Low Resistivity Al-rich AlGaN Grown by Plasma-Assisted Molecular Beam Epitaxy

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A highly conductive p-type AlGaN layer is crucial for obtaining high efficiency deep ultraviolet (UV) light emitting diodes (LEDs) and semiconductor laser diodes. Mg, which is a common p-type dopant for III-nitrides has a very large activation energy (up to 500-600 meV) in Al-rich AlGaN [1-3], and its solubility decreases significantly with increasing Al composition [4, 5]. Resistivity values ~10^2 to 10^4 Ω·cm have been commonly reported for p-type AlGaN epilayers with Al compositions ~80%, compared to <1 Ω·cm for p-type GaN.

We report on the achievement of low resistivity (~1-10 Ω·cm) p-type AlGaN epilayers with Al compositions in the range of 75-95% by using plasma-assisted molecular beam epitaxy. The growth was carried out under slightly metal rich conditions to ensure a smooth surface and good crystalline quality. Detailed characterization of the samples was carried out using X-ray diffraction (XRD), atomic force microscopy, and Hall effect measurements. We measured a hole concentration of ~1×10^{18} cm^{-3} and mobility ~6 cm^2/V·sec for AlGaN with Al composition ~75% at room temperature, which are significantly higher than previously reported values for AlGaN grown by MOCVD. Moreover, a relatively high hole concentration ~4×10^{17} cm^{-3} was achieved for AlGaN with Al composition >90%. The resistivity varies from ~1 to 4 Ω·cm with increasing Al composition from 75% to 92%. Detailed temperature dependent Hall measurements showed a small activation energy (~15 meV) for hole concentration near room temperature, suggesting the important role of hole hopping conduction in the Mg impurity band. The realization of high efficiency AlGaN deep UV LEDs is in progress and will be reported.

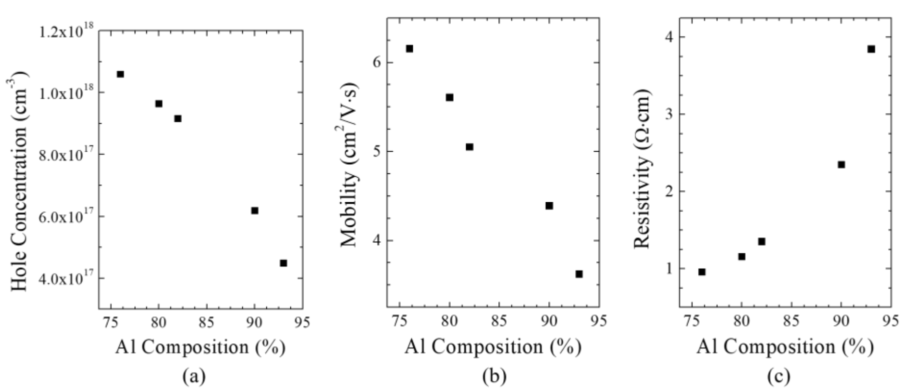

Figure 1. Variations of (a) hole concentration, (b) mobility and (c) resistivity with Al composition.

[1] L. M. Nakarmi et al, Appl. Phys. Lett. **89**, 152120 (2006). [2] Y. Taniyasu, M. Kasu and T. Makimoto, Nature, **441**, 325 (2006). [3] U. Kaufmann et al, Phys. Rev. B, **62**, 10867-72 (2000). [4] T. Zheng et al, Nanoscale Res. Lett., **9**, 40 (2014). [5] C. Stampfl and C. G. Van de Walle, Phys. Rev. B, **65**, 155212 (2002).

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Supplementary Pages

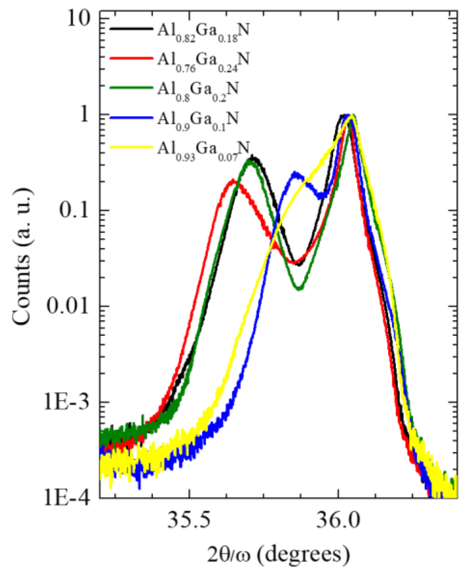

Figure 2. XRD 2θ/ω scans for the samples grown having different Al compositions.

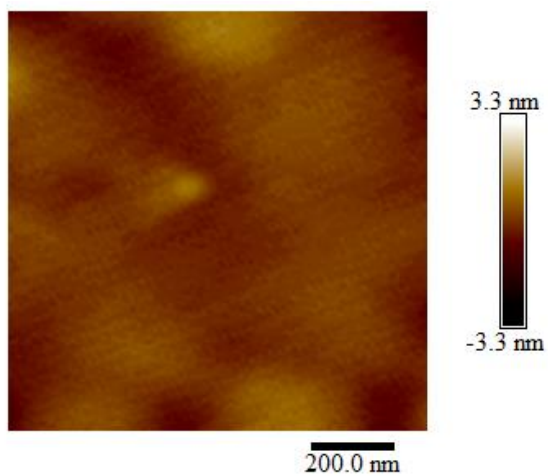

Figure 3. Representative 2D AFM scan of the surface of the sample having Al composition of 80%. The RMS roughness is below 0.5 nm.

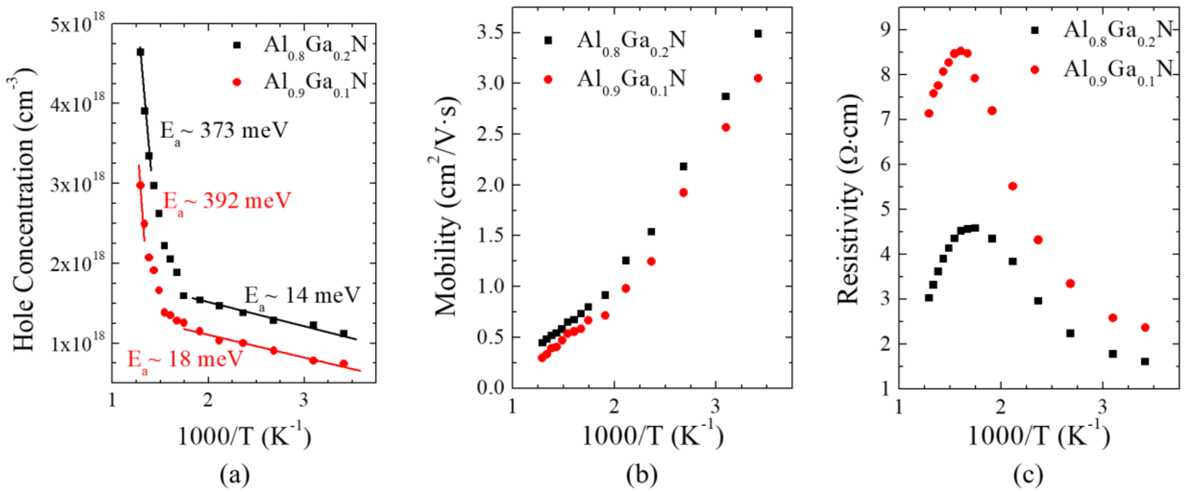

Figure 4. Temperature dependent measurements of (a) hole concentration, (b) mobility and (c) resistivity for samples having 80% (black squares) and 90% (red circles) Al composition. The activation energies for impurity band transport and thermal activation of Mg dopants is shown.