Influence of N$_2$ Gas Pressure on the Structural Properties of Sputter-deposited GaN Thin Films

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GaN thin films were deposited on Si (100) substrates at room temperature by RF magnetron sputtering of a GaN target in a pure N$_2$ gas whose pressure ranged between 7 and 50 mTorr. The influence of N$_2$ gas pressure on the structural properties of the deposited GaN films was systematically investigated. The crystalline structure in the GaN films changed from wurtzite to zinc-blende as the N$_2$ gas pressure was reduced from 50 to 7 mTorr. The observed change in crystalline structure was found to correlate strongly with the changes in the microstructure, surface topography, and internal stress of the GaN films. The microstructure of the GaN films changed from a voided columnar structure having a rough surface to an extremely condensed structure with a very smooth surface morphology as the N$_2$ gas pressure was decreased. The internal stress of the GaN films was slightly tensile (~0.34 GPa) at 50 mTorr and became increasingly compressive upon decreasing the N$_2$ gas pressure, reaching a value of ~3.08 GPa at 7 mTorr. The above experimental results show that the N$_2$ gas pressure plays a crucial role in determining the crystalline structure, microstructure, surface topography, and internal stress of the sputter-deposited GaN films.

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I. INTRODUCTION

GaN has been the focus of extensive research efforts due to its unique properties, including wide direct bandgap, high thermal conductivity, high peak and saturation velocities, high electrical breakdown field, and thermal, mechanical, and chemical robustness [1]. GaN has a number of applications for the fabrication of a wide range of optoelectronic devices, such as blue and UV light-emitting diodes and lasers, UV detectors, and electronic devices for high-power, high-temperature, and high-frequency operation [1,2]. In addition, when doped with rare-earth elements, GaN emits light ranging from UV through visible to near-IR, which makes it attractive for applications in full-color flat-panel displays and fiber-optic telecommunications [3,4]. Also, GaN is one of the most prominent candidates for spintronics applications because of its ferromagnetic behaviors at room temperature when doped with transition and rare-earth metals [5].

GaN films have been grown by using many different methods, such as metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), and hydride vapor phase epitaxy (HVPE). Sputtering has also been used for the deposition of GaN films. The main advantage of sputtering is the relative ease of process control and scale-up to a larger apparatus. The GaN films prepared by sputtering exhibit a wide range of properties that strongly depend on the preparation conditions [6,7]. In sputter deposition, gas pressure is one of the most important process parameters in determining the final film’s characteristics. However, the effect of gas pressure on the film properties in the deposition of GaN by sputtering has not yet been thoroughly investigated. Therefore, we report here a detailed study of sputter-deposited GaN films, with main emphasis on the influence of the N$_2$ gas pressure on the structural properties of the GaN films. The crystalline structure of sputter-deposited GaN films has been previously observed to change with varying N$_2$ gas pressure [8]. However, the correlation between N$_2$ gas pressure and film’s characteristics such as microstructural and morphological properties was insufficient in the previous study. In this paper, we present the results obtained over an extended range of pressure and discuss the detailed changes in crystalline structure, microstructure, surface topography, and internal stress of the sputter-deposited GaN films as a function of the N$_2$ gas pressure.

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II. EXPERIMENTS

Thin films of GaN were deposited by RF magnetron sputtering of a GaN target in a pure N\textsubscript{2} gas. The substrates were (100)-oriented p-type Si wafers. No intentional substrate heating was employed, and the Si (100) wafers were placed on a water-cooled stainless-steel susceptor during the film’s deposition. The sputtering chamber was evacuated to a base pressure of around 1 × 10\textsuperscript{−7} Torr. High-purity N\textsubscript{2} gas was then introduced into the sputtering chamber by using a mass flow controller (MFC). The RF power input to the GaN target was kept constant at 15 W, and the N\textsubscript{2} gas pressure was adjusted between 7 and 50 mTorr. The thickness of the GaN films for all the samples was in the range of 500 nm.

A JEOL JSM 6335F field-emission scanning electron microscope (FESEM) was used for the study of the cross-sectional microstructure. The surface topography of the deposited GaN films was examined by using atomic force microscopy (AFM) with a Nanoscope III system from Digital Instruments, Inc. The crystalline structure of the GaN films was investigated by using an X-ray diffraction (XRD) analysis with a Philips PW 1729 diffractometer. The phase identification was achieved by comparison with data from the Joint Committee on Powder Diffraction Standards (JCPDS) cards [9]. The internal stress of the GaN films was measured at 23\textdegree C by determining the bending of the Si (100) substrate before and after the film’s deposition. The internal stress, \(\sigma\), was then obtained from the formula

\[
\sigma = \frac{E_s t_s^2}{6(1 - \nu_s)} t_f \frac{R}{R_f},
\]

where \(t_s\) and \(t_f\) are the Si substrate’s and the GaN film’s thicknesses, respectively. \(E_s\) and \(\nu_s\) are Young’s modulus and Poisson’s ratio of the Si (100) substrate, respectively. \(R\) is the net change in the radius of curvature of the Si substrate before and after deposition.

III. RESULTS AND DISCUSSION

Figure 1 presents the XRD scans collected from the GaN films deposited on (100)-oriented Si substrates as a function of N\textsubscript{2} gas pressure. The diffraction intensities are expressed on a logarithmic scale. Figure 2. XRD pattern of the GaN films deposited on Si (100) substrates at 17 mTorr. A peak deconvolution was performed to show the details of separation between the wurtzite (0002) and the zinc-blende (111) peaks. The open circles correspond to the experimental data points whereas the dashed lines represent the deconvoluted components. The sum of the deconvoluted components is marked by the solid lines.

In Fig. 1, when the N\textsubscript{2} gas pressure is decreased, the intensity of the wurtzite (10 \textup{1} 1) peak is seen to decrease and finally to become undetectable for the GaN films deposited at pressures \(\leq 10\text{ mTorr}\). As can also be seen