study were grown by metalorganic chemical vapor deposition on (0001) sapphire substrates. The LED structure (dominant wavelength at 460 nm) consists of a low-temperature 200-nm-thick GaN buffer layer, a 1-µm-thick undoped GaN layer, a 2-µm-thick highly conductive n-type GaN layer, a InGaN/GaN multiple-quantum well active layer, and a 0.3-µm-thick p-type GaN layer. A mesa with dimension of 300 µm × 300 µm was created by an inductively-coupled-plasma (ICP) etcher for current isolation purpose. Then the ICP process was used to etch through the p-GaN and active layer until the n-GaN surface appeared. Electron-beam evaporated Ni/Au (after annealed in oxygen at 500°C for 10 min) and Ti/Al films were used as p- and n-contacts, respectively. Then the ITO and SiO_2 thin film were deposited on NiAu/LED respectively as the roughened layer. After completing the conventional LED structure, the electrodes were protected by photoresist. Then, the polystyrene sphere was spin on the top surface of LED randomly as the natural mask and the LED sample was subjected to the dry etching process. After plasma etching, the GaN LED with a textured surface was obtained.

3. Results and discussion

In this study, the natural lithography and dry etching techniques were used to form a textured surface. Fig. 1 shows the surface-textured ITO and SiO_2 films on the top GaN LED surface. Clearly, the ITO and SiO_2 films became rougher after dry etching process by using the polystyrene sphere as the natural mask. The surface morphologies of textured GaN LEDs were measured by atomic force microscope and shown in Fig. 2. It was found that the roughness of textured ITO layer (Rms=75 nm) was rougher than that of textured SiO_2 layer (Rms=15 nm). This phenomenon could be due to the same dry etching condition in this work and result in the different etching rate.

The corresponding current-voltage (I-V) characteristics of the GaN LED samples are shown in Fig. 3. It was found that the I-V curves of three devices are nearly the same. Surface-textured LEDs exhibit a normal *p-n* diode behavior with a forward voltage (@ 20 mA) of 3.1 V. Furthermore, the leakage currents (@ -5V) were in the range of 1~5 nA. These indicate that the dry etching process does not adversely affect the LED performance because the dry etching process does not destroy the p-GaN layer. Hence, the p-GaN ohmic contact characteristic can be preserved after the dry etching process. Fig. 4 shows the output power as a function of injection current where the chips were encapsulated in lamp form. The output power of surface-textured ITO, SiO_2 and original LEDs are 10.9, 9.5, and 8.5 mW at 20 mA, respectively. It is obviously found the output power of the surface-textured LED was higher than typical LED and the enhancement of output power can be attributed to the presence of the surface-textured ITO or SiO_2 layers.

4. Conclusions

The surface-textured GaN LEDs were investigated using a combination of natural lithography and dry etching techniques. It can be obviously found that the LED with a textured surface can improve the light extraction efficiency. Moreover, by inserting an ITO or SiO_2 layer on the GaN LED surface, the plasma damage of p-GaN top layer during the surface texturization process can be avoided.

Acknowledgements

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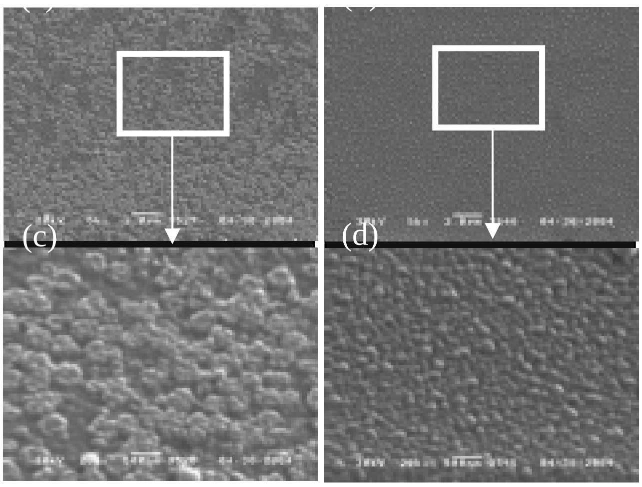

Fig. 1 SEM micrographs of (a) surface-textured ITO and (b) surface-textured SiO_2 top layer on GaN LEDs. (c) and (d) are the partial magnification micrograph of sample (a) and (b), respectively.

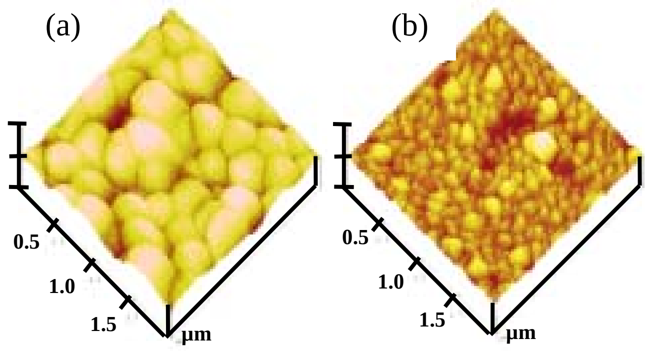

Fig. 2 AFM Surface Morphologies of textured (a) ITO and (b) SiO_2 top layers on GaN LEDs.

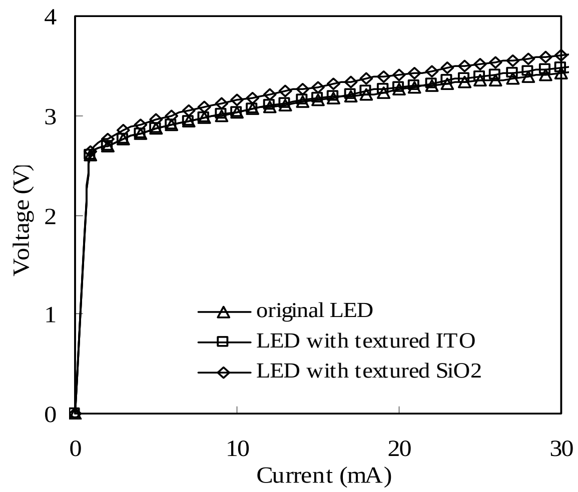

Fig. 3 Current versus voltage characteristics of GaN LEDs with textured ITO and SiO2 top layers. The original GaN LED is also shown as a reference sample.

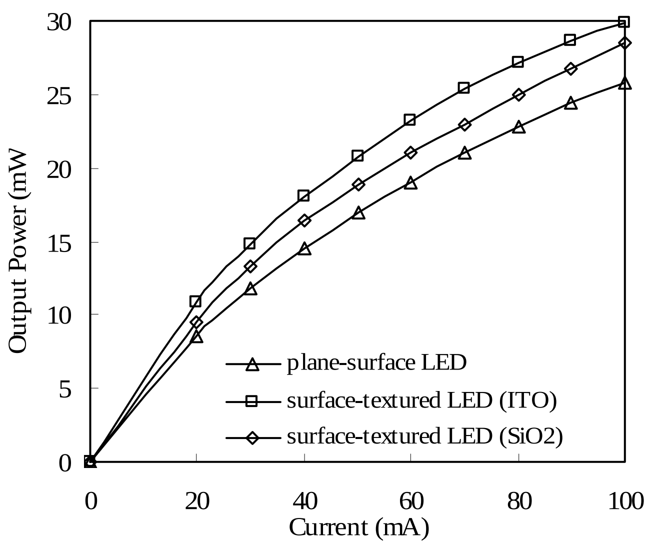

Fig. 4 Output power as a function of injection current for GaN LEDs with and/or without surface texturization.