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Nitride-Based LEDs with an Insulating SiO_2 Layer Underneath p-Pad Electrodes

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We proposed a simple method to reduce the current crowding effect of nitride-based light emitting diodes (LEDs) without extra dry etching and refill. It was found that we can achieve much better current spreading by inserting an insulating SiO_2 layer between the epitaxial layer and the p-pad electrode. It was also found that we can enhance light output intensity by 22%. Furthermore, it was found that 20 mA forward voltage only increased slightly from 3.32 to 3.37 V with the insertion of the SiO_2 layer. The reliability of the proposed LED is also good.

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Nitride-based, wide-bandgap semiconductors have recently attracted considerable interest. These materials are useful for light emitters operating in blue, green, and ultraviolet wavelength regions.[1-3] Nitride-based blue and green light-emitting diodes (LEDs) are already extensively used in traffic light lamps and full color displays.[4-7] However, current spreading is still an important issue for nitride-based LEDs because hole concentration in p-GaN is low in general. Even with the transparent current spreading layer, such as Ni/Au or indium tin oxide (ITO), a portion of the injected carriers will still be confined underneath the thick metal bonding pad.[8,9] As a result, a significant amount of light will be absorbed or reflected by the opaque p-pad electrode. To solve this problem, one can selectively activate the p-GaN layer to form a highly resistive region underneath the p-pad electrode.[10] Although this method is low cost and easy to implement, one needs to carefully control the activation temperature of the p-GaN layer. It is also possible to insert an insulating SiO_2 current blocking layer (CBL) underneath the p-pad electrode. Using this CBL, Huh et al. reported a 62% increase in LED output power at 20 mA.[11] To form this CBL, however, it is necessary to add an extra dry etching step to partially remove the epitaxial layer followed by an extra plasma-enhanced chemical vapor deposition (PECVD) step to refill the etched area with SiO_2. The complex processing steps might result in lower production yield and higher cost. In this study, we inserted a SiO_2 layer between the epitaxial layer and the p-pad electrode without extra dry etching and refill. It was found that we can still achieve better current spreading and enhance LED output power with this simple method. The fabrication process and the characteristics of the fabricated LEDs are also reported.

Samples used in this investigation were all grown by a metallorganic chemical vapor deposition on *c*-face 2 in. sapphire Al_2O_3 (0001) substrates. Details of the growth procedures can be found elsewhere.[12-14] The LED structure consists of a 30 nm thick GaN nucleation layer grown at 550°C, a 3 μm thick Si-doped n-GaN buffer layer grown at 1050°C, an unintentionally doped InGaN/GaN multiquantum well (MQW) active region grown at 770°C, a 50 nm thick Mg-doped p-$Al_{0.15}Ga_{0.85}N$ electron-blocking layer grown at 1050°C, a 0.6 μm thick Mg-doped p-GaN layer grown at 1050°C and a Si-doped n^+-short period superlattice (SPS) tunnel contact structure.[15] The InGaN/GaN MQW active region consisted of five pairs of 3 nm thick $In_{0.23}Ga_{0.77}N$ well layers and 7 nm thick GaN barrier layers. The as-grown samples were subsequently annealed at 750°C in N_2 ambient to active Mg in the p-type layers.

After the growth, we partially etched the surface of the samples until the n-GaN layer was exposed. We then deposited a 200 nm thick SiO_2 layer only on the p-pad electrode region by PECVD, photolithography, and buffer oxide etching. We subsequently deposited a 320 nm thick ITO layer onto the sample surface to serve as the transparent p-contact layer. We then deposited Ti/Al/Ti/Au on top of the ITO layer and the exposed n-type GaN layer to serve as the p-pad electrode and n-pad electrode. Figure 1a shows schematic drawing of the fabricated LEDs. For comparison, LEDs without the SiO_2 layer were also fabricated. We subsequently used scanning

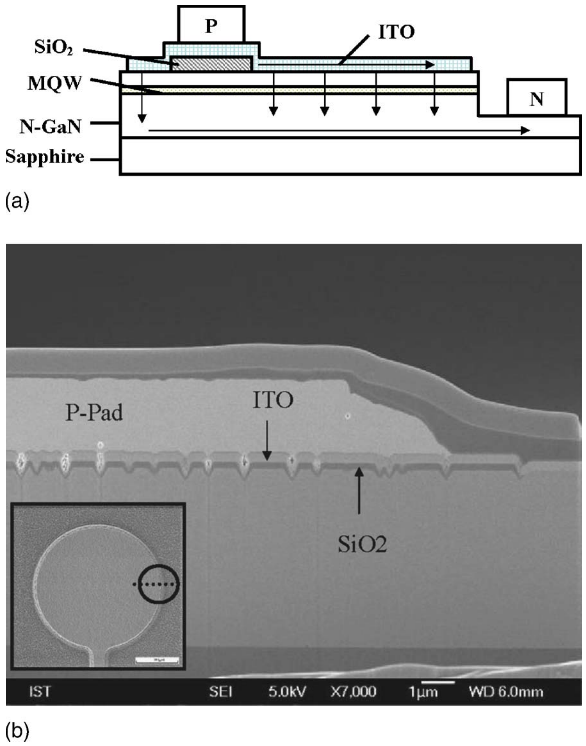

Figure 1. (Color online) (a) Schematic drawing and (b) enlarged cross-sectional SEM micrograph of the fabricated LEDs with an insulating SiO_2 layer under a p-type electrode. The inset of (b) shows a top-view SEM micrograph of the fabricated device.

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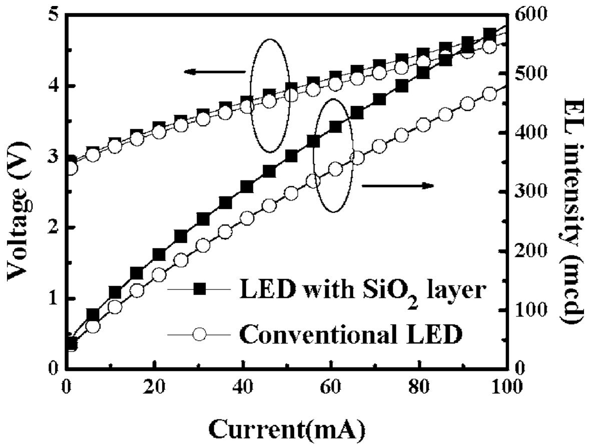

Figure 2. L-I-V characteristics of the fabricated LEDs.

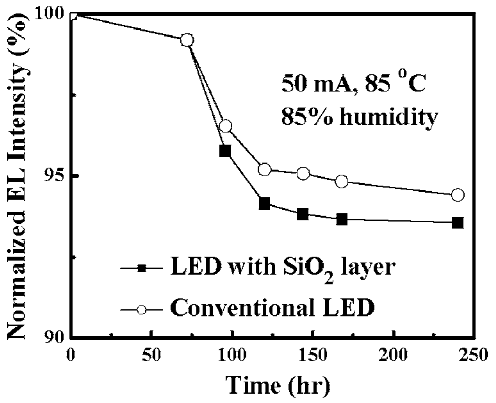

Figure 4. Life tests of relative luminous intensity measured from the LEDs, normalized to their respective initial readings.

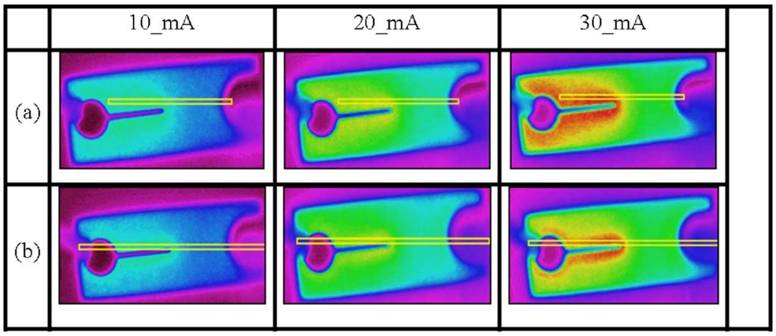

Figure 3. (Color online) Output power mappings for the LEDs (a) with and (b) without the insulating SiO_2 layer.

electron microscopy (SEM) to physically characterize the processed LEDs. We then lapped the epitaxial wafer down to about 100 μm and fabricated the 250 × 600 μm LED chips. These LED chips were then packaged into LED lamps. Current-voltage (I-V) measurements of the fabricated LEDs were then performed by an HP4155 semiconductor parameter analyzer. Intensity-current (L-I) characteristics were also measured from the top of the devices using molded LEDs with an integrated sphere detector by injecting different amounts of dc current into these LED samples.

The inset of Fig. 1b shows a top-view SEM micrograph, while Fig. 1b shows an enlarged cross-sectional SEM micrograph of the fabricated LED chips with an insulating SiO_2 layer underneath the p-type electrode. It can be seen that the deposited SiO_2 layer only covers the p-pad electrode region. Figure 2 shows L-I-V characteristics of the fabricated LEDs measured at room temperature. It can be seen that output intensities of these two LED lamps both increased with the injection current. The electroluminescence (EL) peak position occurred at 470 nm for both LEDs when the injection current was 20 mA. Under the same injection current, it was found that output intensities of the LED with the SiO_2 layer was always larger than that of the conventional LED. Under 20 mA current injection, it was found that output intensities were 187 and 153 mcd for the LEDs with and without the insulating SiO_2 layer, respectively. In other words, we achieved a 22% increase in EL intensity by inserting a SiO_2 layer between the epitaxial layer and the p-pad electrode. Such an enhancement should be attributed to the reduced current crowding. Under 20 mA current injection, it was also found that forward voltages were 3.37 and 3.32 V for the LEDs with and without the insulating SiO_2 layer, respectively. The slightly larger forward voltage observed from the LED with the SiO_2 layer should be attributed to the reduction of total contact area between the epitaxial layer and the p-pad electrode.[11] The 3.37 V operation voltage observed from the LED with the SiO_2 layer is still electrically acceptable.

Figures 3a and b show output power mappings for the LEDs with and without the insulating SiO_2 layer, respectively, measured by a charge-coupled-device (CCD) image sensor. Compared with the conventional LED, it was found that light output power distributed more uniformly for the LED with the insulating SiO_2 layer, especially when the injection current reached 30 mA. Such a result agrees well with that observed from Fig. 2 and again indicates that the inserted SiO_2 layer can effectively enhance current spreading. Figure 4 shows the life tests of relative luminous intensity measured from the two LEDs, normalized to their respective initial readings. During life test, the LEDs were driven by 50 mA injection current at 85°C and 85% relative humidity. It can be seen that the EL intensity decreased by only 5.3% after 200 h for the conventional LED, while EL intensity decreased by 6.4% after 200 h for the LED with the insulating SiO_2 layer. The slightly larger EL intensity decay is probably due to the larger operation voltage for the LED with the insulating SiO_2 layer. Under the same current injection, larger operation voltage results in larger thermal effect and thus shorter device lifetime. Although the LED with the insulating SiO_2 layer is slightly less reliable, the 6.4% decay after 200 h under the test condition is still reasonably good for most applications.

In summary, we proposed a simple method to reduce the current crowding effect of nitride-based LEDs without extra dry etching and refill. It was found that we can achieve much better current spreading by inserting an insulating SiO_2 layer between the epitaxial layer and the p-pad electrode. It was also found that we can enhance light output intensity by 22% while still achieving good forward voltage and device reliability.

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