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Low temperature growth of *c*-axis oriented AlN films on γ-$LiAlO_2$ by radio frequency magnetron sputtering

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Abstract

Aluminum nitride (AlN) films were prepared on γ-$LiAlO_2$ substrates by radio frequency (rf) magnetron sputtering. The influence of substrate temperature (T_s) and nitrogen (N_2) concentration on film growth was investigated. The X-ray diffraction (XRD) results reveal that highly *c*-axis oriented AlN films can be obtained in the temperature range from room temperature (RT) to 300 °C. A smoother surface and a crystalline quality decrease with increasing N_2 concentration have been observed by XRD and atomic force microscopy (AFM) for the films deposited at lower substrate temperature. On the contrary, the degradation of the surface smoothness and the higher crystalline quality can be observed for the films deposited at a higher substrate temperature with N_2-rich ambient. The growth mechanism which leads to different crystalline quality of the films is discussed.

Keywords: Aluminum nitride; Magnetron sputtering; γ-$LiAlO_2$ substrate; XRD; AFM

1. Introduction

In recent years, AlN has become a rising star among III–V compounds for a series of specific properties, such as a direct and wide band gap (6.2 eV), high thermal conductivity (285 W/mK), high velocity of acoustic waves, high chemical and thermal stability, etc. [1–3]. Based on its excellent properties, AlN is a promising material for fabrication of deep ultraviolet light emitting diode, short wavelength light detectors and surface acoustic wave devices, etc. [3–5]. AlN films can be grown on sapphire by metal organic chemical vapor deposition [6,7] or molecular beam epitaxy [8–10] at high growth temperature. The crystalline quality of AlN films is deteriorated by threading dislocations which usually originate from the large lattice mismatch and the thermal expansion coefficient discrepancy between AlN and sapphire. So growth of AlN films on small lattice mismatched substrate at relative low temperature gradually attracts people's attention. Ueno et al. [11] reported that reducing the growth temperature to 300 °C led to a remarkable improvement in crystalline quality and surface morphology of AlN film grown on ZnO $(0\,0\,0\,\bar{1})$ substrates by pulsed laser deposition. Kim et al. [12] studied the epitaxial growth mechanisms of AlN on SiC substrates at room temperature (RT). However, few work has been done in AlN growth on small lattice mismatched substrate γ-$LiAlO_2$. γ-$LiAlO_2$ is a promising substrate material for heteroepitaxy of GaN [13]. The atomic arrangement of γ-$LiAlO_2$ (1 0 0) plane is very close to hexagonal lattice, the lattice mismatch between γ-$LiAlO_2$ (1 0 0) and AlN (0 0 0 2) is about 1%. Fig. 1 shows the atomic arrangement of γ-$LiAlO_2$ (1 0 0) and AlN (0 0 0 2) plane.

In this article we report *c*-axis oriented AlN films growth on γ-$LiAlO_2$ (1 0 0) substrate at low temperature by rf magnetron

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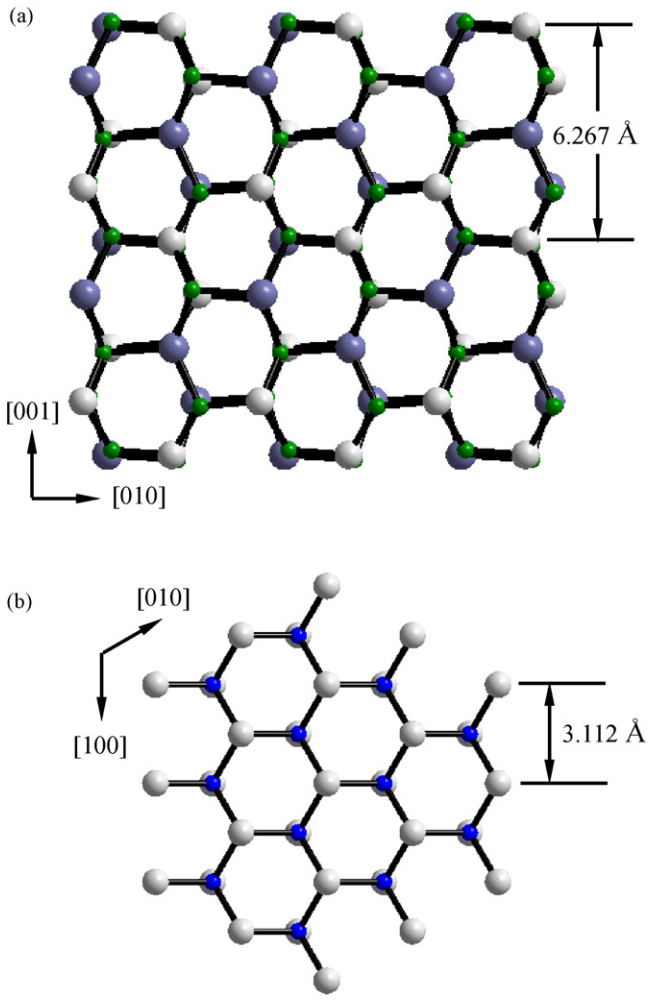

Fig. 1. Surface meshes of (a) γ-$LiAlO_2$ (1 0 0), Li atoms are indigo, Al atoms are gray, O atoms are green, (b) AlN (0 0 0 2), N atoms are blue, Al atoms are gray. Note that the lattice constant in *a* direction of AlN is nearly a half of that of γ-$LiAlO_2$ in *c* direction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

sputtering. The purpose of this work is to investigate the possibility for applying γ-$LiAlO_2$ substrate in epitaxy of AlN films. The dependence of crystallization and surface morphology on various sputtering conditions, such as substrate temperature and nitrogen concentration (N_2/Ar + N_2), were investigated and discussed.

2. Experiments

The AlN films were deposited on γ-$LiAlO_2$ (1 0 0) substrate by rf magnetron sputtering technique in a simple sputtering chamber. A water-cooled aluminum nitride ceramic target was employed with 2 in. in diameter and 99.99% in purity. 10 mm × 10 mm γ-$LiAlO_2$ (1 0 0) wafers were used as the substrate. After the chamber was evacuated to the level better than 2×10^{-6} Torr, high-purity Ar gas (99.999%) or Ar + N_2 (99.999%) mixture controlled by mass flow controllers was introduced into the chamber. And the chamber pressure was maintained at 60 mTorr. Before the deposition process, the aluminum nitride target was sputtered at the same deposition conditions for about 10 min with the substrate covered by a shutter to remove the surface impurity. Then the deposition was started and lasted for 1 h. The sputtering parameters are shown in Table 1.

The crystalline structure and the crystallographic orientation of the films were characterized by a Rigaku D/max 2200 X-ray diffractometer using Cu Kα radiation. The crystalline quality of the films was determined through the (0 0 0 2) rocking curve. The thickness of the films was measured by a stylus instrument. The surface morphology and the surface roughness of the AlN films were recorded by atomic force microscopy (AFM) (Veeco NanoScope IIIa MultiMode) in the contact mode.

Table 1
Specific parameters used for sputter deposition of AlN films

Base pressure (Torr)	$<2 \times 10^{-6}$
Sputtering pressure (mTorr)	60
rf power (W)	50
Ar gas flow rate (sccm)	21.2
N_2 gas flow rate (sccm)	0–3.7
Substrate temperature (°C)	25–300
Substrate to target distance (mm)	50
Sputtering time (h)	1

3. Results and discussion

Fig. 2(a)–(c) shows the X-ray diffraction (XRD) patterns of AlN thin films deposited without using N_2 gas at various substrate temperatures (T_s: RT, 100 °C and 300 °C). From these figures it is observed that AlN (0 0 0 2) and AlN (0 0 0 4) diffraction peaks appear at $2\theta \sim 36.5°$ and $2\theta \sim 77.5°$, respectively, because the films grows with a small tilt (∼0.23°) toward the γ-$LiAlO_2$ *c*-axis, similar results were obtained in some study in GaN growth on γ-$LiAlO_2$ substrate [14]. In addition, peaks of some oxide at $2\theta \sim 31.2°$ appear due to the relative low base vacuum degree. Even so, it still suggests that AlN can grow with preferred *c*-axis orientation on γ-$LiAlO_2$ substrate in the investigated temperature range (RT to 300 °C). However, in some studies AlN is hard to crystallize under certain conditions at

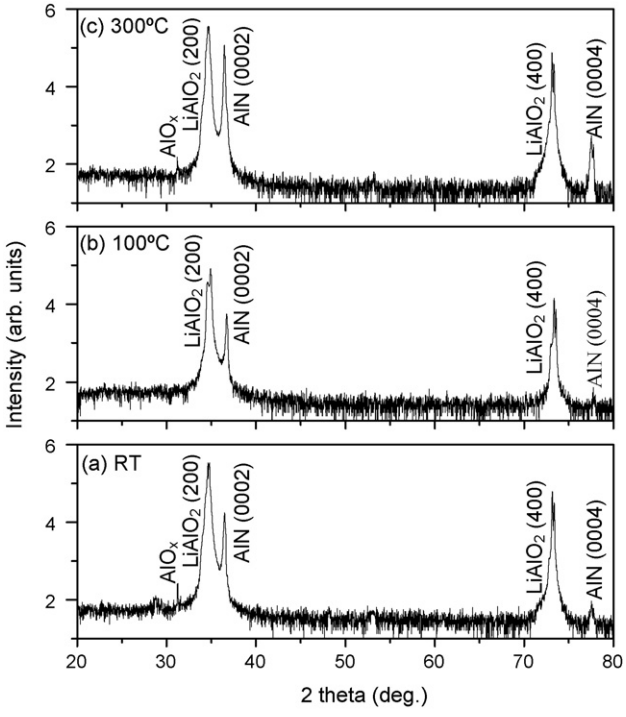

Fig. 2. XRD patterns of AlN films deposited with N_2 concentration = 0% at (a) T_s = RT, (b) T_s = 100 °C, and (c) T_s = 300 °C.