

Tunnel Injection GaN/AlN Quantum Dot UV LED

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Light weight and robust ultraviolet (UV) light emitting sources find multitude of uses, for example in water purification, sterilization, bio sensors, solid state lighting and lithography. Direct bandgap III-Nitride semiconductors exhibit bandgap energies extending upto 6.2 eV (210 nm, deep UV). Thus, III-Nitrides are potential candidates for fabricating UV LEDs. But as we move to higher Al compositions to reach shorter wavelengths the internal quantum efficiency (IQE) severely degrades due to factors such as the valence band asymmetry, high threading dislocation densities, quantum confined Stark effect and inefficient n- and p-type doping. To mitigate the adverse effects of such factors and boost the IQE, we propose and demonstrate a new design which incorporates GaN quantum dots (QDs) in AlN barriers and uses tunneling to inject and transfer carriers through the active region.

Quantum dots (QDs) are 0 dimensional nanostructures which provide 3-dimensional confinement of carriers leading to improved radiative recombination efficiency and thus allows low threshold light emitting diodes (LEDs) and lasers. III-Nitride (InAlGaN) QDs, grown by Stranski-Krastanov (SK) and anti-surfactant methods, have been shown to emit in the ultra violet(UV) [1] as well as visible region [2] of the electromagnetic spectrum. Due to strong confinement QDs favor significant increase in emission energy with decrease in the size of the QDs for relatively less content of Al, than in quantum wells. In our design, the spatial distribution of electron and hole wavefunctions in pyramidal GaN QDs [3] as well as the thin AlN barrier promotes tunneling transport of carriers (electrons and holes) despite the large effective mass of holes, because confinement shifts the wavefunctions to higher energies, which in turn extends deep into the barriers. Since tunneling is the mode of transport, we need n- and p- type contact regions which absorb just above the emission wavelength of the QDs, leading to a relatively low composition AlGaIn layers resulting in improved doping. Besides, the much speculated phonon bottle neck [4] problem associated with QD systems can be overcome, as the carriers are injected directly into the lowest energy state of the QD. Therefore, as a consequence of QDs in the active region most of the issues associated with high Al content in UV LEDs could be solved.

In this work, we report on electroluminescence from 8 period self-assembled GaN QDs embedded in AlN barriers (Figure 1) grown by plasma assisted molecular beam epitaxy (PAMBE), in SK growth mode, on commercially available AlN/sapphire templates. Heavily Si and Mg doped $\text{Al}_{0.45}\text{Ga}_{0.55}\text{N}$ layers were used as n-type and p-type contact layers respectively. From Z-contrast Scanning Transmission Electron Micrograph (Figure 1(b)) the QD and AlN barrier thickness was found to be 0.55 nm and 2.8 nm respectively. The Atomic Force Microscopy (AFM) scan of uncapped QDs shows a QD density of $\sim 3 \times 10^{11} \text{ cm}^{-2}$. Electron beam deposited Ti/Al/Ni/Au and Ni/Au were used as n-and p-type contacts respectively. Thereafter the UV LED was characterized for room temperature electroluminescence. The spectrum showed peak emission at 341 nm at injection current of 25 A/cm^2 . On increasing the injection current to 62 A/cm^2 , emission was obtained at three different peak wavelengths: 341nm, 301nm and 261nm. The 341nm peak is attributed to emission from ground state of the QDs, the intense 301 nm emission is due to bandfilling effects at high injection currents and 261 nm appears when carriers recombine in the AlGaIn contact region resulting from carrier spillover. The low voltage threshold for emission in QD incorporated structures paves way for efficient LEDs and laser diodes (LDs).

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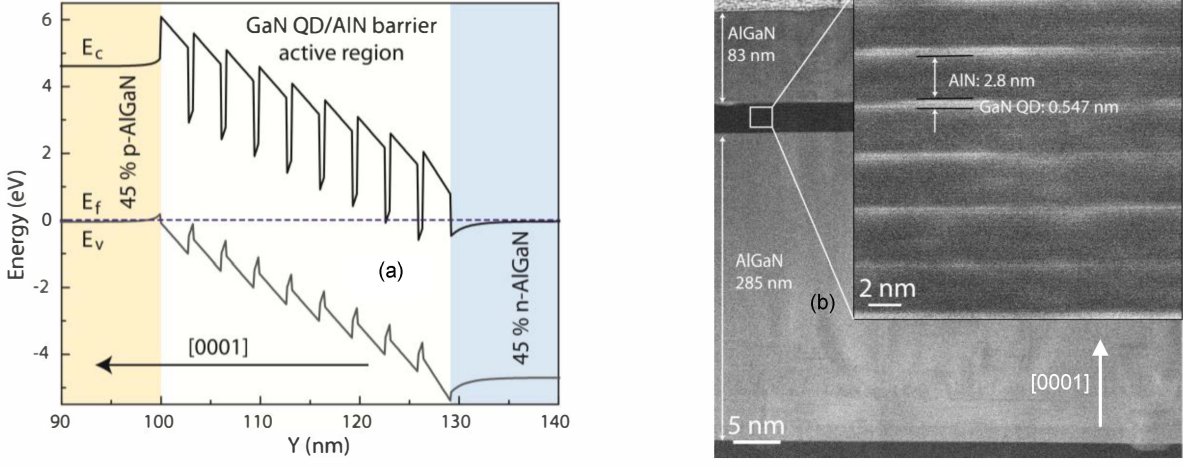


Fig 1. (a) Simulated energy band diagram of GaN/AlN quantum dot LED structure (b) Z-contrast Scanning Transmission Electron Micrograph of GaN/AlN QD LED structure showing the QD height and barrier thickness.

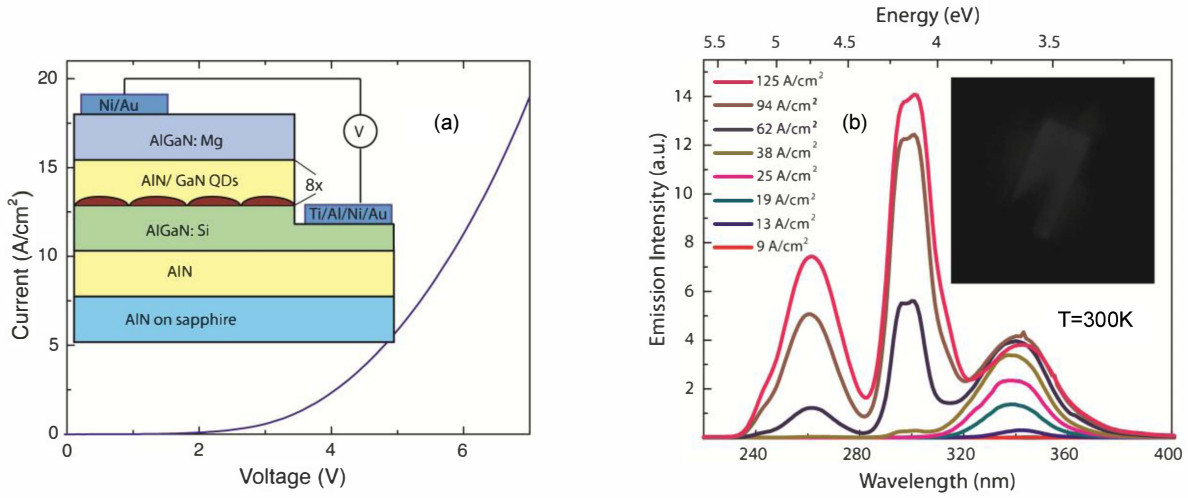


Fig 2. Experimental device characteristics of a MBE-grown GaN/AlN QD UV LED structure using tunnel transport of carriers. (a) The current-voltage characteristics indicate threshold voltage less than the GaN bandgap; (b) The electroluminescence spectrum indicates a peak at 340 nm at lower current densities. At higher current densities three different peak wavelengths: 341nm, 301nm and 261nm are observed. The illuminated LED is shown in the inset.