Epitaxial Growth of relaxed InGaN films on ZnO substrate by Plasma-Assisted Molecular Beam Epitaxy

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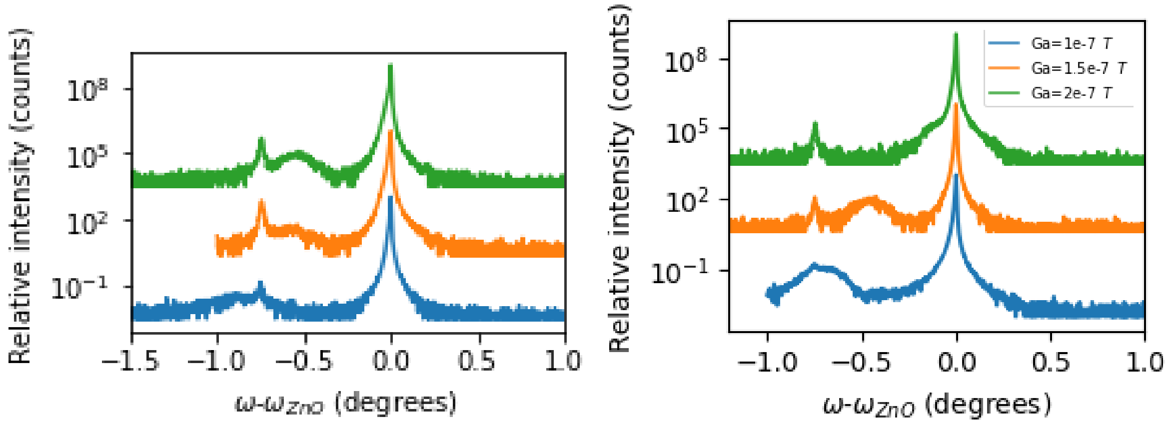
InGaN alloys are attractive for optoelectronic and electronic applications and have been studied extensively for light emitting diodes and lasers in the last two decades. Varying In content in ternary InGaN alloys allows band gap engineering in a wide range of energies from 0.7 eV to 3.4 eV. Nonetheless, growth of large In content InGaN alloys have been challenging due to significant difference in thermal stability of InN and GaN, in addition to large lattice mismatch between InGaN and GaN. The latter limits the critical thickness of InGaN films grown on GaN after which InGaN relaxes plastically via formation of defects.

The above-mentioned challenges have motivated scientists to develop relaxed InGaN as pseudo-substrate. Growth of $In_zGa_{1-z}N$ on relaxed $In_xGa_{1-x}N$ substrate (z>x) is favorable due to smaller lattice mismatch which will result in larger critical thicknesses. Multiple groups have studied growth of relaxed InGaN films on GaN substrates. It has been shown that achieving full or even partial relaxation of an InGaN layer via an abrupt transition results in high density of V-defects and pits that degrade the structural and optical quality of the layer. A fully relaxed $In_{0.1}Ga_{0.9}N$ layer has been achieved on GaN by grading InGaN [1]. However, it has been shown that the relaxation occurs through formation of threading dislocations.

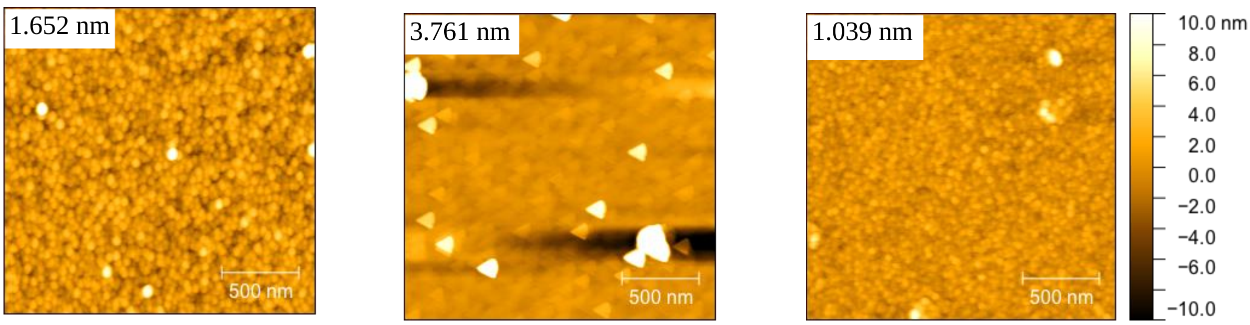
In this work, we have investigated growth of InGaN on ZnO substrates using plasma-assisted molecular beam epitaxy (PAMBE). InGaN and ZnO possess same stacking order. Moreover, based on Vegard's law $In_{0.2}Ga_{0.8}N$ is lattice matched to ZnO in c-plane [2] which is promising for growth of high quality relaxed InGaN buffer layers. Also, PAMBE is a relatively low temperature growth technique which should suppress the formation of unwanted In_2O_3 interlayer because of reaction between O and InGaN at the interface enabling smooth growth on these lattice-matched but chemically dis-similar materials. Here, the impact of In and Ga metal fluxes and substrate temperature on ZnO-InGaN interface quality, InGaN surface morphology and InGaN composition have been studied. We have also compared the ZnO substrate polarity (Zn-face vs O-face) on the InGaN film quality.

References: [1] Hestroferr K. et al physica status solidi (b) vol 253 (2016) [2] Kobayashi A. et al. Scientific Reports vol 7, 12820 (2017)



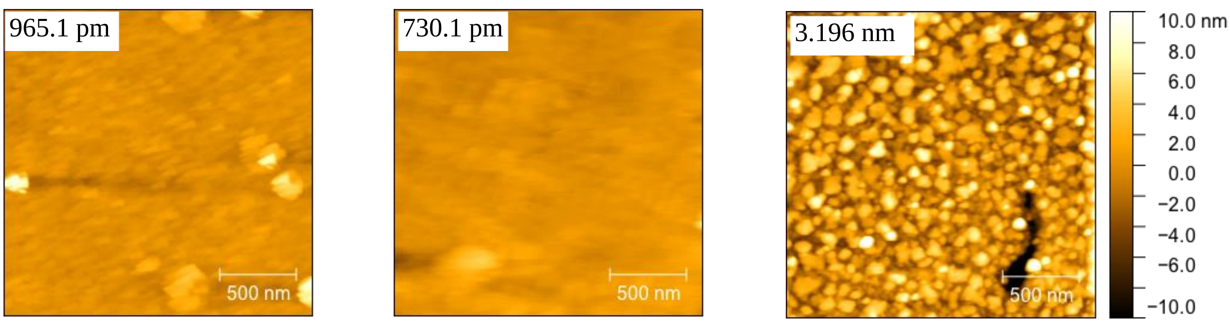
(a) (b)

Figure 1: XRD $2\theta-\omega$ profile along the (002) direction showing InGaN thin films grown on (a) Zn-face (b) O-face ZnO substrates with different Ga fluxes: $1\text{x}10^{-7}$, $1.5\text{x}10^{-7}$ and $2\text{x}10^{-7}$ Torr. The Zn-face ZnO substrates show In incorporation 35%, 26%, 21%, respectively. The O-face ZnO substrates show In incorporation 31%, 15%, 6%, respectively.



(a) (b) (c)

Figure 2: $2\text{x}2\mu\text{m}^2$ AFM images of InGaN thin films on Zn-face ZnO substrates with changing Ga flux: (a) 1e-7, (b) 1.5e-7 and (c) 2e-7 Torr showing RMS roughness of 1.652 nm, 3.761 nm and 1.039 nm, respectively. The inset values show the RMS values of the thin films.



(a) (b) (c)

Figure 3: $2\text{x}2\mu\text{m}^2$ AFM images of InGaN thin films on O-face ZnO substrates with changing Ga flux: (a) 1e-7, (b) 1.5e-7 and (c) 2e-7 Torr showing RMS roughness of 965.1 pm, 730.1 pm and 3.196 nm, respectively. The inset values show the RMS values of the thin films.