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Optimization of GaN barriers during the growth of InGaN / GaN quantum wells at low temperature

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ABSTRACT

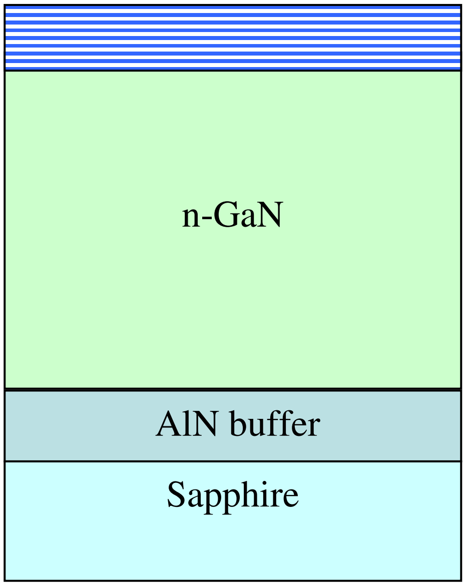
InGaN/GaN MQWs are grown on c-plane sapphire substrates using a low pressure metal organic vapor phase epitaxy (MOVPE) system. Trimethylgallium (TMGa), Triethylgallium (TEGa), Trimethylindium (TMIn) and ammonia were used as precursors for Ga, In and N, respectively and the growths were carried out at low temperature. Structural properties of grown MQWs are characterized using atomic force microscopy (AFM), and scanning electron microscope (SEM) and x-ray diffraction technique (XRD) is used to calculate the Indium incorporation in these MQWs. Surface morphologies over large areas of InGaN/GaN MQWs are observed using the tapping mode AFM; results indicate the surface roughness depends on the barrier thickness. Density of V- defects, effect of barrier width on the surface morphology and also on V-defect density will be presented and discussed.

INTRODUCTION

Group III- nitrides have emerged as a promising material system for optoelectronic applications ranging from infrared to ultraviolet regions as well as for high power/high temperature and high frequency electronics. In particular, quantum wells (QWs) based on InGaN active layers have been playing a key role in the achievement of high brightness blue and green light emitting diodes (LEDs) and laser diodes (LDs) [1,2]. Inspite of the progress made during last several years in the growth technologies; there are still a lot of unresolved issues related to InGaN multi quantum well (MQW) growth. Large lattice mismatch and low miscibility between InN and GaN lead to misfit dislocations and stacking faults, also In incorporation decreases with increase in growth temperature. The lower growth temperature of barriers in these MQW's is followed by an increase in V-defects which affect the reliability and the lifetime of the devices. It has been shown that the growth of these barriers at an increased temperature when compared to the growth of the InGaN well will reduce the density of these defects [3]. In this work the effect of barrier width on the defect density and surface morphology of the InGaN / GaN MQWs is reported.

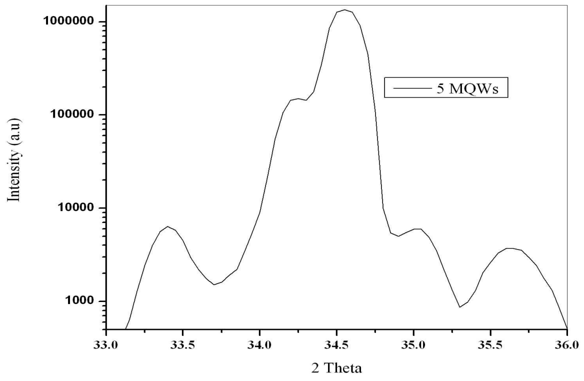
EXPERIMENTAL DETAILS

All the samples are grown on c – plane sapphire substrates using an AIXTRON 200/4 RF – S horizontal metal organic vapor phase Epitaxy (MOVPE) reactor. A thin layer of AlN (~30nm) is used as the buffer layer before the growth of 1.5μm thick n type GaN at higher growth temperature. Trimethylaluminum is used as the precursor during the growth of AlN and Trimethylgallium is used as the precursor for GaN, H_2 is used as the carrier gas and NH_3 as a source for nitrogen during the growth of the above two layers. This was followed by the growth of five periods of InGaN / GaN super lattice structures, Trimethylindium, Triethylgallium and NH_3 are used as the precursors and N_2 is used as the carrier gas, the design of the super lattice structure (Figure 1) and its XRD curve(Figure 2) are shown. The growth temperature is maintained at 720ºC and 740ºC for two different set of growths. The barrier width is varied from 10nm to 5nm at these two different temperatures and the well width is maintained at 10nm. The V / III ratio used for InGaN well and GaN barriers are maintained at 3000 and 9180. AFM and SEM over large areas are used to analyze the structural properties and XRD to deduce the In incorporation and the periodicity of the super lattice structures.



5-period InGaN/GaN super lattice InGaN QW ~10 nm, 20% In , GaN barriers ~ (5 – 10) nm.

Figure 1 – Super lattice design.



Calculated In % was 19% and the thickness of the period was 21nm, which are very close to designed values.

Figure 2 – XRD for the super lattice design in Figure 1.

RESULTS AND DISCUSSION

Figure 3 shows the surface morphologies of InGaN / GaN super lattice structures using a Veeco nanoscope tapping mode AFM over large areas. The data collected over these large areas is used for calculating the defect density and surface roughness with the variation of barrier width and temperature. Figure 4 show the variation of surface roughness with varying barrier width and temperatures.

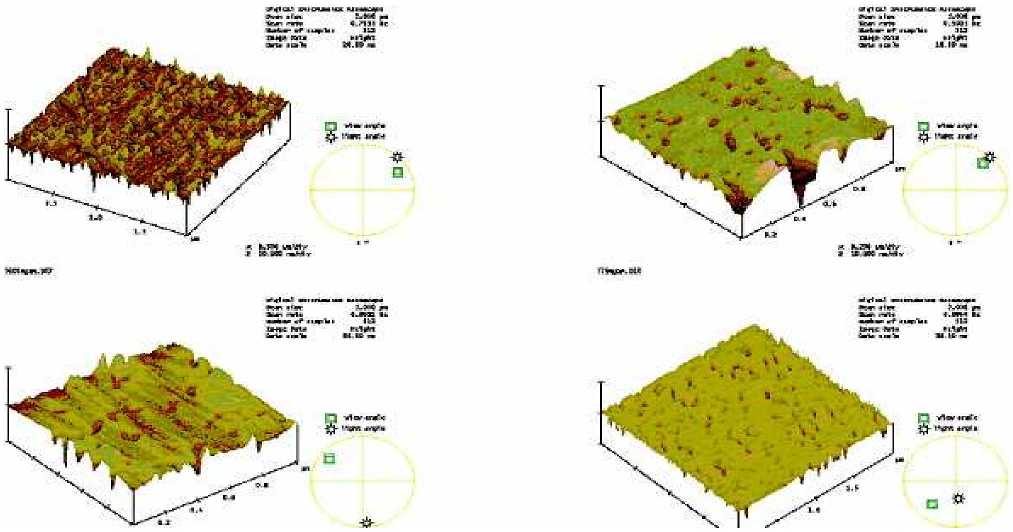


Figure 3 – AFM images of InGaN / GaN super lattices grown at different temperatures

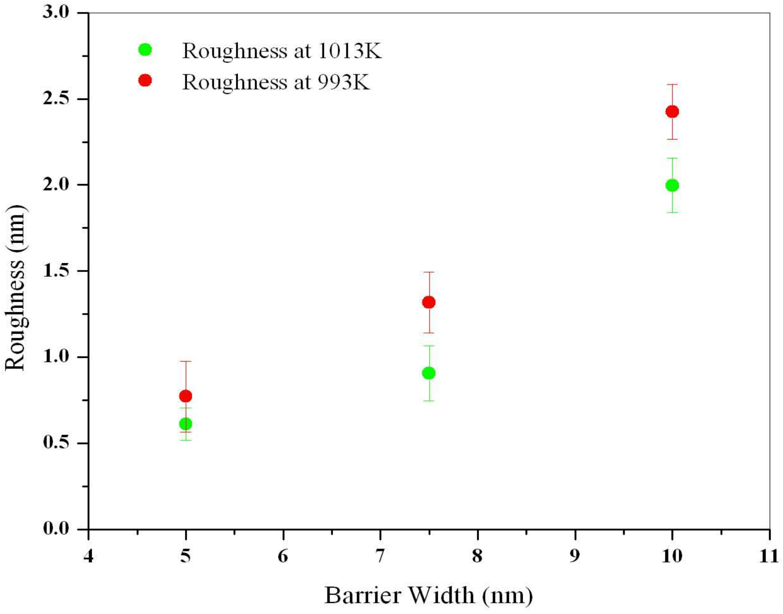


Figure 4 – Roughness as a function of variation in barrier width at two different temperatures.

From Figure 4 it can be seen that with increasing the barrier width, there is an increase in surface roughness and also with increasing the growth temperature there is an improvement of the surface morphology, which agrees with previously reported results [3]. The roughness increase could be attributed to the increase in V – defect depth. Figure 5 shows the effect of barrier width on the defect density at two different temperatures; it can be seen that there is an increase in the defect density with increase in barrier width initially and then there is a decrease. It is also observed that with the increase in growth temperature of the barrier, there is a decrease in defect density.

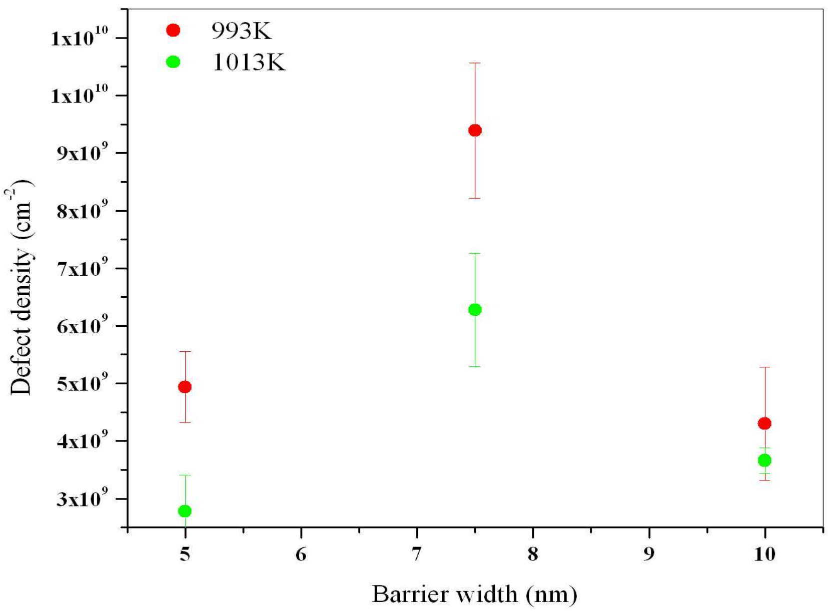


Figure 5 – Defect density as a function of variation in barrier width at two different temperatures

There are a lot of reports on [6, 7, 8] the origin of V – defects during the growth of InGaN / GaN super lattices. Recent work by Florescu et al [3] and Ting et al [3] shows that V – defect formation in MQW structures may be caused by a combination of effects due to barrier growth temperature and formation of In – rich regions within the quantum wells. Chen et al [4] proposed that In segregation around the dislocation cores inhibits the crystal growth leading to pit formation .Wu et al [5] reported that the formation of V – defects is not primarily related to strain relief, but the reduced Ga incorporation in {10-11}planes compared with the (0001) plane. The increase in defect density with increase in barrier width initially can be explained using the strain mechanism as the growth changes from two dimensional to three dimensional resulting in V – defect formation, after this initial increase there is a drop in the defect density with further increase in barrier width. This can be because of the relaxed nature of the super lattice structures and hence a decrease in strain thereby reducing the V – defect density.

It is shown that the barrier width has an effect on both the surface morphology and the defect density of InGaN / GaN super lattice structures. It is believed that by optimizing the growth parameters at low temperatures a reduction in V - defect density can be achieved

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