Electron Blocking Layer Free Full-Color InGaN/GaN White Light-Emitting Diodes

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Indium gallium nitride (InGaN) compound semiconductor alloys have been intensively studied and utilized for white light-emitting diodes (LEDs) [1, 2]. Compared to conventional planar structures, III-nitride nanowires can exhibit significant advantages including greatly reduced dislocation densities and polarization fields, due to the effective lateral stress relaxation. Additionally, the nanowire LEDs with the incorporation of quantum dots/disks in the active region may lead to superior carrier confinement, promising for high efficiency LEDs with tunable emission [2]. However, nanowire LEDs still contain several challenges to further improve the quantum efficiency and light output power, which includes inefficient carrier confinement in the active region, nonuniform carrier distribution, and electron overflow. The integration of an electron blocking layer (EBL) in the LED mitigates electron leakage problem to an extent but it also lowers the hole injection into the active region if not designed properly causing poor hole transport problem. Hence, the LED without EBL, with efficient carrier confinement capability, negligible carrier leakage from active region is the optimal choice [3].

In this work, we have demonstrated EBL free high-performance phosphor-free InGaN/GaN nanowire white LEDs. The proposed structure is grown on Si (111) substrate by RF plasma-assisted MBE (Veeco Gen II MBE) under nitrogen-rich condition, then fabricated devices for characterization. The proposed LED structure (LED3) consists of a 200 nm thick *n*-GaN nanowire template, 10 multiple quantum wells (MQWs) of 3 nm GaN quantum barrier (QB)/ 3 nm InGaN quantum well (QW) in the active region and a 100 nm thick *p*-GaN. In addition, we have incorporated 30 nm *n*-$In_{0.2}Ga_{0.8}N$ QW between the *n*-GaN and the active region to control electron overflow. Moreover, to utilize the electrons escaped from the active region, a second 10 nm *p*-$In_{0.1}Ga_{0.9}N$ QW is introduced between the active region and *p*-GaN. This second QW reduces electron loss to the *p*-GaN and contributes blue light emission to relatively control the white light emission from the LED device. The schematic diagram of the proposed structure is shown in Fig. 1(a). A comparison has been made with the conventional LED structure (LED1: 200 nm *n*-GaN, 10 MQWs (3 nm)/MQBs (3 nm), 100 nm *p*-GaN) and EBL based structure (LED2: 200 nm *n*-GaN, 10 MQWs (3 nm)/MQBs (3 nm),10 nm *p*-$Al_{0.1}Ga_{0.9}N$ EBL, 100 nm *p*-GaN) to understand the enhanced performance of the proposed LED structure. As a result, we observed that proposed LED has better performance in terms of less electron leakage, high hole injection, improved internal quantum efficiency (IQE), external quantum efficiency (EQE) and output optical power as compared to other conventional and EBL based InGaN/GaN LEDs. The resulting device exhibits high IQE of 58.5% with highly stable emission characteristics. The relative EQE and output optical power of the LEDs are shown in Figs. 1(b) and 1(c). Such unique EBL free nanowire LED structure is a promising approach to achieve high-power phosphor-free LEDs for general illumination and display applications.

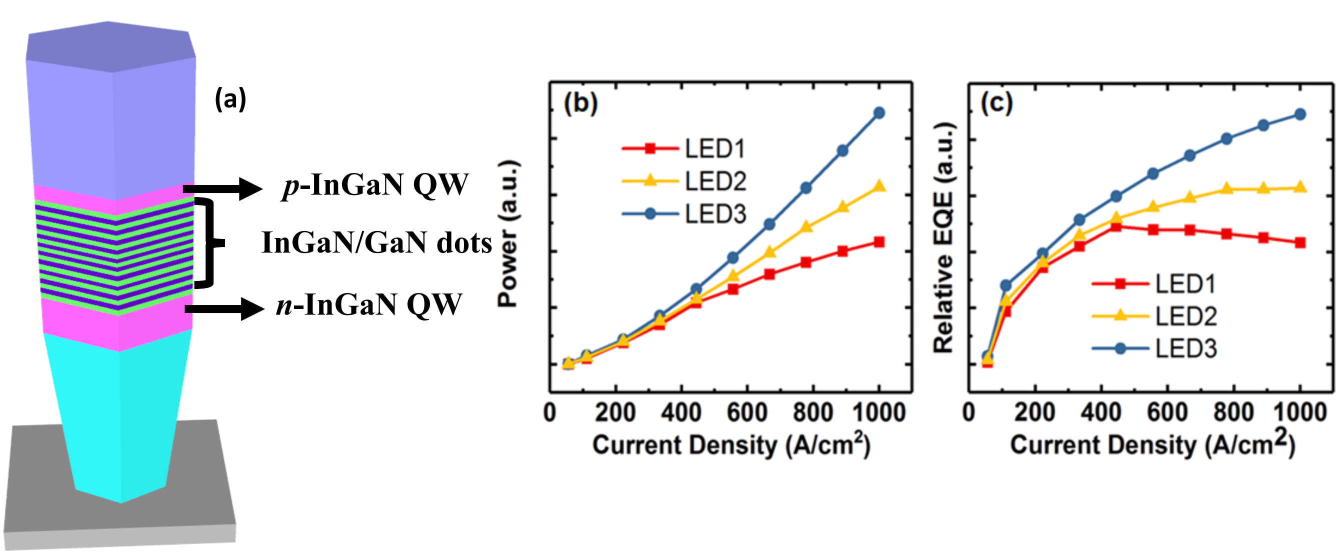

Fig. 1: (a) Schematic diagram of the proposed structure i.e. LED3, (b) Relative output power, (c) Relative external quantum efficiency of LED1, LED2, and LED3.

References:

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3. B. Jain, et al., Optics Express, 2020. **28**(1): p. 665-675.