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Influence of the nitrogen fraction on AlN thin film deposited by cathodic arc ion

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ABSTRACT

Thin films of aluminum nitride (AlN) have been grown, using the cathodic arc ion deposition technique. The effects of nitrogen fractions in the discharge on synthesized films growth rate, stoichiometric ratio (N/Al), crystal orientation and molecular mode of vibration have been investigated. AlN films have been studied by means of Rutherford backscattering (RBS) spectroscopy, X-ray diffraction (XRD), Fourier transforms infrared spectroscopy (FTIR), scanning electron microscope (SEM) and the four probe method. In RBS results, it has been found that growth rate and stoichiometric ratio decrease while reducing the nitrogen content in the synthesized chamber. XRD patterns indicated that films prepared in 100–85% nitrogen condition exhibit mixed phase of wurtzite+FFC, with preferential orientation along (002) corresponding to the hexagonal phase. It also demonstrated that at lower nitrogen environment, the transformation from mixed phase of wurtzite+FCC to a single phase of FCC–AlN occurs. FTIR spectroscopic analysis was employed to determine the nature of chemical bonding and vibrational phonon modes. Its spectra depicted a dominant peak around 850 cm^{-1} corresponding to the longitudinal optical (LO) mode of vibration. A shift in the LO mode peak toward lower wavenumbers was noticed with the decrease of nitrogen fraction, illustrating the decline of nitrogen concentration in the deposited AlN films. The 75% nitrogen fraction appeared critical for AlN film properties, such as shifting of mixed (wurtzite+FCC) phase to single FCC–Al(N), a sharp drop of stoichiometric ratio and deposition rate. Measurements of resistivity recorded by the four probe method depicted a sharp decline in the corresponding growth condition.

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1. Introduction

Aluminum nitride (AlN) thin film with a wurtzite crystalline structure is of immense scientific importance due to its distinctive properties. AlN thin film, being a piezoelectric material with a high acoustic velocity, is a superior applicant for high frequency devices, like surface acoustic wave (SAW) devices, resonators, high frequency filters and pressure sensors working in an aggressive environment [1–3].

AlN thin films have been prepared by several deposition techniques including chemical vapor deposition [4], reactive evaporation [5], molecular beam epitaxy [6,7], ion beam-assisted deposition [8], metal organic chemical vapor deposition [9] and reactive sputtering [10]. In most of these deposition techniques, process temperature is quite high, which limits the choice of substrate and may cause film deterioration due to thermal stress [11]. Cathodic arc ion, like magnetron sputtering has the advantage of low temperature and conformal coating process. However, the former

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technique has the advantages of high throughput and considerable quantities of ions rather than neutral species of the cathode material. A disadvantage is the production of cathode material macro-particles in the cathodic arc ion process [12].

The development of c-axis orientated AlN films is important for surface acoustic wave devices owing to its piezoelectric property. The process parameter such as the nitrogen gas fraction plays an important role in the orientation of the AlN film [13] and is not yet fully exploited, particularly in a cathodic arc ion process. In the present work, (002) oriented AlN thin films have been prepared by cathodic arc ion deposition technique. Nitrogen gas fraction: $N_2/(Ar+N_2)$% was varied and the subsequent dependency of material characteristics has been investigated. Characterizations of the deposited AlN films have been performed using Rutherford backscattering (RBS) spectrometry, X-ray diffraction (XRD), Fourier transformed infrared spectroscopy (FTIR), scanning electron microscope (SEM) and the four probe method.

2. Experimental

Cathodic arc ion technique was employed for the growth of aluminum nitride thin films. Deposition was made in a commercial cathodic arc ion system having dual cathodes and Kaufman ion sources as shown in a schematic diagram of Fig. 1. The base pressure of 10^{-4} Pa was obtained in the deposition chamber using a turbo-molecular pump. Two aluminum discs (purity: 99.99%) were simultaneously used as targets. The distance between the two targets was 120 mm. To obtain higher throughput of depositing species/particles, both targets were utilized. Samples were deposited without heating the substrates during film growth. During deposition, the substrate temperature was measured with the help of a thermocouple inserted through a ceramic tube that was screwed to the bottom of the substrate holder. Glass substrates were used for thin film growth. Substrates were ultrasonically cleaned in trichloroethylene for about 15 min with subsequent rinsing in de-mineralized water and acetone.

To avoid/minimize contamination of growing films by oxygen and other impurities, a three-stage procedure was adopted. First, the chamber was evacuated and the substrates were degassed at 150 °C temperature in order to remove adsorbed species on the substrates. Next, the substrates were sputter etched for 15 min using two Kauffman argon ion sources (1 keV each). Lastly before aluminum nitride film growth, targets were pre-sputtered in pure argon atmosphere for 10 min to clean the surface of the targets. Before removing the shutter, the arc was created to settle the $Ar+N_2$ flow at pressure $\sim 3\times 10^{-1}$ Pa. The plasma ignition current of each target was kept constant at 50 A, while bias voltage was set at −300 V. Once the parameters settled at their respective values, the shutter was removed and species were allowed to deposit on the substrate.

Initially sample S_1 was deposited at 100% nitrogen flow (100 sccm). In the next case, various controlled nitrogen fractions ($N_2/(N_2+Ar)$%) were injected in the deposition chamber during film growth. The samples were deposited by mixing increasing argon content in the deposition chamber at constant pressure. Details of the flow ratio are listed in Table 1. During deposition, the spontaneous heating of the DC plasma arc raises the temperature of the substrate.

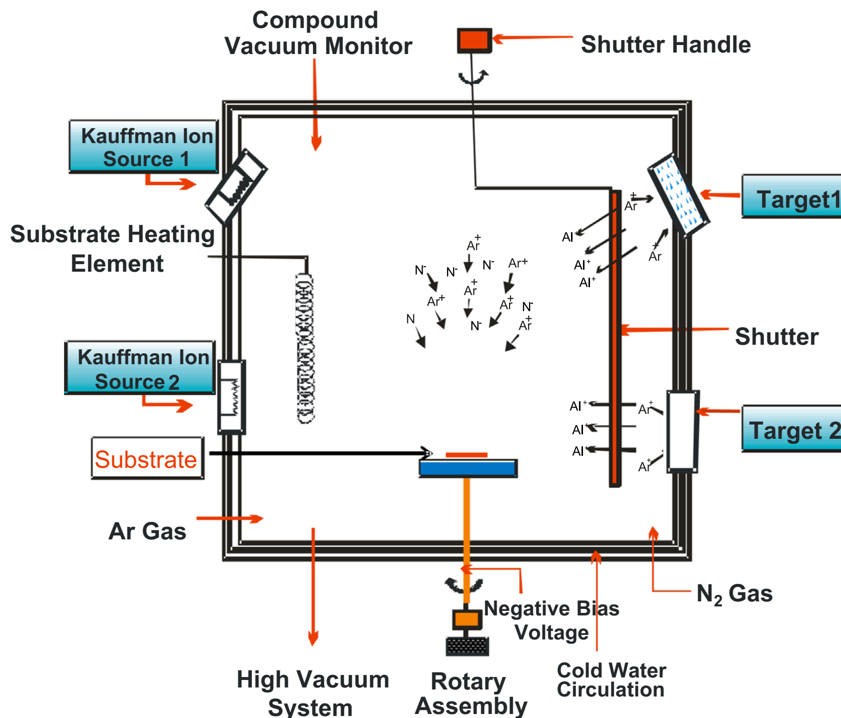

Fig. 1. Schematic diagram of deposition chamber.

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