Tunnel-Junction p-Contact Sub-250 nm Deep-UV LEDs

Shyam Bharadwaj, Kevin Lee, SM Islam, Vladimir Protasenko, Huili (Grace) Xing, and Debdeep Jena
School of Electrical and Computer Engineering, Cornell University, Ithaca, NY 14853, USA
Author e-mail address: sb2347@cornell.edu

Abstract: We demonstrate a 243 nm deep-ultraviolet (deep-UV) GaN/AlN heterostructure light-emitting diode with and without a tunnel-junction p-contact. Optical emission occurs from 2 monolayer thick GaN quantum structure active regions. Use of a tunnel-junction enhances the current density under forward bias.

OCIS codes: (230.3670) Light-emitting diodes; (230.5590) Quantum-well, -wire, and -dot devices

1. Introduction

Deep-UV light-emitting diodes (LEDs) are used in water purification, optical storage, and UV curing, amongst many other applications. Emitters operating in the UV-C range are optimal for water purification and sterilization applications. At shorter wavelengths (<250 nm), increased Aluminum composition in the p-AlGaN cladding region leads to poor hole activation and large contact resistances. To address this issue, we investigate the use of a GaN tunnel-junction (TJ) above the p-type cladding layer, allowing the hole-injection contact to be made to n-AlGaN, lowering the contact resistance. The entire heterostructure is grown by Plasma-assisted (PA) MBE on bulk AlN substrates to inhibit leakage through dislocations, and a deep-UV 243 nm LED with a tunnel-junction is realized for the first time.

2. Experimental

High quality bulk AlN substrates with a dislocation density of $1\text{x}10^5$ were used as the substrate to grow deep-UV LED structures (as shown in Fig. 1b). The growths were performed in a Veeco Gen 930 N_2-Plasma Molecular Beam Epitaxy system. Prior to growth, the substrates were sonicated in acetone, methanol, and isopropanol to remove organic contaminants, and outgassed at 200°C for 7 hours, followed by 450°C for 1.5 hours. The substrate temperature was kept at 750°C (thermocouple reading) during the growth except for the p-AlGaN layer. A Nitrogen plasma power of 200W was used for a growth rate of 110 nm/hr**.** A 10 nm AlN layer was nucleated on the substrate using migration-enhanced epitaxy (MEE). Then, 110 nm of linearly graded down (100% to 55%) n-type AlGaN doped with a Silicon concentration of $5\text{x}10^{19}$ cm^{-3} was grown on top as a buffer to accommodate strain. A 110 nm layer of 55% n-AlGaN was then grown, followed by 110nm of graded up (55% to 95%) n-AlGaN to assist with electron injection. Linear grading was implemented to benefit from polarization-induced doping [1]. The active region of the structure consists of 4 periods of 2 monolayer GaN quantum dots separated by 2.5 nm AlN barriers. The thickness of the quantum dots is chosen for emission around 240 nm [2]. A low growth temperature (700°C) was used for the graded down (95% to 75%) p-type AlGaN layer to enhance Magnesium incorporation. Indium was used as a surfactant to increase the adatom mobility at this lower temperature. Two separate samples were grown to study the impact of a tunnel-junction: a control sample and a TJ sample. The above conventional LED structure was grown as the control sample. For the TJ sample, an additional 10 nm GaN QW followed by 70 nm graded up (75% to 95%) n-AlGaN was grown to make low resistance hole-injection contacts.

An optimal TJ can potentially enhance injection current [3]. To fabricate the TJs, Cl_2 RIE etching was used to define 100μm x 100μm Mesas. Metal contacts were deposited in order to perform electrical measurements on these samples. For the control sample, a 5 nm Ni/5 nm Au current spreading contact was deposited followed by 20 nm Ti/100 nm Au on top as the p-type contact. The n-type contact, consisting of Ti/Al/Ni/Au – 20/100/40/50 nm, is made to the constant 55% n-AlGaN layer for both samples, as well as to the TJ sample's 75% n-AlGaN Mesa.

3. Results

High resolution TEM and EDX analysis shown in Figure 1(c) confirms that the compositions and thicknesses of the layer structure are as desired. Room temperature electroluminescence measurements were performed in pulsed mode (10 KHz, 5% duty cycle) on the structures to confirm deep-UV emission (Figure 2). The peak emission wavelength is at 243 nm with a linewidth of <10 nm. A side peak at 269 nm from the 55% n-AlGaN is also observed. The broader emission at ~460nm comes from deep level defects introduced during the crystal growth. Both emission windows can be eliminated in future studies; we now focus on the aspect of tunnel-junction p-contact.

To characterize the role of the tunnel-junction p-contact, the contact and sheet resistances of the structures were measured by the transmission line method (TLM) at room temperature. The structure with the TJ has both lower

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hole-injection contact resistance ($5.87\text{x}10^{-5}$ Ωcm^2) and sheet resistance (42 kΩ/□) as compared to the control sample for which values of $1.40\text{x}10^{-3}$ Ωcm^2 contact resistance and 1.19 MΩ/□ sheet resistance were measured.

Current-Voltage characteristics were measured at room temperature with a Cascade EP6 probe station. The TJ device shows higher current density than the device without a TJ for forward bias (Figure 3). Further optimization of the QW design can lead to larger forward bias current in addition to better wall plug efficiency (WPE).

4. Figures

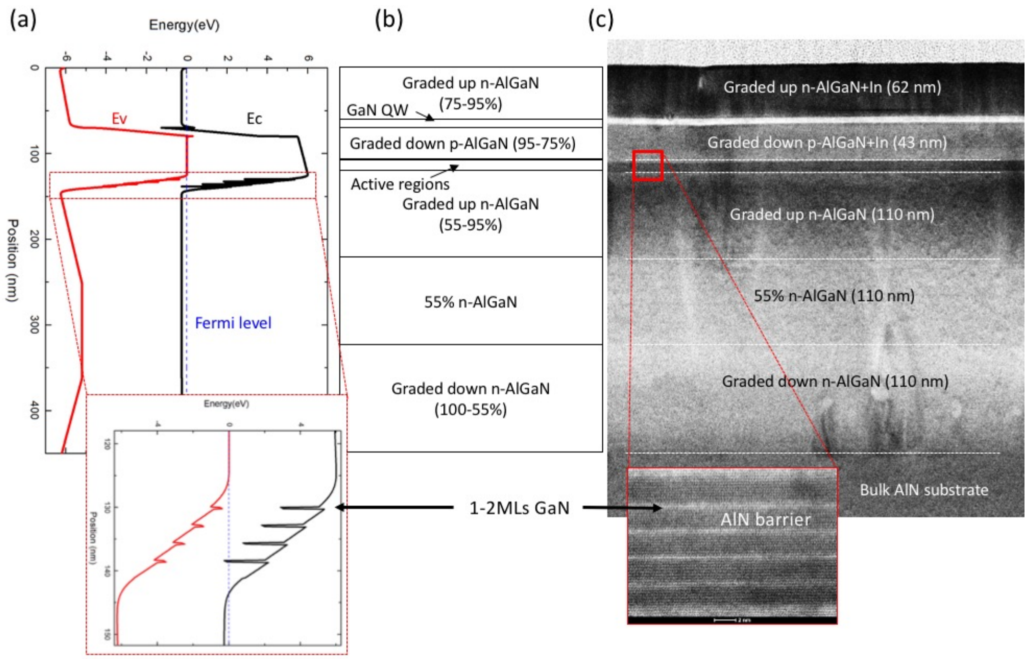

Figure 1. (a) Band diagram of the TJ UV-LED structures, (b) detailed layer structures. (c) HR-TEM image of LED structures. Right and left inset figure are the active region zoomed-in image of band diagram and TEM consisting 2 ML GaN QD.

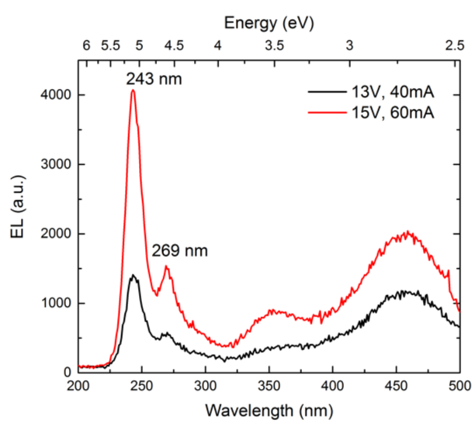

Figure 2. Electroluminescence spectrum of TJ LEDs.

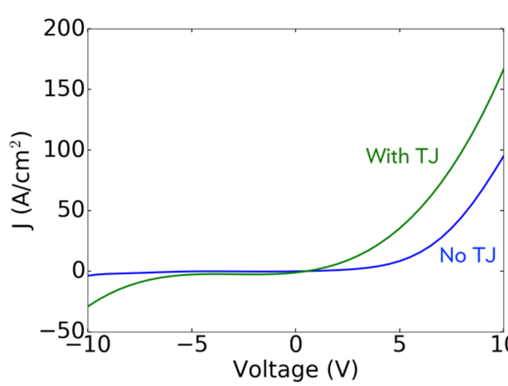

Figure 3. IV measurement for LED with and without TJ structures.

5. References

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