LATE NEWS: Sidewall Activation of Buried p-GaN layers in Tunnel-Junction Enabled Multi-Junction Cascaded Blue LEDs

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Tunnel junction (TJ) enabled cascaded light-emitting-diodes have garnered much research interest over the past few years. This is owed to their unique device design’s potential to combat the efficiency droop phenomenon native to the III-Nitride based visible light-emitting diodes. By allowing one to increase the luminous power density by increasing the operation voltage rather than the driving current, efficiency droop can be effectively mitigated to a substantial degree.

In this work we report on a detailed study of the optimized activation condition for the buried p-GaN layers within the first GaN homo-junction tunnel junction enabled cascaded multi-junction LEDs. The initial optimization of post mesa-isolation sidewall activation of the buried p-GaN layers was performed on metal organic chemical vapor deposition (MOCVD) grown GaN pn-junctions with Molecular Beam Epitaxy (MBE)/MOCVD hybrid tunnel junctions regrown on top of the pn-junctions. The devices consisted of a 500nm n+GaN bottom contact layer with [Si]= 3*10¹⁸, followed by a pn-junction comprised of a 200nm n-GaN layer with [Si]= 2*10¹⁶ and a 90nm p-GaN layer with [Mg]=3*10¹⁹, the GaN homo-junction tunnel junction consisted of a 12nm MOCVD grown p++GaN layer with [Mg]= 2*10²⁰, followed by an MBE regrown 8nm n++GaN layer with [Si]= 3.5*10²⁰, and a 60nm n+ GaN top contact layer with [Si]=10¹⁹. Various Mg activation conditions were studied. Activation at 725C in dry air was tested for 30, 40 and 50 minutes. Activation was also tested in N₂ ambient at 725C for 40 minutes and at 900C for 12 minutes. It was determined that activation completed at 900C in N₂ ambient for 12 minutes resulted in the lowest turn-on voltage and the most uniform electroluminescence.

The optimized sidewall activation condition was then utilized to fabricate monolithic GaN homo-junction tunnel junction enabled multi-junction cascaded light-emitting diodes. Both samples were grown completely by MOCVD, on GaN on sapphire templates. Two separate device structures were grown for comparison purposes. Sample A consisted of a single blue LED with a GaN homo-junction tunnel junction on top. Sample B was comprised of two LEDs cascaded, with a GaN homo-junction tunnel junction on top of each LED. Each LED/TJ stack contained a multi-quantum well (MQW) active region emitting at peak emission wavelength of 452nm. 200nm p-GaN cladding layer with [Mg]= 3*10¹⁹, a tunnel junction consisting of a 12nm p++GaN layer with [Mg]= 2*10³⁰ and a 10nm n++GaN layer with [Si]=3*10³⁰, followed by a 500nm n-GaN contact layer with [Si]= 5*10¹⁸. Both samples contained a 190nm thick In₀.₀₄Ga₀.₉₆N underlayer below the first LED/TJ stack.

A combination of IV characteristics and optical micrographs confirming uniform electroluminescence were utilized to verify complete sidewall activation of the buried p-GaN layers within the LEDs and TJs present in the cascaded LED devices. Optical micrographs confirm bright uniform emission at 2.5A/cm² driving current for 105 x 105 um² devices on both samples. IV measurements showed that the forward-voltage at 2.5A/cm² driving current scales closely with the number of cascaded LED/TJ stacks. Sample A produced a forward voltage of 3.4V at 2.5A/cm² and sample B produced a forward voltage of 7.2V at 2.5 A/cm². Electroluminescence spectra show no appreciable shift in peak wavelength of emission for a given current density between the two samples. This work provides insight into an activation process which can enable the realization of tunnel junction enabled cascaded LEDs.

Topic Area: Light Emitting Devices (LEDs, μLEDs, Laser Diodes, UV, VIS, IR)