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Characterization of AlGaN-based GRINSCH Using TEM and Electron Holography

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AlGaN alloys have much potential as ultraviolet (UV) optoelectronic devices, including UV semiconductor lasers, since varying the alloy composition results in corresponding band gaps that span the UV wavelength range [1]. Current trends in electrically pumped deep-UV semiconductor lasers reveal the necessity of *p*-type doping for AlGaN [2]. One promising solution to this as yet unmet need is the graded-index-separate-confinement-heterostructure (GRINSCH), in which the active region of the heterostructure is confined on either side by compositionally graded alloys [2]. The graded layers assure a gradual change in refractive index of the heterostructure and therefore confine the optical power of the device in addition to the mobile carriers [3]. In the current work, a $Al_xGa_{1-x}N/Al_{0.72}Ga_{0.28}N/Al_xGa_{1-x}N$ GRINSCH grown on a (0001)6H-SiC substrate by molecular beam epitaxy (MBE), as shown in Fig. 1, has been investigated. Device cross-sections were examined by diffraction-contrast and high-resolution phase-contrast TEM using a JEM-4000EX operated at 400keV, and off-axis electron holography was used to study the electrostatic profile across the active device region.

Numerous threading dislocations begin at the SiC/AlN cladding and buffer layer interface, as shown in Fig. 2(a). In areas such as zone 1, the dislocations annihilate in the buffer layer, while in other areas such as zone 2, the dislocations continue through the AlN. Out of these that continue to propagate, a large number are annihilated at the lower $Al_xGa_{1-x}N$/AlN interface, as shown in Fig. 2(b). These results suggest that an additional advantage of the graded layers is to accommodate the strain caused by gradually transitioning from the lattice constant of AlN to that of $Al_{0.8}Ga_{0.2}N$. Phase and approximate thickness profiles reconstructed from an electron hologram are plotted from the surface through the second graded layer to the AlN buffer layer, as shown in Fig. 3. Since the sample is assumed to be uniformly thick, the "thickness" profile is instead indicative of the mean free path for inelastic scattering and is therefore useful in identifying the different layers. The profile is flat for approximately 75nm, in agreement with the uniform composition of the 75-nm active $Al_{0.72}Ga_{0.28}N$ region. On either side, the profile slopes downwards, again in accordance with the graded layers on either side. The rise of the phase profile in conjunction with the top graded layer is noteworthy, as is the continued increase in phase until approximately the end of the active layer. These results indicate that the conduction and valence band energies may change not only in the active region, but also in the top graded layer. Next steps in this investigation will include verification and quantification of this effect, and comparison with previously calculated theoretical values.

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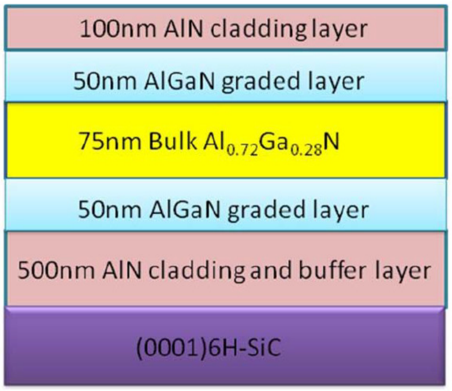

Fig. 1. Structure of GRINSCH under investigation.

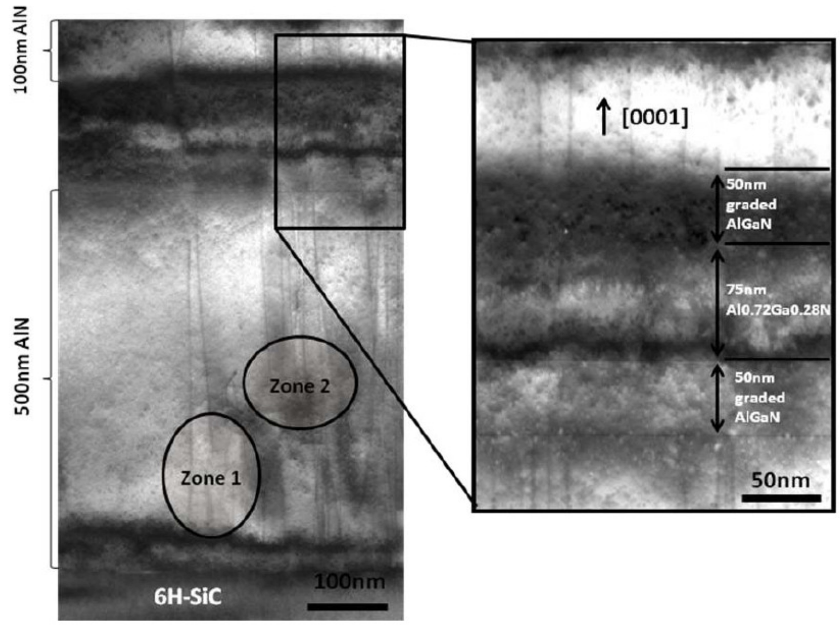

Fig. 2. (a) XTEM image of GRINSCH structure. (b) Image of inset, showing graded structures and active region.

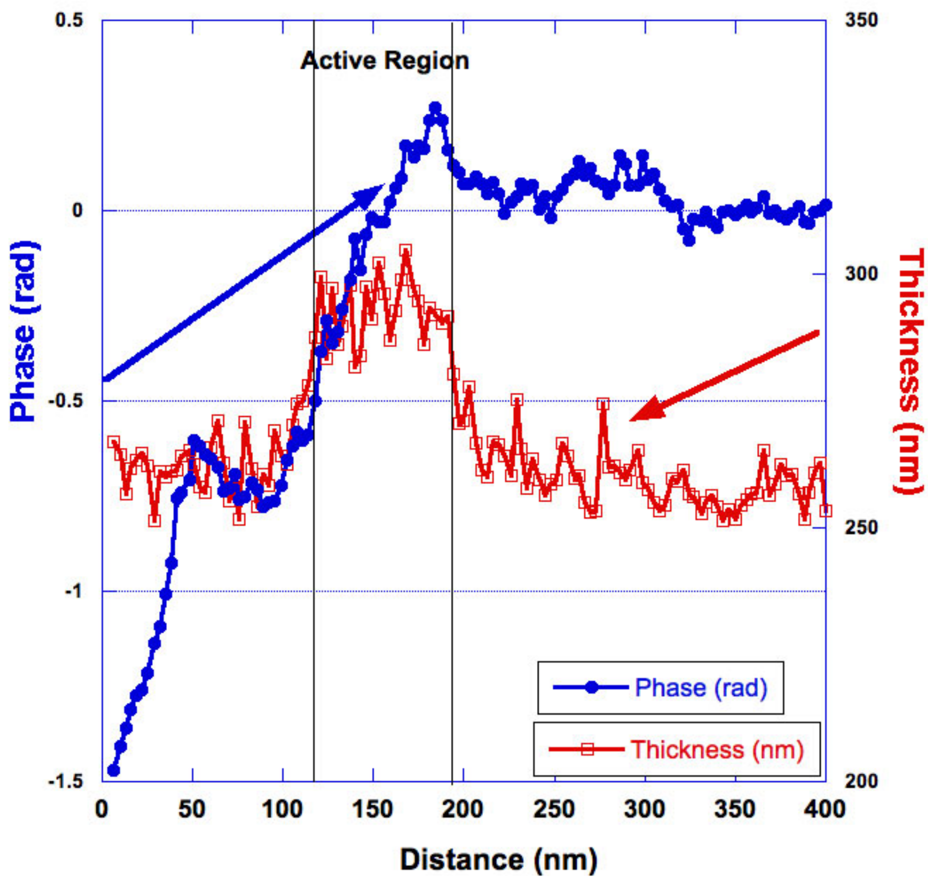

Fig. 3. Phase and approximate thickness profiles as reconstructed from electron hologram, with distance scale beginning from inside the top cladding layer. Vertical lines enclose the active region.

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