

# Atomic force microscope study of GaN films grown by hydride vapor phase epitaxy

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## ABSTRACT

We report the results of the investigation of the structural, surface morphological, and optical properties of GaN films grown by hydride vapor phase epitaxy. These films were grown on sapphire substrate with no intentional dopings. These as-grown GaN film samples with thickness ranging from 5.58  $\mu\text{m}$  to 14.9  $\mu\text{m}$  were investigated under room temperature conditions. The surface morphology of these films was investigated using an atomic force microscopy (AFM). The root mean square (RMS) values of surface roughness range from 0.281 nm to 0.133 nm. The thicker films show lower defect counts with a defect density of about  $2 \times 10^8 \text{ cm}^{-2}$ . The structural property of these films was measured by double crystal X-ray diffraction (DC-XRD). The full width at half maximum (FWHM) of X-ray diffraction angle decreases as the film thickness increases with a lowest FWHM of about 265.5 arcsec. The optical properties of these films were investigated by photoluminescence (PL) measurement at room temperature. The results show a dominant near band-edge UV emission peak that increases with the film thickness with very weak yellow emission band.

**Keywords:** GaN, wide bandgap material, hydride vapor phase epitaxy, atomic force microscopy, photoluminescence

## 1. INTRODUCTION

The group-III-nitrides have received much attention recently. Many GaN-based light emitting devices such as blue light emitting diodes and blue laser diodes have been realized<sup>1</sup>. These devices are commonly grown on foreign substrates such as sapphire and SiC because of the lack of availability of GaN substrate. However, due to the large mismatches of lattice constant and thermal expansion coefficient of these substrate and GaN, the GaN device wafer structure epitaxially grown on these foreign substrate generally have poor crystal quality such as high defect density and induced stress and bowing.<sup>2</sup> As a result the reliability of the devices fabricated on these substrates may be affected. For realization of reliable and high performance light emitting devices, it would be most desirable to use the GaN material as substrate. Although the bulk GaN material is not readily available because of the difficulty in the growth of GaN bulk crystal, thick films of GaN materials can be grown using Hydride Vapor Phase Epitaxy (HVPE) method. Therefore, there may be possibility of using HVPE grown thick GaN material as the substrate. In this paper, we report the results of our investigation of the structural, surface morphological, and optical properties of a series of HVPE grown GaN film samples with thickness ranging from 5.58  $\mu\text{m}$  to 14.9  $\mu\text{m}$ .

## 2. EXPERIMENTS AND RESULTS

We investigated the crystal quality of the GaN samples using the double crystal X-ray diffraction (DC-XRD) technique. The DC-XRD rocking curves were recorded and the full width half maximum (FWHM) of this curve was analyzed. Fig. 1 shows a typical rocking curve of a 7  $\mu\text{m}$  thick GaN sample, which has a clean single peak with FWHM of 269.5 arcsec. The FWHM values of all the samples measured vary from 535 arcsec to 269.5 arcsec. The FWHM values show a general decreasing trend as film thickness increases indicating better crystal quality for the thicker film.

The surface morphological properties of GaN films were characterized using atomic force microscopy (AFM). The investigation was conducted under room temperature conditions. We used a Nanoscope multimode AFM with a  $\text{Si}_3\text{N}_4$  tip. The AFM is operated under contact mode by measuring the forces between a probe and the sample. The surface topography is obtained by scanning the tip across the sample with a typical scan area of 1  $\mu\text{m}$  square. Fig. 2 shows a typical AFM image of a 14.9  $\mu\text{m}$  thick GaN sample. As shown in Fig. 2, the growing pattern of GaN film is clearly observable, so are the defects appearing as small dark circular dots. The defect densities estimated from the AFM image to be approximately  $2 \times 10^8 \text{ cm}^{-2}$  for this sample.

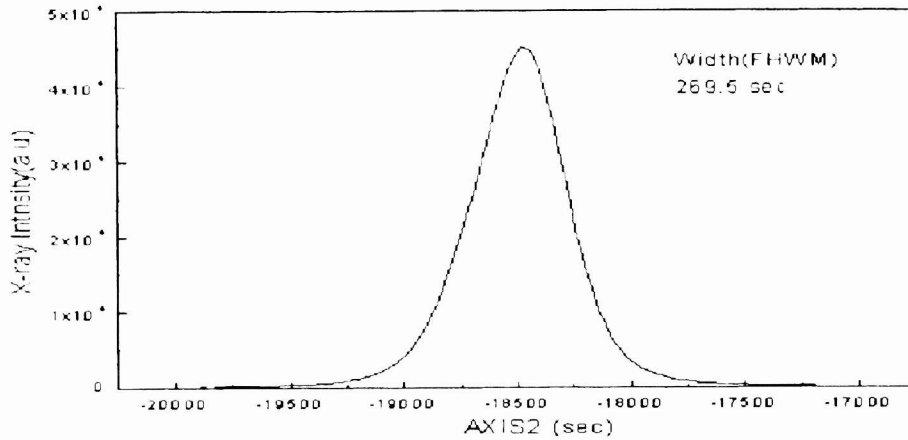


Fig. 1. A typical rocking curve of a 7  $\mu\text{m}$  thick GaN sample.

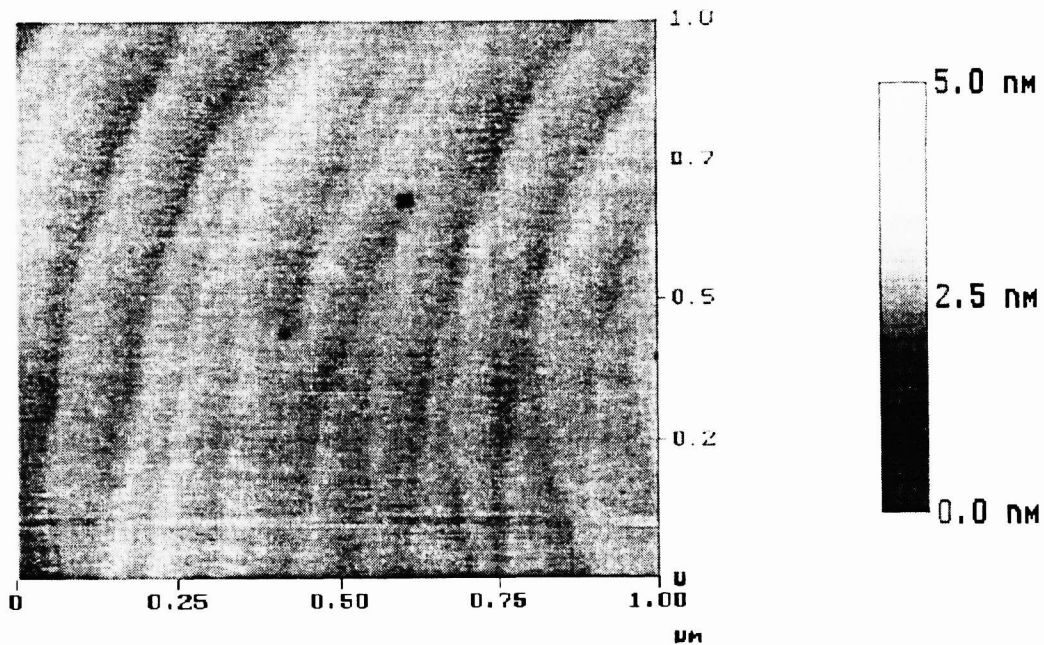


Fig. 2 Plan-view AFM image of a 14.9  $\mu\text{m}$  thick GaN film.

From the AFM images of all the GaN samples, the estimated defect densities vary from  $1.8 \times 10^9 \text{ cm}^{-2}$  to  $2 \times 10^8 \text{ cm}^{-2}$  with lower defect density for the thicker films. These estimated defect densities are either lower or comparable with the reported typical defect density of  $10^8 - 10^{10} \text{ cm}^{-2}$  for the group-III-nitride epilayers.<sup>3-5</sup>

The section analysis was conducted along the surface growth pattern as depicted by the dark line drawn in the AFM image of Fig. 3. We selected the marker positions on the line to obtain the RMS of surface height variation between the two markers. Fig. 3 shows a typical section analysis data of a 7.0  $\mu\text{m}$  thick film along with the AFM image. The RMS value for this sample is 0.16 nm.

Section analysis data were obtained for all different thickness samples and the AFM software performed both section analysis and roughness analysis of the measured data. The root mean square (RMS) values of the surface height roughness analysis and sectional analysis data were obtained for all samples. Fig 4 depicts the RMS variation with the sample thickness. The RMS values of sectional analysis fluctuate between 0.273 nm and 0.113 nm with no apparent correlation with film thickness. The 14.9  $\mu\text{m}$  thick film has the lowest RMS value of 0.113 nm. While the RMS of surface roughness increases from 0.154 nm to 0.281 nm as the film thickness increases except for 14.9  $\mu\text{m}$  thick film which has a lowest value of 0.133 nm.

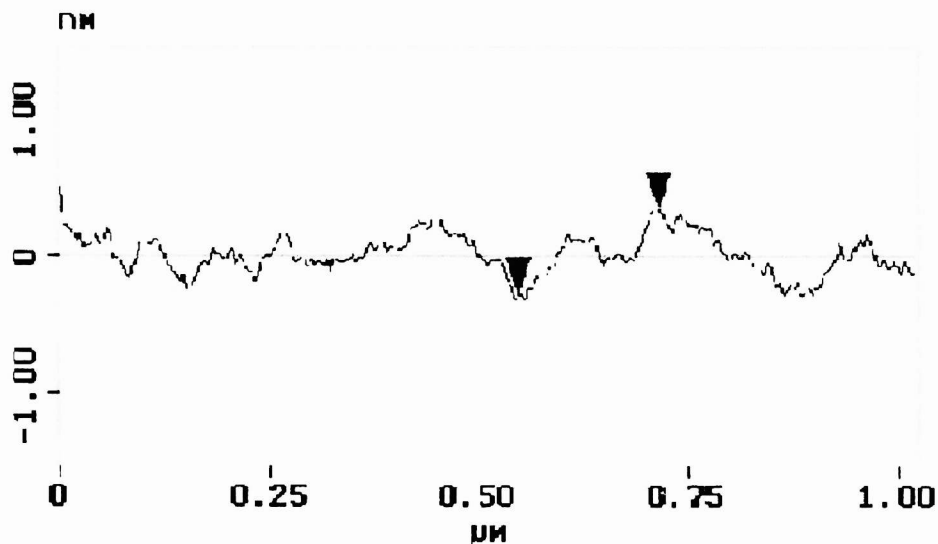
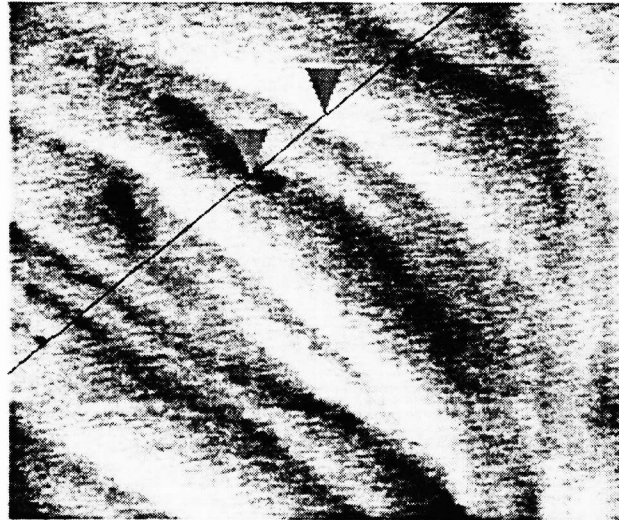


Fig. 3 The section analysis of 7.0  $\mu\text{m}$  thick GaN film.

The optical properties of GaN film samples were investigated by ordinary photoluminescence (PL) at room temperature. A He-Cd 325-nm laser was used as the excitation light source and the experiment was conducted under room temperature conditions. The laser power incident on the sample was about 15 mW. Fig. 5 depicts the PL spectra of the GaN samples with film thickness ranging from 5.58  $\mu\text{m}$  to 14.9  $\mu\text{m}$ . The PL spectrum shows a strong UV emission line at  $363.2 \pm 0.5$  nm and a weak  $370.4 \pm 0.9$  nm line with phonon replicas,<sup>6</sup> and a very weak yellow band fluorescence. The 363.2 nm line seems to correspond to the near-band-edge emission and the intensity of this line increases as film thickness increases. The 14.9  $\mu\text{m}$  thick film almost has an intensity as least three times stronger than the other samples. The FWHM of the UV emission line varies from 4.73 to 7.44 nm with thicker film showing narrower linewidth. The yellow band emission band is very weak compared with the UV emission line indicating relatively good crystal quality of these films.

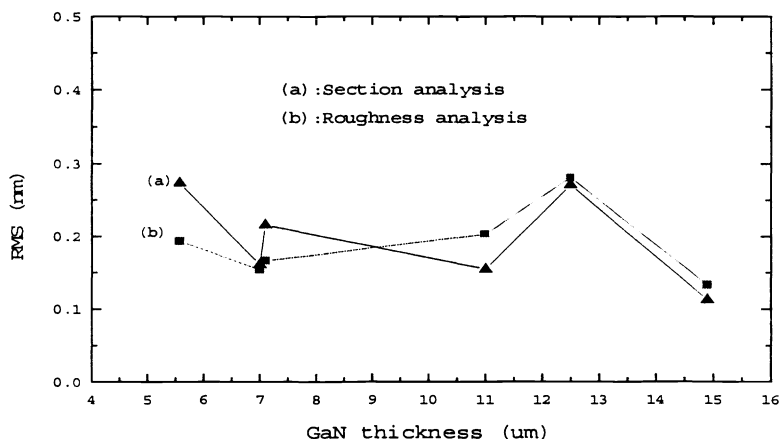


Fig. 4 Variation of RMS values with GaN film thickness.

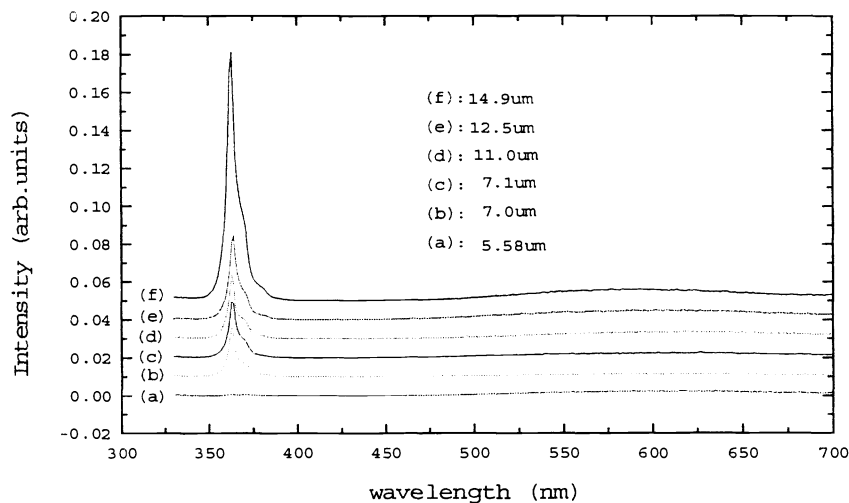


Fig. 5 Room-temperature PL spectra of the HVPE-grown undoped GaN samples.

### 3. CONCLUSION

In conclusion, we have investigated the crystal quality of HVPE grown GaN film samples with thickness ranging from 5.58 to 14.9  $\mu\text{m}$  under room temperature conditions. From the AFM measurement we obtained the RMS values of surface height variation ranging from 0.113 nm to 0.273 nm with the lowest RMS value of 0.113 nm for 14.9  $\mu\text{m}$  film. The RMS of surface roughness increases from 0.154 nm to 0.281 nm as the film thickness increases except for 14.9  $\mu\text{m}$  thick film which has a RMS of 0.133 nm. We also estimated the defect densities of these films and found the thicker films have lower defect density with a defect density of  $2 \times 10^8 \text{ cm}^{-2}$  for 14.9  $\mu\text{m}$  thick film. From the double crystal X-ray diffraction measurement data, we observed that the thicker the film, the more perfect is the crystal quality of the film. All the samples show a dominant near-band-edge UV emission with very weak yellow emission band indicating relatively good crystal quality of these films. Based on these preliminary investigation results we found the HVPE grown GaN films possess relatively good crystal quality that could be a promising substrate material for epitaxial growth of GaN devices structures.

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