Abstract

III-Nitride semiconductors are attractive for quantum applications as well as popular for 2DEG based heterostructures. Integration of III-N heterostructures on Silicon is most promising to achieve low cost, reliable and robust hetero-integration. Thin barrier heterostructures are attractive for enabling vastly improved quantum applications, but technologically constrained by severe epitaxial limitations related to differences in properties of III-Nitrides on Silicon. Two III-N based materials that complement each other in view of piezoelectric polarization induced strain and growth are AlGaN and InAlN. Although epitaxy of thin barrier AlGaN/GaN on Si is relatively easier compared to that of InAlN/GaN on Si heterostructures and able to provide maximum 2DEG at its heterointerface but it suffers from strain induced piezoelectric polarization that affects some of its applications. While nominally lattice matched InAlN/GaN heterostructure overcome the strain related issues but overall growth procedure for this thin barrier alloy system is quite difficult.

This work deals with novel growth of AlGaN/GaN and InAlN/GaN heterostructures having buffer thickness of 600 nm/400 nm/200 nm on Si substrate by plasma assisted MBE, involving appropriate substrate oxide desorption, initial silicon nitridation, AlN nucleation layer formation and carefully managed buffer layers capable of supporting thin barrier heterostructures. Successful growth of both heterostructures using our unique growth recipe is followed by comparative structural characterization and analysis based on High-Resolution X-Ray Diffraction (HRXRD), Reciprocal Space Mapping (RSM), Room-Temperature Photoluminescence (RT-PL), Transmission Electron Microscopy (TEM) and Atomic Force Microscopy (AFM) results. Analysis reveals an increasing biaxial tensile stress of 0.6918 ± 0.04 GPa, 1.1084 GPa, 1.1814 GPa in AlGaN samples with decreasing buffer thickness of 600, 400, 200 nm respectively which is supported by the red-shift in RT-PL peak. Increasing non-radiative recombination rate with decreasing buffer thickness in InAlN samples results a blue-shift in GaN RT-PL peak. XRD-FWHM values, RSM results and root mean square (RMS) value from AFM indicate better crystallographic quality of nominally lattice-matched InAlN/GaN compared to lattice mismatched AlGaN/GaN samples. Impact of varying buffer thickness on the formation of thin 1.5 nm $Al_{0.2}Ga_{0.8}N/In_{0.17}Al_{0.83}N$–1.25 nm GaN–1.5 nm $Al_{0.2}Ga_{0.8}N/In_{0.17}Al_{0.83}N$ heterostructure, in terms of threading dislocation (TD) density is studied. A drastic reduction of TD density from the order 10^{10} cm^{-2} to 10^{8} cm^{-2} with increasing optimized buffer thickness resulting smooth thin active region for both thick buffer structure, whereas; nominally lattice-matched InAlN/GaN based thick buffer provides less TD affected, smooth and prominent thin active region. Experimental work is followed by modelling of as-grown optimized structures in quantum field as resonant tunneling diode (RTD) and resonant tunneling high electron mobility transistors (RTHEMT). It can be summarized that optimized thick buffer provides lower TD density that improves pick to valley current ratio (PVCR) by enhancing current which is because of lower recombination in the TDs. Predictable application through comparative modelling of thin barrier AlGaN/GaN and InAlN/GaN based heterostructure such as RTD and RTHEMT exhibits superior performances and opens up promising new applications enabled by novel epitaxial process and characterization conducted in this research.