Quaternary AlInGaN-InGaN MQW Based Vertically Conducting Light Emitting Diodes on SiC.

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III-N based multicolor light emitting diodes are key to developing solid-state lighting sources, where relative intensity of primary colors in such diodes should be adjusted to yield white light. We demonstrate the use of a unique approach of using quaternary AlInGaN/InGaN multiple quantum well (MQW) LED structures for tuning of the emission spectra and relative intensities. This tuning is achieved by controlling the quantum well and barrier composition and by optimizing the thicknesses and the number of the quantum wells. Tuning of polarization and strain induced electric fields using the quaternary (AlInGaN) barriers allows us to obtain a nearly independent control of built-in fields and quantum-confinement. This, in turn, can change the position and the intensities of the emission peaks by changing the potential profile of the MQW. Preliminary results on vertically conducting devices (over n-type 4H-SiC) show a dramatic increase (of over an order of magnitude) in emission-intensity for the structures with AlGaInN barriers compared to those using conventional GaN barriers. We attribute this improvement to the reduction in piezo/spontaneous polarization-fields and to the improved quality of the quantum well barrier layers. We also observed a strong non-monotonic dependence of the PL intensity on the level of silicon doping.

The InGaN MQW structures with AlGaInN barrier were deposited on the SiC substrate following growth a conduction buffer layer consisting of a 0.8 μm thick superlattice of $n^+ Al_{0.2}Ga_{0.8}N$ and GaN followed by a 0.1 μm thick n-GaN layer. The structures included three $In_{0.2}Ga_{0.8}N$ quantum wells sandwiched between $Al_{0.15}In_xGa_{0.85-x}N$ barrier layers. The In- fraction in the barrier layers varied from 0 to 15% and the thicknesses of the well and the barrier layers varied between 20-50 Å and 40 to 50 Å, respectively. The growth temperature and pressure for the MQW layers were 800 °C and 200 torr respectively. The MQW structures were capped with p-AlGaN clad, p-GaN contact layers as shown in Figure 1. Comparison of PL spectra for AlGaInN/InGaN and GaN/InGaN structures for the same well composition shows blue shifted emission by about 15nm for sample with quaternary barriers and considerable increase in emission intensity.

We fabricated vertically conducting stripe-geometry (4 μm x 500 μm) AlGaInN/InGaN and GaN/InGaN edge-emitting MQW LEDs. Ni/Au and Ti/Al were used for the top p-contact and for the bottom n-contact to the SiC substrate. A differential resistance of about 50 ohms was measured for the LED structures with either GaN or AlInGaN barrier layers in the MQW region. Electroluminescence (EL) spectra at 10 mA DC for InGaN MQW LEDs with GaN and $Al_{0.15}In_{0.15}Ga_{0.70}N$ barriers are shown in Figure 2. As seen an increase by a factor of 20 in the emission intensity is observed for the quaternary barrier LED. This difference further increases at higher pump currents (Please see Figure 3). The EL spectra also demonstrate significant reduction in the intensity of long-wavelength tails confirming considerable improvement in MQW quality. It is also evident from Figure 3 that the higher quality of the MQW structure leads to a more linear light-current dependence for case of AlInGaN barrier.

We have also carried out several other experiments to determine the mechanism responsible for these observed changes in emission spectra. These, and the results of high current DC and pulsed pumping of the quaternary barrier InGaN MQW LEDs will be presented. Some preliminary results of emission from MQW structures with quaternary AlInGaN layers both in the well and barrier region will also presented.

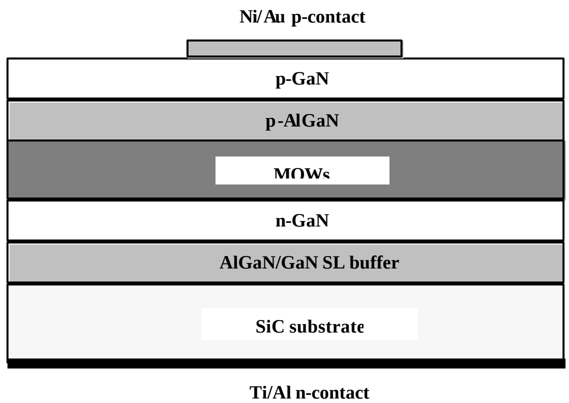

Figure 1. MQW structure over SiC substrate with conducting buffer.

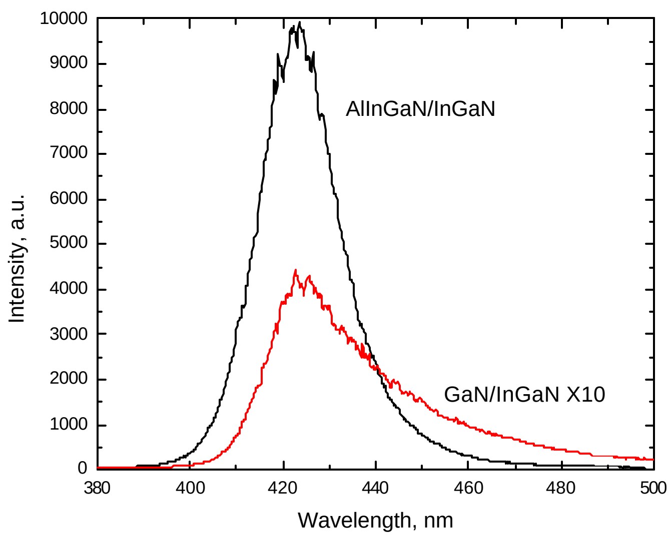

Figure 2. EL spectra of AlInGaN/InGaN and GaN/InGaN QWs at 10mA DC.

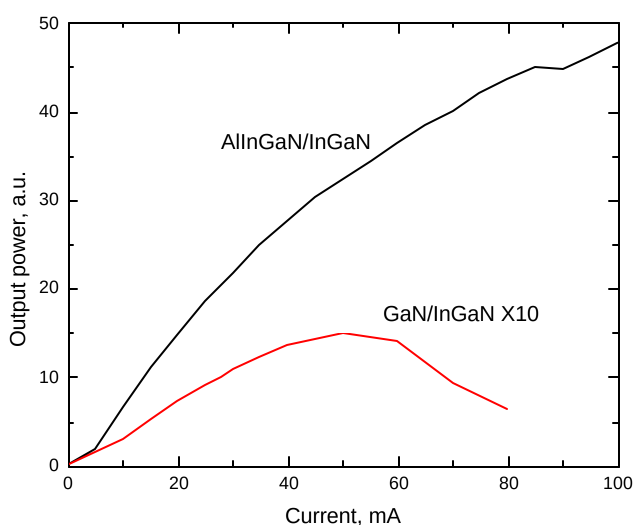

Figure 3. Light intensity vs. current dependencies of AlInGaN/InGaN and GaN/InGaN QWs.