Growth and Characterization of Mg-doped AlGaN/AlN Superlattices

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Motivation—AlGaN semiconductor alloys have tremendous potential for enabling deep ultraviolet (UV) LEDs and laser diodes for fluorescence-based bioagent sensing, water purification and other applications. To date, the realization of high performance devices has been frustrated by numerous AlGaN materials challenges. One of the most formidable challenges is obtaining effective p-type doping and hole transport in these wide bandgap alloys. In this work, we explore Mg-doped short-period superlattice structures as a method to overcome p-type doping limitations in deep UV light emitters.

Accomplishment—One promising approach to circumventing the high acceptor activation energies of III-nitride alloys is the application of superlattice (SL) structures doped with Mg. These periodic structures exploit the large polarization fields in wurzite III-nitrides to achieve enhanced hole activation and free hole concentrations. Much of the reported work on these structures has focused on GaN/AlGaN p-SLs with effective bandgaps suitable for near-UV and visible device applications. In this work, we developed Mg-doped short-period AlGaN/AlN superlattice structures (Mg-SPSLs) with significantly higher effective bandgaps suitable for deep UV devices. The Mg-SPSL structures employed nm-thick AlN and $Al_{0.23}Ga_{0.77}N$ epilayers grown by metal-organic vapor phase epitaxy. Mg-SPSL structures with periods ranging from 10-25 Å and with an average Al composition of 0.42 to 0.74 were investigated. Structures studied consisted of up to 1000 periods for a total thickness of 1 μm.

Optical, structural, and electrical characterization was performed to assess the applicability of these Mg-SPSLs to deep UV LED or laser structures. Optical transmission measurements demonstrated that these structures have an optical transparency similar to random-alloy $Al_xGa_{1-x}N$ epilayers of the same average composition (Figure 1). X-ray diffraction (XRD) measurements confirmed that the period and average Al composition of the Mg-SPSL were in agreement with targeted values. Additionally, we observed that Mg-doping of SPSL structures degraded or eliminated satellite peaks that were observed in XRD spectra from undoped or Si-doped SPSL structures, suggesting that the presence of Mg during growth alters the interfaces of the epilayers.

P-type lateral resistivities less than 10 ohm-cm were measured from Mg-SPSLs with an average Al composition from 0.42 to 0.74. Notably, a p-type resistivity of 6 ohm-cm was measured in a Mg-SPSL structure with an average Al composition of 0.74 and having an effective bandgap of ~5.3 eV. Analysis of temperature dependent resistivity showed an activation energy of 29 meV for a Mg-SPSL with an average composition of 0.62 and 18 meV for a Mg-SPSL with a composition of 0.49 (Figure 2). These values are significantly reduced from the > 200 meV values predicted for bulk AlGaN alloys. Overall, the combined characteristics of these Mg-SPSLs show promise for application to deep UV optoelectronic device structures.

Significance—Overcoming p-type doping challenges of AlGaN alloys represents a very significant step toward extending high performance LED and laser diode technology into the deep ultraviolet. These AlGaN materials may enable a new generation of compact, robust and highly integratable UV emitters for a wide array of applications including sensing, decontamination, spectroscopy and material processing.

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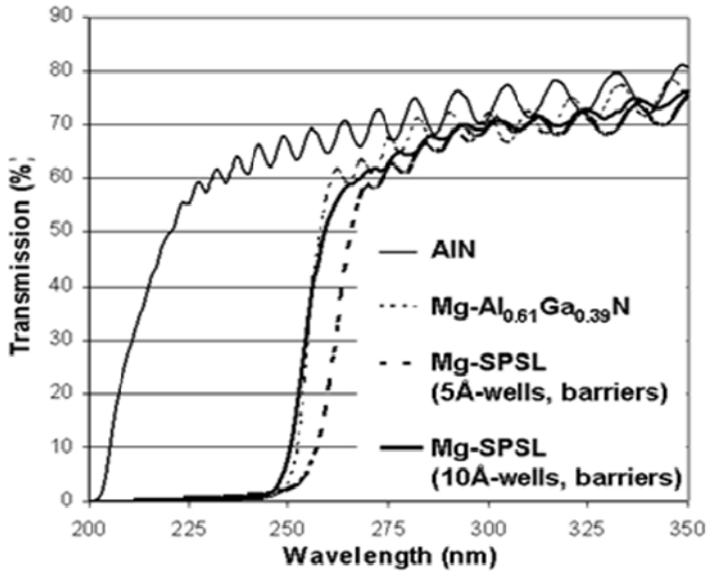

Figure 1. Optical transmission spectra are shown for an AlN-on-sapphire template, a 0.3µm-thick $Al_{0.61}Ga_{0.39}N$ Mg-doped epilayer, and two different 0.3µm-thick Mg-SPSL structures. Both Mg-SPSL structures have a target average Al composition of 0.61 but differing periods (10Å and 20Å). The data demonstrate that a Mg-SPSL structure with an average Al composition of 0.61 replicates the transmission properties of a random alloy of the same composition.

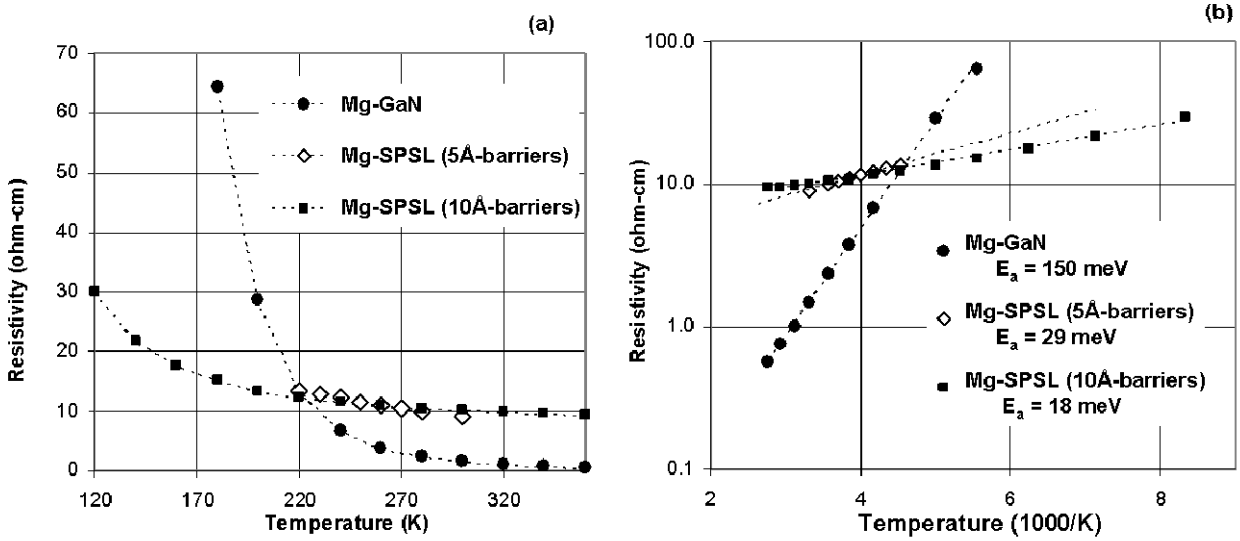

Figure 2. Resistivity vs (a) temperature and (b) inverse of temperature for p-GaN (circles), and a Mg-SPSL with 5 Å AlN barriers and 5 Å (diamonds) or 10 Å (squares) $Al_{0.23}Ga_{0.77}N$ well layers. Dashed lines in (a) are guides to the eye and in (b) are fits to the data using an Arrhenius model.