250 nm Deep UV LED Using GaN/AlN Heterostructures On Bulk AlN Substrates

SM Islam, Vladimir Protasenko, Huili (Grace) Xing, and Debdeep Jena
Department of ECE, Cornell University, Ithaca, NY 14853, USA
email: smislam@cornell.edu

Abstract: A 250 nm deep UV LED is realized on the bulk AlN substrate. Leakage current is reduced significantly. Polarization doping is used for the p-region and GaN active region to enhance the light extraction.
OCIS codes: (250.5590) Quantum-well,-wire and –dot devices, (260.7190) Ultraviolet, (300.2140) Emission

1. Introduction

The deep-UV (DUV) light emitting diodes specially <260 nm are attractive for germicidal applications and diagnostics. DUV emission of various wavelengths spanning over the entire 200-300 nm have been realized by using AlGaN/AlGaN heterostructure as the light emitting media. So far, the extremely low external quantum efficiency is limiting the DUV LED performance.The low efficiency is caused by three factors, presence of extended threading dislocations (TDs) and point defects in the light emitting region, poor doping of high composition AlGaN specially p-type and the inferior light extraction due to total internal reflection and absorption by metal contacts. One approach of reducing the TD density is to use high quality bulk AlN substrates instead of commonly used AlN templates on Sapphire. The currently available bulk AlN from Hexatech has a TD density of ~1x10^{4} cm^{-2}; 6 orders less than the AlN templates. These substrates have a potential in realizing higher efficiency DUV LEDs. Also use of GaN/AlN based active regions are attractive for enhanced light extraction because GaN emits TE polarized light compared to TM polarized emission from high Al compostion AlGaN based light emitters.

2. Experimental

In this work, we used high quality bulk AlN substrates from Hexatech to grow deep UV LED structures by plasma assisted molecular beam epitaxy (PAMBE). A thermocouple temperature of 750º C and RF plasma power of 200 W corresponding to growth rate of 0.17 ML/s was utilized for the growth of the LED structures. Fig. 1(a) shows the schematic of the LED structure. First a 20 nm AlN nucleation layer was grown on the bulk AlN substrate. This AlN was grown in slightly metal rich condition. A 110 nm linearly graded down buffer layer was grown after the AlN. For the n-region, a Si-doped 110 nm 77% $Al_xGa_{1-x}N$ layer was grown. 3 periods of GaN/AlN heterostructure were inserted as the DUV light emitting region. For this 2 monolayers thick GaN quantum-disks were grown in Stranski-Krastanov in 2.5 nm AlN barriers. The disks were grown in Ga/N<1 growth condition. For the p-region, polarization doping technique was used to enhance the p-doping. A 60 nm thick linearly graded down AlGaN layer (Al% was graded down from 100%-77%). Mg was used as the dopant atom. In order to compare the impact of the substrate, two substrates (bulk AlN and AlN template on Sapphire) were co-loaded and the LED device structure were grown on them with a single growth run. TEM analysis were performed to investigate the layer structure. As shown in Fig. 1(b), desired thicknesses and composition of different layers were achieved. For LED device processing, a Cl_2 based RIE etching were carried out for MESA etch. Then the metal contacts were put on the p (5 nm Ni/5 nm Au current spreading followed by 20 nm Ti/100 nm Au) and the n regions (Ti/Al/Ni/Au-20/100/40/50 nm).The energy band diagram at 6V forward bias helps to explain the device operation. By using 2.5 nm thin AlN barriers in the active region, tunnel injection in the GaN region is achieved which improves the efficiency of the devices. The polarization doping for the p-region is manifested by the smooth valence band profile which is conducive to hole transport. To characterize the LED performance, electroluminescence (EL) and I-V characteristics were measured. A 250 nm DUV emission was achieved with a narrow 13 nm FWHM (Fig. 3). The I-V characteristics were measured for both the LEDs grown on bulk and template AlN. Fig. 4 shows the comparison. For the LED grown on the template substrate, large reverse bias leakage current was observed making the device non-rectifying (Fig. 4(a)). On the contrary, the LED grown on bulk AlN show improved rectification property (Fig. 4(b)). The turn on voltage is also pretty low like 4V for a 250 nm LED. This reduction in the leakage current on bulk AlN can significantly enhance the overall efficiency of the LED compared to devices grown on template substrates.

3. Conclusion

We presented a 250 nm deep UV LED using GaN/AlN heterostructure on high quality bulk AlN substrates. The leakage current can be significantly reduced by using bulk substrates which can therefore enhance the overall efficiency dramatically.

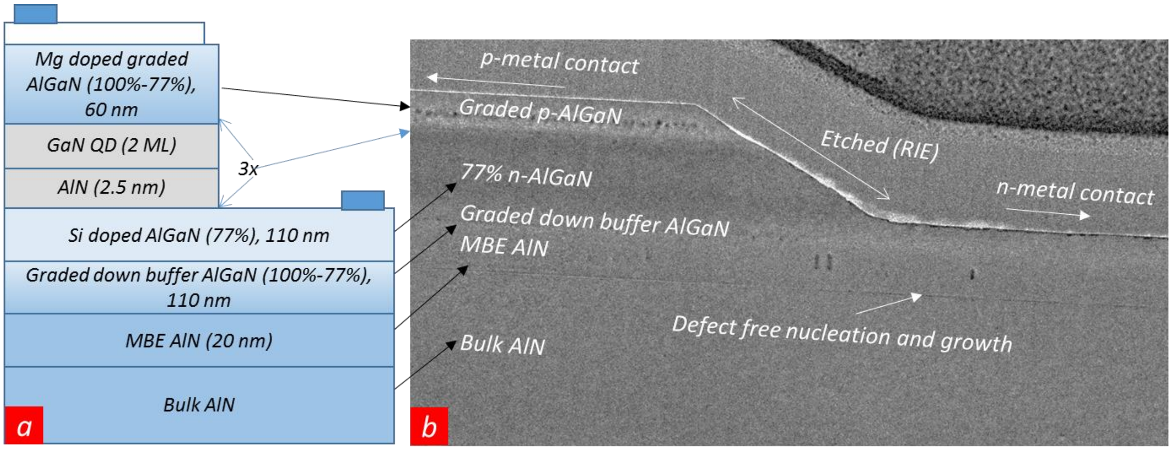

Fig. 1: (a) Schematic of the GaN/AlN LED structure, (b) HRTEM image showing thickness of different grown layers

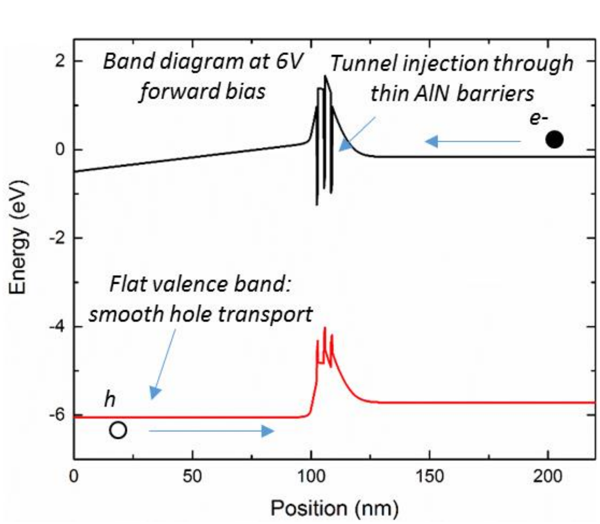

Fig. 2: Energy band diagram at 6V forward bias

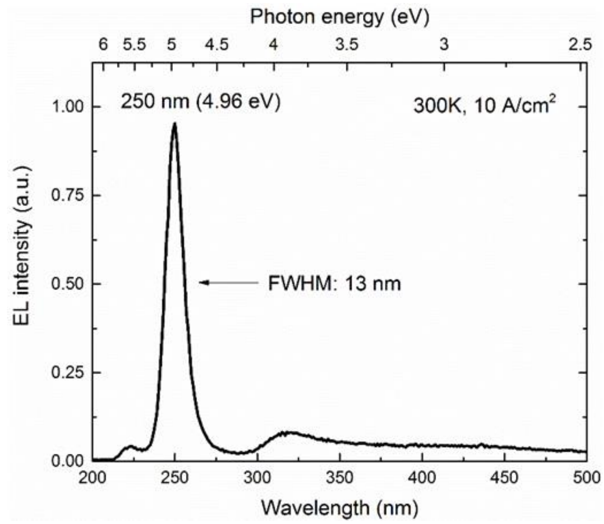

Fig. 3: EL spectra showing 250 nm sharp emission

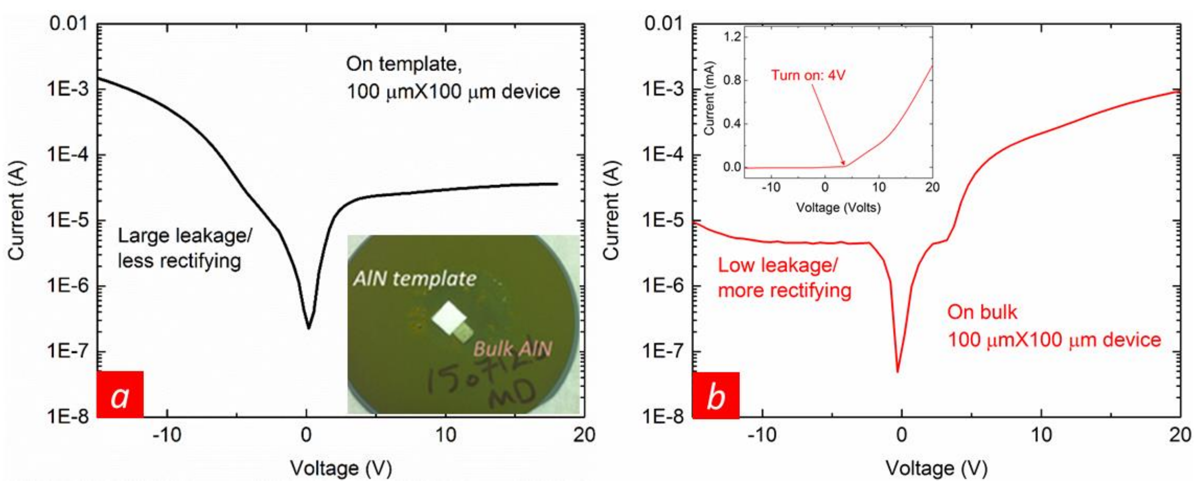

Fig. 4: I-V characteristics of the deep UV LEDs grown on (a) AlN template/Sapphire substrates, (b) bulk AlN substrates. Inset of (a) shows the co-loaded substrates before MBE growth. The turn on voltage of 4V is highlighted in the inset of (b).