Enhanced Light Extraction of InGaN-based Light-Emitting Diodes by ZnO Nanorod Arrays

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Having widely tunable emission wavelengths, nitride-based LEDs act as a promising candidate in solid-state lighting. However, due to the considerable difference in the refractive index of the semiconductor and surrounding material (i.e. air or resin), the critical angle of a conventional nitride-based LED is only ~ 23°, which indicates poor extraction efficiency and hence a low EQE.

In this work, ZnO nanorod arrays (NRAs) were synthesized on InGaN-based LEDs by a hydrothermal method. Through careful control of the growth condition, tapered ZnO nanorods were formed. The tapered shape of the nanostructure is revealed in the SEM images shown in Fig. 1. This novel nanostructure provides a gradual change in refractive index from GaN surface to air, and guarantees higher extraction efficiency. Without modifying the quantum well region, the reported etching-free method improves the output intensity of LED with only a subtle change in its electrical property, as can be seen in the I-V and L-I curves in Fig. 2. The result is supported by the simulation using finite-difference time-domain (FDTD) method in Fig. 3. Different surface conditions are applied in the simulation scheme, namely, bare LED, LED with flat-end NRAs, and with tapered-end NRAs. Strongest output field is observed for the LED with tapered-end nanostructure, proving its superiority in light extraction efficiency than the flat-end counterpart. In addition, the radiation profiles of the LEDs are measured, as shown in Fig. 4. The LED with tapered ZnO nanorods exhibit a more collimated beam pattern, which might be attributed to the particular enhancement of light output in the normal direction.

As a short summary, the proposed etching-free method provides an efficient way of improving the light output of nitride-based LEDs and would be beneficial to the solid-state lighting technology.

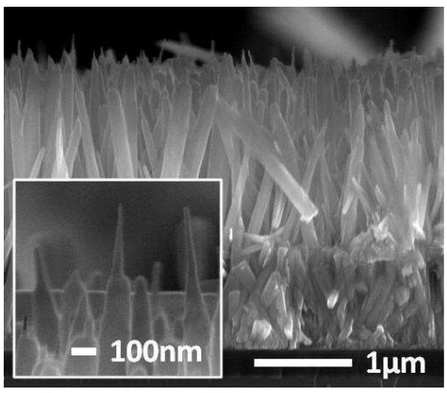

Figure 1 Cross-sectional SEM image of the tapered ZnO NRAs. The inset specifies the tapered shape at the top of nanorods.

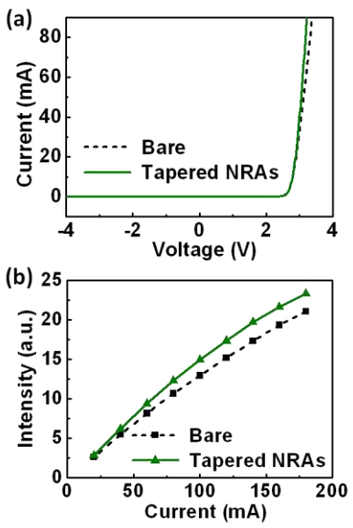

Figure 2 (a) Current-voltage (I-V) and (b) light output intensity-injection current (L-I) characteristics of the LEDs with different surface morphology, namely, bare and with tapered ZnO NRAs.

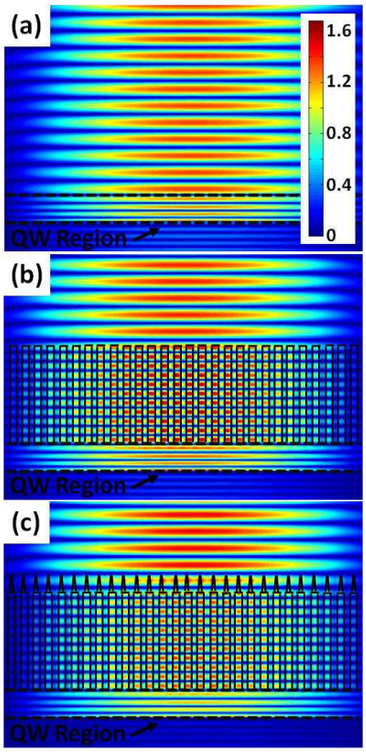

Figure 3 Time-averaged and normalized TE field distribution simulated by FDTD method at 528.5-nm wavelength with different surface conditions, (a) bare, (b) with flat-end NRAs, and (c) with tapered-end NRAs.

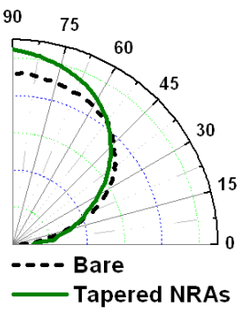

Figure 4 Radiation profiles of the LEDs with different surface morphology under 20 mA injection current.