World Applied Sciences Journal 9 (Special Issue of Nanotechnology): 52-55, 2010
ISSN 1818-4952

Characterization of Aluminum Nitride Nano Film Deposited by RF Magnetron Sputtering in Buffer Layer Applications

Javad Karamdel, C.F. Dee, M.M. Salleh and Burhanuddin Yeop Majlis

[1]Institute of Micro Engineering and Nanoelectronics (IMEN),
Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract: A set of aluminum nitride (AlN) nano film, deposited by RF reactive magnetron sputtering using aluminum metal as a target material was characterized as buffer layer. In order to investigate the effects of temperature on crystallinity of the specimens, annealing processes were carried out on the deposited nano films. The results showed that the structure of obtained films is dependent on sputtering and annealing conditions. The SEM results showed a columnar growth of thin layer on the surface of Si substrates. From the XRD measurements, better crystalline film can be achieved in case of heating substrate up to 300°C during the sputtering. Morphological studies revealed that the annealing process increases grains size and active nucleation sites with uniform distribution on surface, which is suitable for buffer layer applications. In addition, the crystallinity of the deposited films was improved with annealing process. Although deterioration of electrical resistivity was observed in samples which had been sputtered at higher temperature or annealed, they still had high resistivity.

Key words: AlN thin film · Sputtering · Buffer layer

INTRODUCTION

Aluminum nitride (AlN), which is a compound semiconductor with a hexagonal wurtzite structure, possesses many extraordinary properties, including wide direct band gap (around 6.2 eV), chemical and thermal stability, high thermal conductivity and high electrical resistivity [1]. Highly c-axis oriented aluminum nitride (AlN) thin film can be used in a wide variety of applications such as electroacoustic and optical devices, thermal conductors, protective coatings, insulating layers and buffer layers [2-6]. The most attractive application of crystalline AlN is being used as substrate or buffer layer for epitaxial growth of GaN and ZnO due to the same wurtzite crystal structure and close lattice parameters.

It has been shown that the properties of AlN thin films are greatly influenced by their morphology and structures for example, preferential orientation of crystalline AlN thin films affects and often improves the properties of practical use in piezoelectric and buffer layer applications [6- 10]. On the other hand, the roughness and densities of nucleation centers are important parameters in buffer layer applications [11- 13]. Hence, it is important to study the conditions, under which highly oriented AlN thin film structures with a uniform surface roughness can be grown.

Up to now, several approaches have been reported for synthesizing AlN, such as molecular beam epitaxy (MBE), chemical vapor deposition (CVD), pulsed laser deposition (PLD), ion-beam sputtering, ion-beam assisted deposition and reactive sputtering [11-17]. Most of these methods are complicated and expensive, whereas, reactive sputtering is a simple method and can work under low process temperature to provide good film quality. This method, therefore, is adopted here for realizing high quality AlN thin films. In this paper, the influence of the sputtering and post annealing conditions on the structural and surface morphological properties of AlN thin films are investigated.

Corresponding Author: Burhanuddin Yeop Majlis, Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
Tel: +603-89265861; E-mail: burhan@ukm.my.

MATERIALS AND MATHODS

AlN thin film was deposited on Si (100) substrate using RF magnetron sputtering technique. A target of aluminum (Al) with purity of 99.99% and diameter of 6 inches reacted with a mixture of nitrogen (N) and argon (Ar) gases. First of all, substrates were cleaned in the ultrasonic bath using acetone, methanol and isopropyl alcohol for 10 minutes each. Then, they were cleaned by 10% HF acid to remove any native oxide from surface and rinsed with DI water, respectively. The distance between the target and substrate was 12 cm. The RF power was 350 watts and sputtering pressure was fixed on 12 mTorr. Since for a given pressure of sputtering, the crystallinity and morphology of product is influenced by the ratio of N/Ar gases and sputtering temperature, the flow rates of Ar and N were varied from 3 to 10 sccm and 3 to 18 sccm respectively and the substrate temperature was varied from 50°C to 300°C. The chamber was pumped down to low pressure region around 10^{-6} Torr using a turbo pump. A summary of the deposition parameters and ranges used in fabricating the AlN thin film is listed in Table 1. The target is pre-sputtered with pure argon for 20 minutes with the closed shutter to remove any oxides on the surface. Then the shutter was opened and AlN was deposited on the Si substrate while using heating during the process. To prevent the formation of SiN_x layers at the interface, the mass flow controller of nitrogen gas was opened several seconds after starting the plasma and sputtering. Subsequently the films were annealed in a horizontal furnace for 40 and 60 minutes in the presence of pure nitrogen. The annealing temperature was varied from 400°C to 800°C. The morphology of samples was characterized by atomic force microscopy (AFM) and scanning electron microscopy (SEM) and the crystallinity of samples was studied by x-ray diffraction (XRD) measurements. The resistivity of samples has been measured by four points probe.

Table 1: Deposition parameters

Substrate temperature	50-300°C
Targets	Aluminum (99.99%)
Gas flow rate	N2 (10-20 sccm)Ar (6-10 sccm)
Base pressure	8 × 10-6 torr
RF Power	350 W
Sputtering pressure	12 mtorr
Deposition time	10-40 minutes

RESULTS AND DISCUSSION

Fig. 1 shows a good columnar film growth which is investigated by SEM. The thickness of films was varied from 10 to 100 nm depending on duration and condition of growth. The adatom mobility at the surface of the substrate influences the crystallization and the orientation of the deposited layer, therefore temperature is a main parameter for control. The chamber temperature for normal sputtering was around 50°C.The films were deposited at temperatures ranging from 50°C to 300°C. Obviously, the higher substrate temperature helps produce better c-axis oriented quality films. It can be concluded that the higher mobility of adatom helps not only to form c-axis orientated film but also better polarizations.

The typical AFM results of sputtered and annealed samples under different conditions are shown in Fig. 2(a-c). It was found out that when the flow rate of Ar and N were 3 sccm and 12 sccm respectively, the surface of sample had more excitation points with uniform distribution and low roughness (Fig. 2-a). The analysis revealed a value of rms surface roughness of 6.01 Å which is low for sputtered AlN thin film. For lower or even higher flow rate of N the surface morphology was not as well as above conditions (Fig. 2-b). Shown in Fig. 2-c, is a typical result of annealed sample at 800°C. The results disclose that increasing the annealing temperature up to 800°C caused the surface to become smoother and rms surface roughness decrease to 4.21 Å, but the sharpness of excitation points were lower than un-annealed samples.

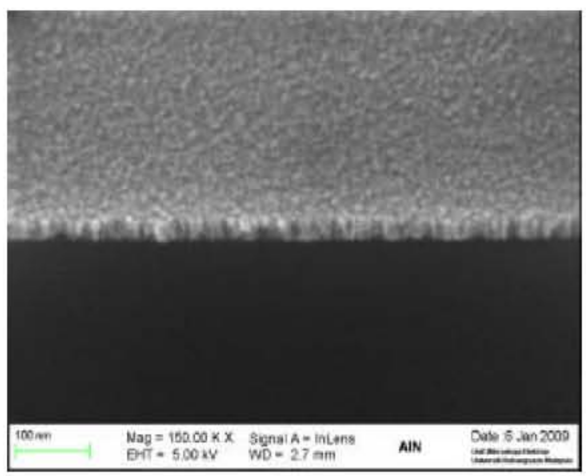
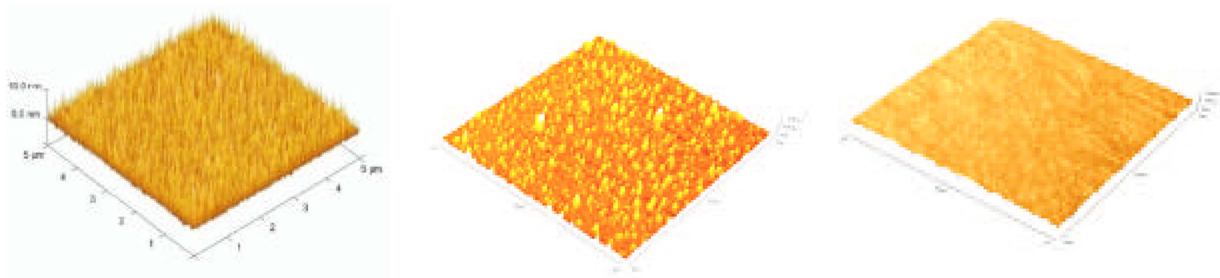


Fig. 1: Cross section SEM image of the AlN thin film shows columnar structure



(a) (b) (c)

Fig. 2: AFM images of the AlN thin film showing different surface morphologies for a) sample which was sputtered at 300°C and 12 sccm N gas flow rate (b) sample which was sputtered at 200°C and 18 sccm N gas flow rate and (c) annealed sample at 800°C temperature

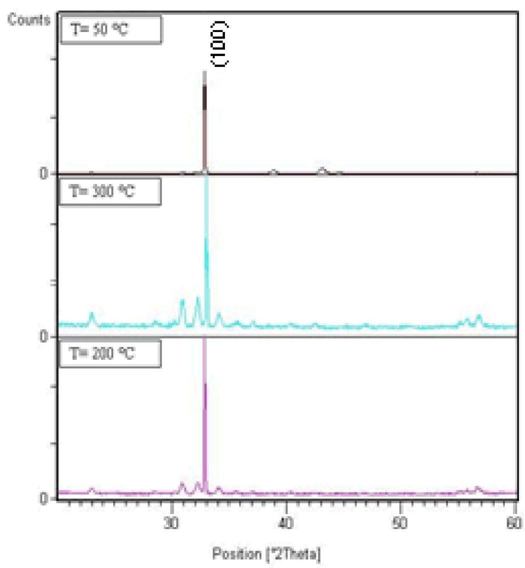


Fig. 3: XRD patterns of the AlN films deposited at various substrate temperatures

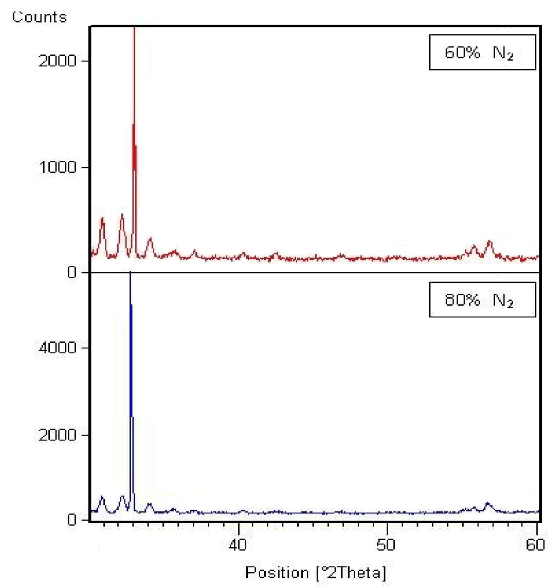


Fig. 4: Dependence of XRD pattern of AlN thin films on nitrogen fraction in the Ar/N2 gas mixture

The XRD spectra of samples revealed that all the deposited films were hexagonal wurtzite AlN. The evolution of preferred orientation (100) was recorded by 2θ XRD results in Fig. 3. It can be seen that the optimum characteristic for preferred orientation is achieved when the temperature of substrates is 300°C during the sputtering. More over the XRD spectra, which is shown in Fig. 4, demonstrate a strong dependence of AlN crystalline film quality on nitrogen fraction in the Ar/N2 gas mixture.

Electrical resistivity measurements were carried out using four point prob method at room temperature. The resistivity of samples which have been sputtered under higher temperature or higher N gas flow rate or have been annealed showed a reduction from around 8.8×10^{10} Ω.cm to 2×10^{10} Ω.cm. Despite deterioration of electrical resistivity, thin films still had high resistivity for being utilized as an insulator.

CONCLUSION

We have obtained high-quality epitaxial AlN films with a uniform and smooth surface morphology by radio-frequency magnetron sputtering. The effects of the sputtering gases and substrate heating temperature on the preferential orientation of the AlN films were studied.

The results showed that a columnar growth with hexagonal crystalline structure can be achieved in case of heating substrate up to 300°C during the sputtering. Also, the results revealed that post annealing process increases grain sizes and active nucleation sites with good superficial uniformity, which is suitable for buffer layer applications. In addition, the crystallinity of films was improved by increasing the annealing temperature and process temperature. The resistivity of samples was decreased by annealing process.

ACKNOWLEDGEMENT

The authors wish to express their hearty thanks to the Islamic Azad University-South Tehran Branch of Iran and the ministry of higher education of Malaysia for financial supports under [UKM-GUP-BTT-07-26-179].

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