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Structural and Electrical Characterization of GaN Thin Films on Si(100)

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Abstract

The Gallium Nitride (GaN) layers grown on silicon substrates by electron beam evaporation technique. X-ray diffraction revealed that polycrystalline GaN was obtained indicating the enhance crystallinity of the films with annealing temperature at 600˚C. Crystalline quality of the GaN films was determined by Scanning Electron Microscopy (SEM). The crystalline size increases with increasing annealing temperature. The fabricated MIS structures were characterized using Capacitance-Voltage (C-V) measurements, the capacitance remains nearly constant over a large range in higher negative as well as over a large range in higher positive gate voltages and Current-Voltage (I-V) measurements shows low forward and reverse current possibly due to high density defect formation in the thin layer of gallium nitride during its growth.The film is characterized by X-Ray photoelectron spectroscopy (XPS). The XPS spectra show that formation of pure GaN without presence of elemental gallium and Ga_2O_3 in this film.

Keywords: Electron Beam Evaporation Technique, GaN Thin Film, C-V, I-V

1. Introduction

GaN (Gallium Nitride) have attracted interest due to their wide and direct band gap and their potential application to blue-ultraviolet light emitting devices, short-wavelength optoelectronic devices and high-power electrical devices [1]. Silicon is increasingly being used as a substrate for GaN growth [2,3] GaN deposited on silicon (Si) substrates has great advantages including excellent wafer quality, less hardness and more design flexibility with current silicon electronic circuit system [4-6]. The Si substrate for GaN growth has some advantages over other substrates. It can be obtained at low cost and the well developed Si growth technology ensures high quality p- and n-type Si wafers. Furthermore, the hetero-epitaxial system of GaN on Si substrate can potentially combine the optoelectronic properties of GaN with those of highly advanced Si electronic devices. Direct growth of a GaN film on Si substrate results in either polycrystalline growth or a substantial diffusion of Si into the GaN film. Direct growth of a GaN film on Si substrate results in either polycrystalline growth or a substantial diffusion of Si into the GaN film. Thin AlN films have been used as buffer layers for GaN growth on Si substrate [7,8]. Threading dislocations and inversion domain boundaries usually form at the early stage of growth and then propagate through the film surface [9]. The initial growth mode and microstructure strongly depend on types of buffer layers [10-13], growth conditions, and growth methods [14-19]. Until now, little effort has been made to study the initial growth of GaN under different growth conditions.

2. Experimental Details:

The GaN thin films were grown on Si(100) substrates by using electron beam evaporation method. Si(100) was chosen due to its trigonal symmetry favoring epitaxial growth of the GaN(0001) plane. The substrate was cleaned by 5% HF solution prior to the epitaxial growth. After a chemical cleaning process, the Si(100) substrate was heated to 1000˚C under hydrogen ambient for 10 min to produce a clean, oxide-free surface to prevent the melt back etching of Si substrate.

The filament is used to activate the nitrogen gas and e-beam for evaporating gallium, water circulation is used for cooling purposes in a reaction chamber. The substrates are kept at a distance of 10 cm above the gallium source which is evaporated by electron beam. There is a tungsten filament heated at 2000˚C by a dc supply in between gallium source and the substrates to activate the nitrogen gas the nitrogen gas is directed on to the hot filament. The GaN experimental samples were grown at room temperature, 300˚C and 600˚C. The thickness of thin film GaN was 250 nm, The contact of as-grown sample was deposited by e-gun evaporator. The annealing process was carried out at 800˚C for 2 minutes to activate the sample and to provide the contact ohmic. The constant pressure 7 × $10^{–5}$ Torr was maintained through out the deposition. The gallium was evaporated using an e-beam of energy and current 100 mA. About 200 nm thick film of GaN were deposited on Si at the rate of 0.2 nm/s. Thickness was controlled by using a water cooling arrangement.

3. Result and Discussion

Figure 1 shows the X-ray diffraction (XRD) spectra of the GaN layer grown on Si substrates. The pattern for film grown at 300˚C only reveal substrate peaks at 33.2° and 69.3˚ which correspond to Si(200) and Si(400) planes respectively. No X-ray diffraction peak corresponding to the crystalline phase of GaN was detected, suggesting an amorphous structure.

For the GaN film grown at 600˚C, weak peak was observed at 34.4˚ which corresponds to (002) hexagonal wurtzite crystalline GaN. X-ray diffraction peaks observed for GaN is in good agreement with JCPDS data of the hexagonal crystalline GaN. The presence of strong and sharp GaN crystalline peaks were observed with increasing annealing temperature, the measured diffraction peaks do not change significantly, but the intensity of these peaks becomes greater and sharper. This is due to the crystallite sizes becoming larger with evaluating the annealing temperature, these films are a mixed phase of crystalline and amorphous structure. This is probably a signature of the microcrystalline phase for GaN. The crystalline (grain) size determined is about 167 nm, thus confirming the microcrystalline structure of the films.

Figure 2(a) shows the surface morphology of the samples by using SEM, there are small grains in the film annealing at 300˚C. This indicates that the mobility of Ga atoms is not large enough to make the grains grow large, so the crystallite size is limited by the diffusion length of Ga atoms. **Figure 2(b)** shows the pattern of the film that was grown at 600˚C. It can be seen that the crystalline size is larger than that of films shown in **Figure 2(a)** This is because the mobility of Ga atoms becomes larger with the increasing annealing temperature, thus it is possible to form larger grains. In the same way, the grains shown in **Figure 2(b)** are much larger than those in **Figure 2(a)** due to the higher annealing temperature. The grain size of the films is found to be about 200 nm in **Figure 2(b)**.

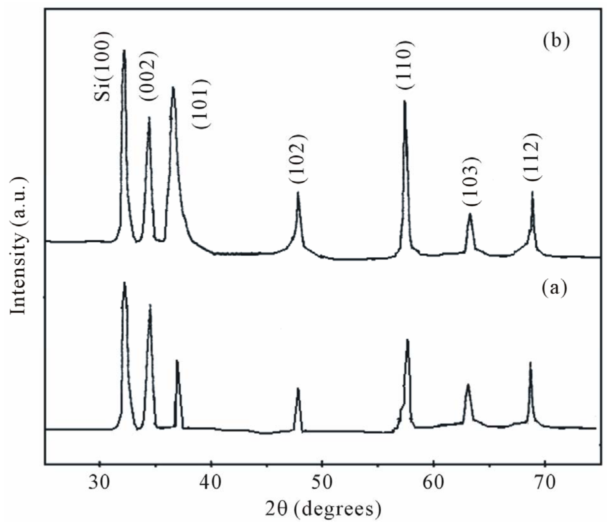
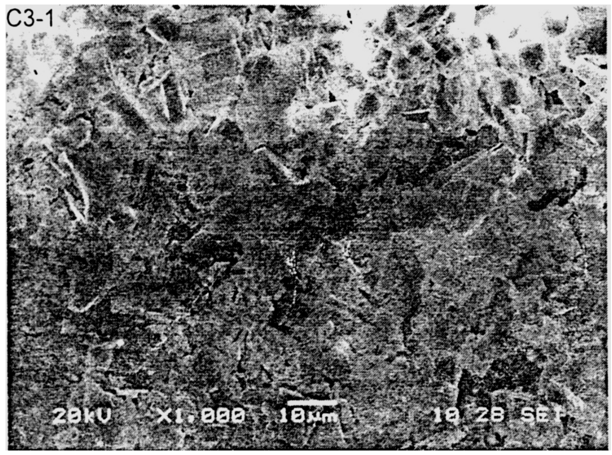
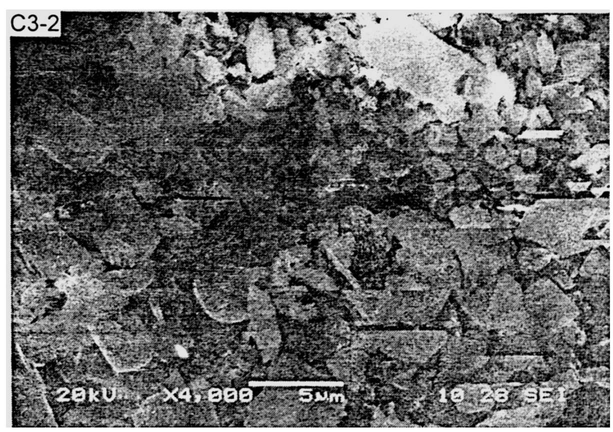


Figure 1. XRD Spectra of GaN thin film on Si (100) substrates annealed at (a) 300˚C and at (b) 600˚C.



(a)



(b)

Figure 2. SEM micrograph of GaN thin film annealed at (a) 300˚C and at (b) 600˚C.

Figure 3 shows FTIR pattern for the sample (nitridated at 600˚C, 8 h) a clear absorption peak at 600 cm^{-1} due to GaN bond stretch was presented. It has been reported that GaN absorbs infrared light at near 1100 cm^{-1} with shoulder at 1200 cm^{-1} due to Si-O bond stretching vibration and at 816 and 446 cm^{-1} due to ring structure. All the above I R absorptions of pure Si are identified in the spectrum of composite at 1220, 900, 600 and 460 cm^{-1} respectively. No other strong peaks were presented in the pattern. It indicated that the element Ga dominantly existed with Ga-N bond in the samples.

4. Electrical Characterization

Figure 4 shows the capacitance-voltage (C-V) measurements of the fabricated MIS structures at room temperature, 300˚C and 600˚C on the GaN thin film deposited at 650˚C. It is observed that, the capacitance remains nearly constant over a large range in higher negative as well as over a large range in higher positive gate voltages indicating a formally pinned surface. However, the capacitance was found to be higher in the negative but lower in the positive gate voltage. Further the capacitance was found to be higher for the thin film GaN at 300˚C in both the zones. The sudden decrease in capacitance at 0 V is due to defect density in the film and also due to the semiconductor fermi level is not properly pinned at the interface. These measurements demonstate that the Al/GaN/Si(111) system possesses the charge control needed for insulated gate field effect transistor operation with a higher dielectric constant.

In this study, Current -Voltage (I-V) measurements were made on MIS structure fabricated by evaporating 2000A˚ of Al on GaN layers deposited on Si(100) substrate. **Figure 5** shows the results of a typical measurement performed at 300˚C. The Current-Voltage characteristics shows low forward and reverse current possibly

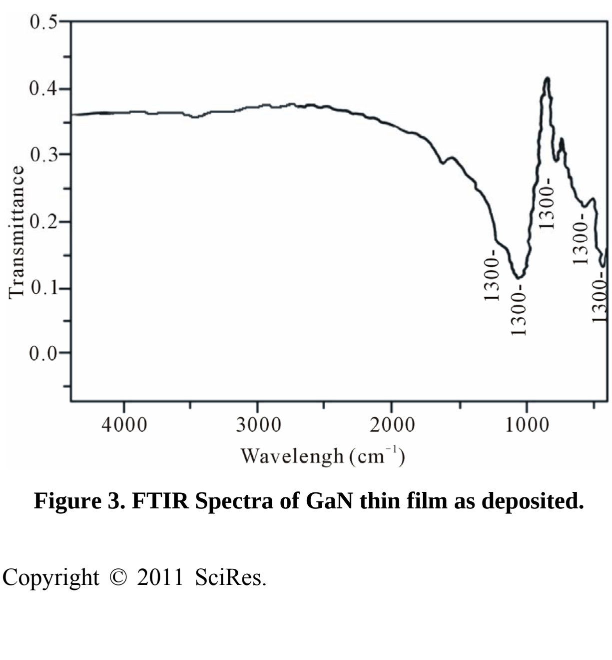


Figure 3. FTIR Spectra of GaN thin film as deposited.

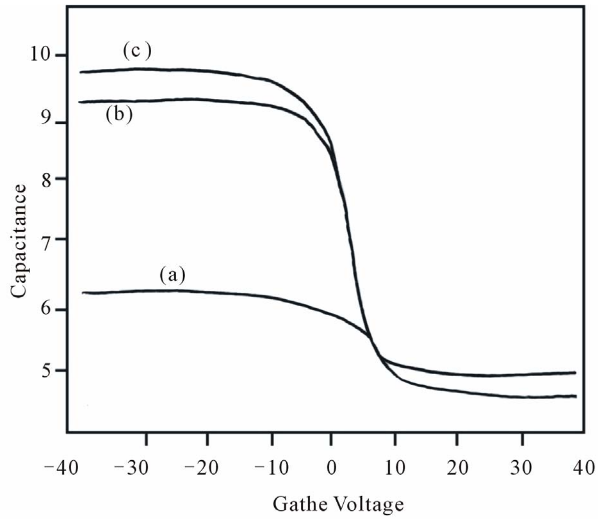


Figure 4. C-V characteristics of GaN thin film on Si at different temperature (a) as deposited (b) at 300˚C (c) at 600˚C.

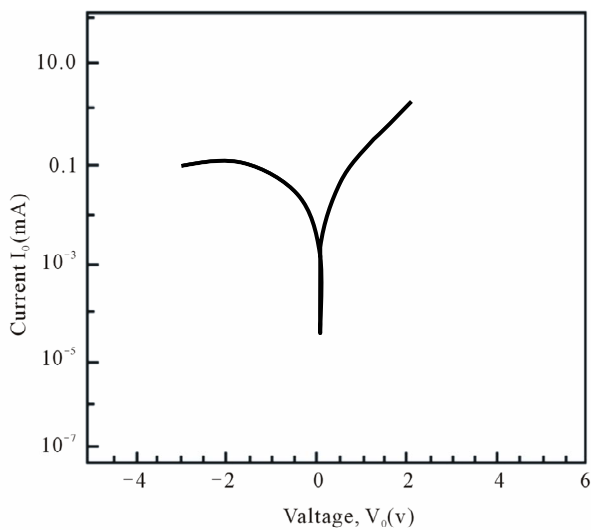


Figure 5. The I-V characteristics of GaN thin film at 300˚C.

due to high density defect formation in the thin layer of gallium nitride during its growth. The leakage current is high at 300˚C, had not damaged the sample. The actual nature of the metal-semiconductor contact is not controllable and in fact may vary substantially from one process to another.

Figure 6 shows the room temperature photoluminescence spectra of GaN film which was annealed at 300˚C. The PL spectrum shows an emission at 353 nm (3.5 eV) for room temperature measurement. The resulting film exhibits a blue-shift in the optical band gap relative to GaN (3.4 eV). It may be explained by quantum confinement model [20]. Both the optical excitation and recombination take place in the nanometer grain, and the energy gap of the grain is enlarged due to the quantum con-

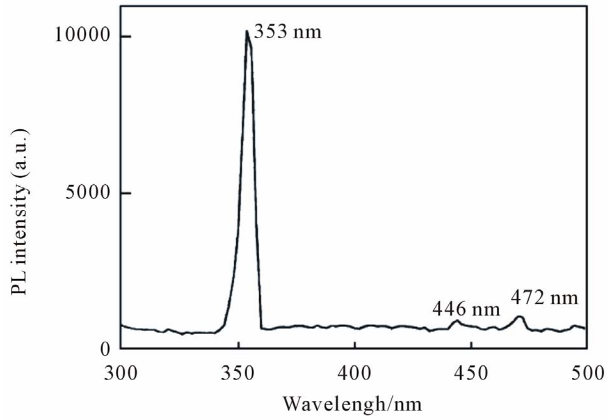


Figure 6. The photoluminesce spectra of GaN.

finement effect. In addition, two other emissions can be observed, which peaked at 446 nm and 472 nm respecttively. The 446 nm peak results from radiative recombinations related to the tail region, and the other peak comes from localized states which are attributed to deep traps like nitrogen vacancies [21].

Figure 7 shows the X-ray photoelectron spectra of N 1s, Ga 2p and Ga 3d for films grown at the annealing temperature of 600˚C. As can be observed, the N 1s signal shown in **Figure 7**(a) contains a main peak centered at 397.5 eV. The width and slight asymmetry of the N 1s peak is attributed to the possible presence of nitrogen in GaN [22]. Ga $2p_{3/2}$ and Ga $2p_{1/2}$ peaks are shown in **Figure 7(b)** with binding energies of 1117 and 1143.2 eV respectively. The core level values of gallium were found to have a positive shift with respect to elemental gallium. Dinescu *et al.* [23] and Elkashef *et al.* [22] have reported the values of the Ga $2p_{3/2}$ peak at 1117 eV and 1119.2 eV in their GaN films respectively. **Figure 7(c)** shows Ga 3d spectra for the films. No bond formation between Ga and O was observed since the Ga 3d spectrum did not show any peak corresponding to Ga_2O_3 as reported by Ishikaua *et al.* [24]. The above results confirm the formation of pure GaN without the presence of elemental gallium and Ga_2O_3 in this film.

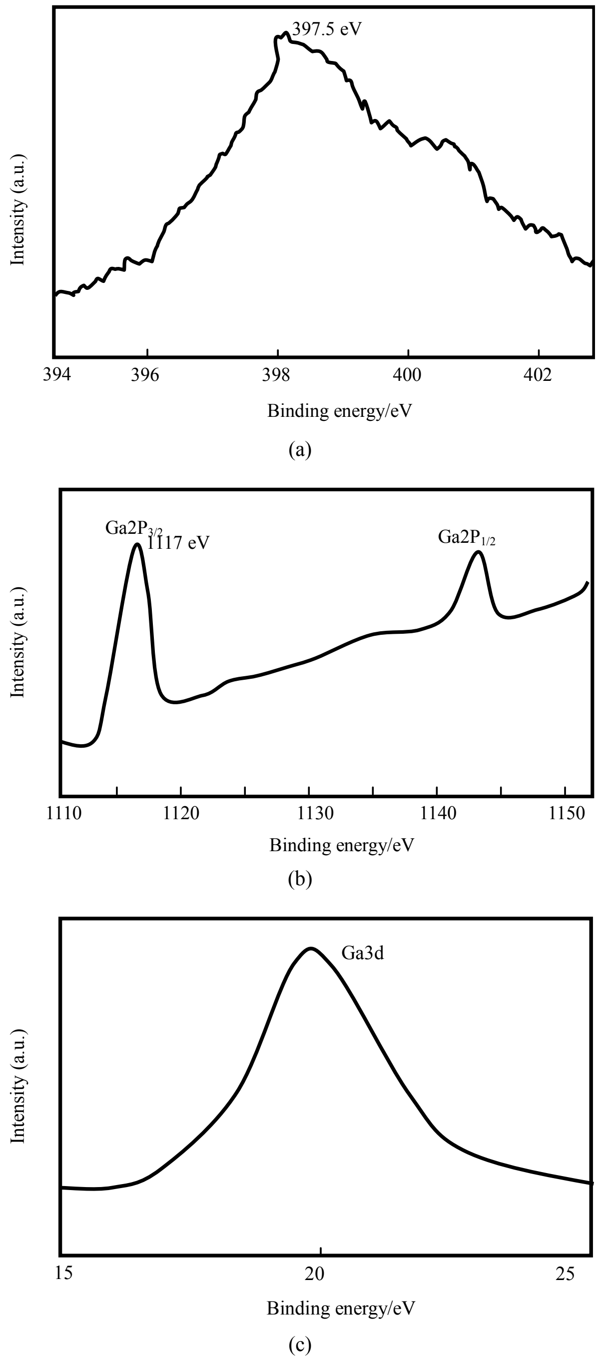


Figure 7. It shows the XPS spectra of GaN thin film on Si (a) N 1s; (b) Ga 2p; (c) Ga 3d peaks for the film.

5. Conclusions

GaN thin film has been deposited on Si (100) by using electron beam evaporation method. The GaN/Si (100) structures were studied by structural and electrical characteristics. The XRD and SEM of GaN/Si(100) indicates the enhance crystallinity of the films with annealing temperature at 600˚C. The C-V measurement of GaN thin film deposited on Si(100) annealed at 600˚C shows large frequency dispersion in the accumulation region. The Current-Voltage (I-V) measurement shows low forward and reverse current possibly due to high density defect formation in the thin layer of gallium nitride during its growth. The XPS spectra show that formation of pure GaN without presence of elemental gallium and Ga_2O_3 in this film.

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