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]= $3*10^{18}$, followed by a pn-junction comprised of a 200nm n-GaN layer with [Si]= $2*10^{16}$ and a 90nm p-GaN layer with [Mg]=$3*10^{19}$, the GaN homo-junction tunnel junction consisted of a 12nm MOCVD grown p++GaN layer with [Mg]= $2*10^{20}$, followed by an MBE regrown 8nm n++GaN layer with [Si]= $3.5*10^{20}$, and a 60nm n+ GaN top contact layer with [Si]=10^{19}. 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 N_2 ambient at 725C for 40 minutes and at 900C for 12 minutes. It was determined that activation completed at 900C in N_2 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, a 200nm p-GaN cladding layer with [Mg]= $3*10^{19}$, a tunnel junction consisting of a 12nm p++-GaN layer with [Mg]= $2*10^{20}$ and a 10nm n++-GaN layer with [Si]=$3*10^{20}$, followed by a 500nm n-GaN contact layer with [Si]= $5*10^{18}$. Both samples contained a 190nm thick $In_{0.03}Ga_{0.97}N$ 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/cm^2 driving current for 105 x 105 um^2 devices on both samples. IV measurements showed that the forward-voltage at 2.5A/cm^2 driving current scales closely with the number of cascaded LED/TJ stacks. Sample A produced a forward voltage of 3.4V at 2.5A/cm^2 and sample B produced a forward voltage of 7.2V at 2.5 A/cm^2. 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)

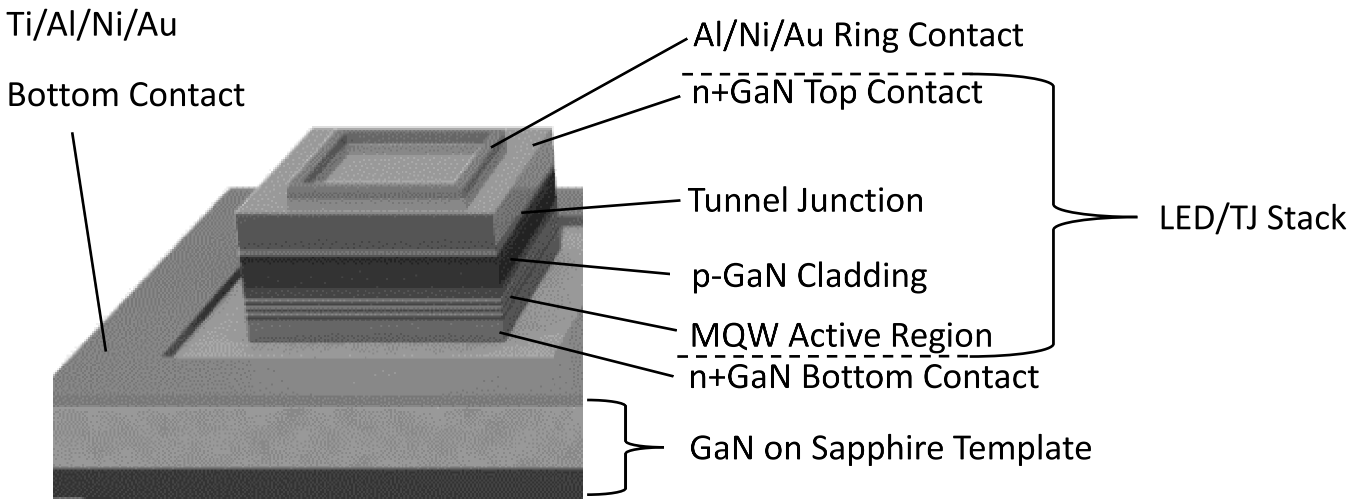

Fig 1. Schematic of sample A, consisting of a single LED/TJ stack. Sample B (not shown here) consists of two repetitions of this LED/TJ stack.

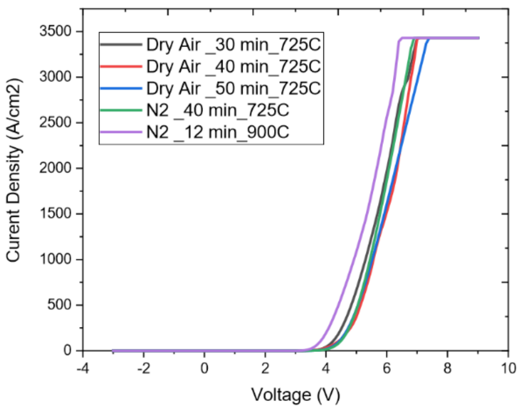

Fig 2. IV characteristics for various sidewall activation conditions tested. The 12 minute annealing in N_2 ambient at 900C resulted in the lowest turn-on voltage.

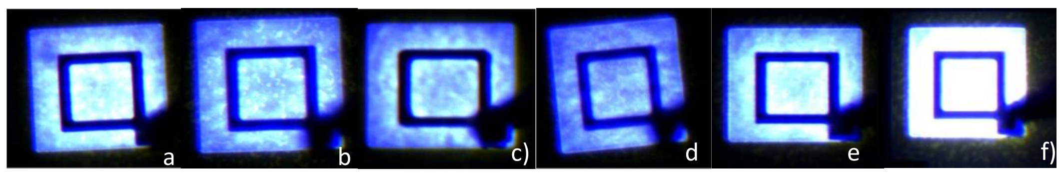

Fig 3. Optical Micrographs of electroluminescence from the pn-junction/TJ devices when driven with 1.6kA/cm^2 for the various sidewall activation conditions tested. a) 30 minutes at 725C in dry air, b) 40 minutes at 725C in dry air, c) 50 minutes at 725C in dry air, d) 40 minutes at 725C in dry air, e) 12 minutes at 900C in N_2, and f) 12 minutes at 900C in N_2 when driven at 3.6kA/cm^2.

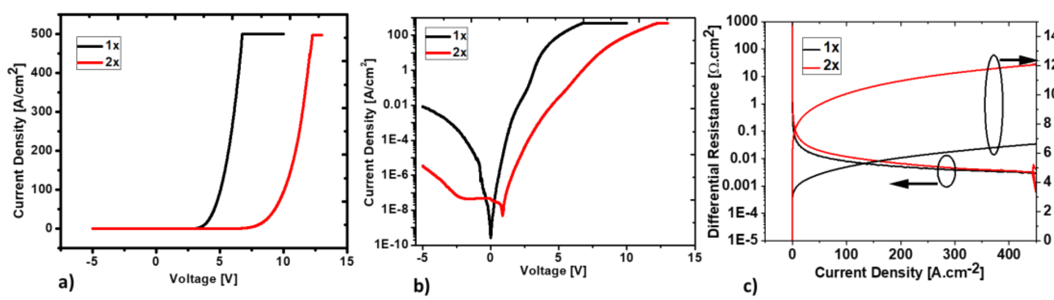

Fig 4. Current voltage characteristics for sample A (black) and sample B (red). (a) in linear scale, (b) in log scale. (c) Differential resistance and voltage for a given current density.

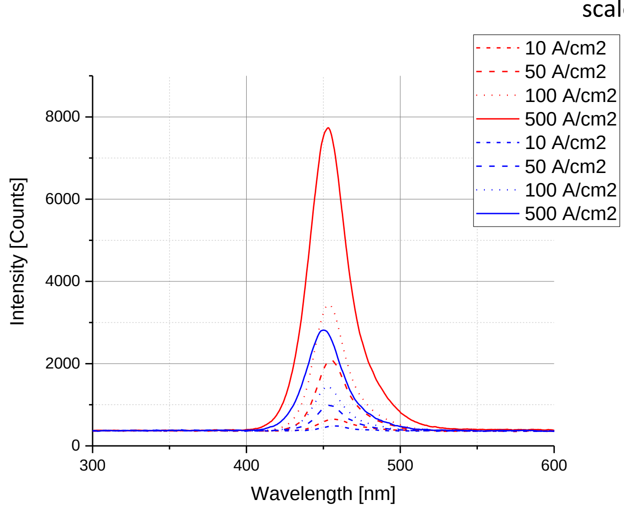

Fig 6. Electroluminescence spectra of both sample A (blue curves) and sample B (red curves) when driven at various current densities. The spectra show no appreciable shift in peak wavelength of emission for a given current density between the two samples.

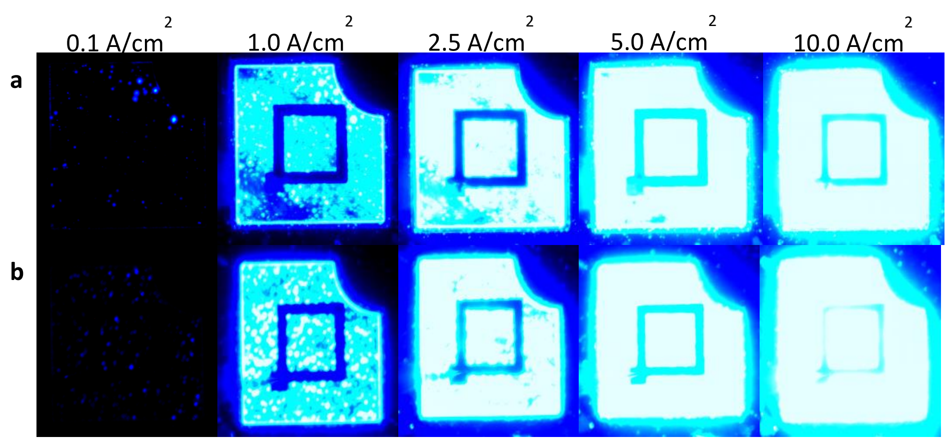

Fig 5. Optical micrographs showing light emission versus driving current for (a) sample A, and (b) sample B. Uniform, bright emission is observed above 2.5A/cm^2. The spotty luminescence apparent at 0.1A/cm^2 is still being studied and addressed at the conference.