SURFACE ROUGHNESS OF ALUMINUM NITRIDE EPILAYERS PREPARED BY MAGNETRON SPUTTERING

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Abstract: AlN films were deposited by magnetron sputtering on the sapphire substrates. The dependence of films morphology on the substrate temperature is defined. The film is represented by well textured areas for higher substrate temperature during deposition process. Adhesion strength of particles and substrate depends on temperature. Increasing of temperature by heating the substrate is important parameter which intences the interaction in interface at the near-surface area.

Keywords: substrate, target, thin film, surface, roughness, atomic force microscopy

1. INTRODUCTION

Aluminum nitride is A_3B_5 group wide band gap (6.3 eV) semiconductor [1], it has wurtzite crystal structure and, according to [2], the experimental crystal lattice parameters are a = 3.11 Å, c = 4.98 Å. There is a considerable ionic component in AlN bonding because of electronegativities (1.6 and 3.0) of Al and N atoms [3]. One aluminum atom is surrounded by four nitrogen atoms, making up a distorted tetrahedron with three bonds and one bond in the direction of the c-axis [4].

Prominent features of aluminum nitride make this material one of the desirable in modern electronics. It is characterized by interesting tribological [5] properties, high values of hardness and high thermal conductivity, moderate piezoelectricity, low dielectric and acoustic losses [6], high resistance to temperature and stability in corrosive medium [7], heat dissipation [8], high dielectric constant, moderately high electromechanical coupling coefficient [9], low coefficient of thermal expansion [4], non-toxic [10], electrically reliability [11].

All these characteristics in combination with large optical band gap make AlN suitable for applications in high power and high frequency devices, surface acoustic wave filters, optical devices and insulating layers [7]. AlN thin films are of interest for metal-oxide-semiconductor field-effect transistor [12], CMOS technologies, microelectromechnical and microoptomechanical systems fabrication [13], electronic packaging, waveguides, sensors, electro-acoustic applications (filters, resonators) [6, 11]. As noted in [7], it can be applied as an medium buffer layer for optical and electronic devices for further materials fabrication of semiconductor base. Attractive properties of AlN define large market of contribution. Although silicon production has a priority it is restricted in the wavelength in optoelectronic and optomechanical device production [9]. AlN has a significant value in optoelectronics because it allows overstep some limits of silicon devices.

In optics the surface statistical parameters have a significant influence. Investigation of AlN morphology has not only technological but also theoretical meaning. Morphology of AlN thin film is a critical factor for its electric properties [4]. The studies of thin film could be separated on the investigations which emphasize chemical and physical properties (mechanical, electrical, magnetic) [6, 9, 12, 13], analysis of the films structure [4, 7] and combined showing the dependences of the properties on the films morphology [11]. The structure of the thin films can utterly differ from the structure of bulk material and have different structural perfection. The surface features such as defect concentration are very important in case of thin films. And some properties of thin films are strongly dependent on the sturcture.

2. EXPERIMENTAL RESULTS

Magnetron sputtering takes place in thin films production for different application in microelectronics, partially integrated circuits and in optoelectronics. We used magnetron sputtering of aluminum target for thin films fabrication. The foundation of this method is sputtering of the target material (high-purity aluminum) by ions of working gas in the plasma of glow discharge. Argon (A2) was used for target sputtering. The plasma occurs in vacuum after applying of high voltage between cathode-target and anode and acts as a conducting medium. The essential constituents of the process are cathode, anode and magnetic system of plasma localization near the cathode surface. High sputtering rate and accuracy of the composite recurrence are the advantages of the magnetron sputtering. The pressure of working chamber was $3 \div 7 \times 10^{-2}$ Pa, current density of discharge $5 \div 7 \times 10$ A/m^2. These parameters define rate of condensation and consequently influence the structure of the films. The films could be obtained by sputtering of the polycrystalline aluminum nitride target, but it is possible to control thin films structure by gas composition in the chamber. The nitrogen gas was used for creation of work ambience and to accomplish nitrogen incorporation in AlN fabrication. Magnetron sputtering device allows fabrication of materials with good stochiometric. This method is compatible with standard silicon technologies.

Sapphire substrates (Al_2O_3) were used for AlN deposition. Monocrystalline sapphire is one of the hardest oxides, with high hardness at high temperatures, good thermo-physical properties and optical transparency. It is chemically resistant to most acids up to 1300 K, and to hydrofluoric acid below 600 K. These properties make sapphire a good material choice when it is necessary to have an optically transparent material in the visible light to near-infrared region [14]. The substrates were cleaned by dry etching in order to remove the traces of polishing and then the nitridization of near surface area was carried out. This helped to create the buffer layer between Al_2O_3 and AlN. The temperature of the substrate is a very important parameter because its changing causes the changing of energetic barrier near the substrate surface. And it also influences the character of film growth: sizes of nucleolus and rate of nucleation. We obtained the film at three temperatures (1000K, 1300K and 1500 K) of the substrate The film becomes smooth at low width if it consist of large value of small nucleous. And in case of large growth islands it should have the island structure. These islands are three-dimensional and they have the noticeable sizes in the normal direction to growth plane [15].

The heterostucture of (0001)AlN /(0001)Al_2O_3 was studied by scanning electron microscopy (SEM Quanta 200 from FEI), the image is in Figure 1. This measurement shows the occurrence of AlN film on the Al_2O_3 substrate. There are crystalline columnar grains of AlN in the image of cross-section analysis image. They have flat tops and not sharp shown faceting of the surface. This measurement shows the occurrence of AlN film on the Al2O3 substrate.

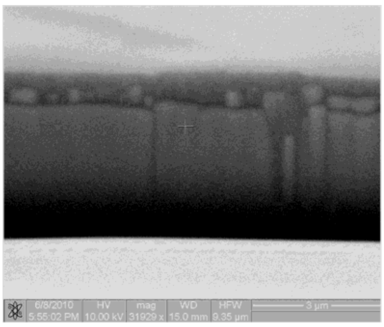
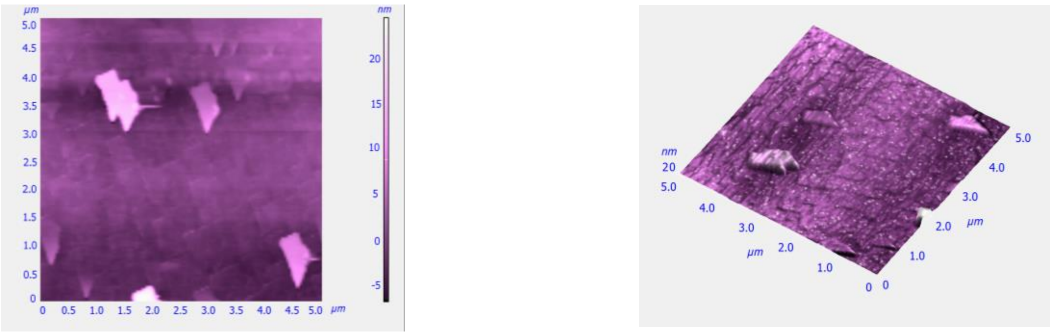


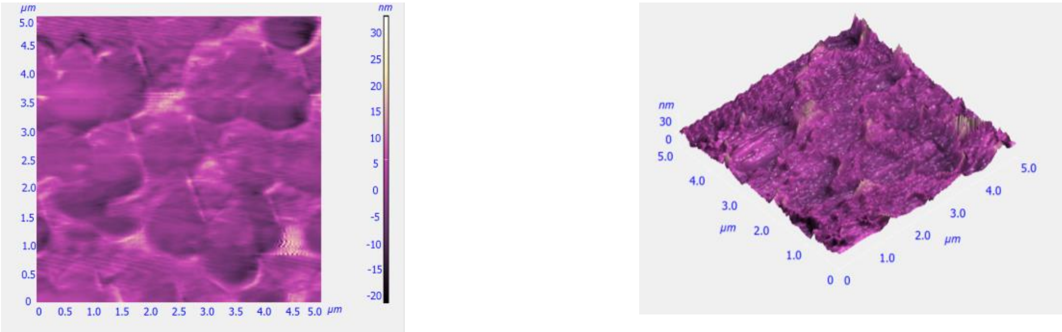
Figure 1: SEM image of the aluminum nitride layer in cross-section.

Surface roughness of the epilayers was investigated by atomic force microscopy Ntegra Prima (NT-MDT, Russian Federation) in semicontact mode. Cantilevers NSG01-DLC were used for precisely measurement (up to 1 nm). The measurements were carried out in air. AFM allows describing the growth character of thin films. The results are shown in Figure 2 - 4.



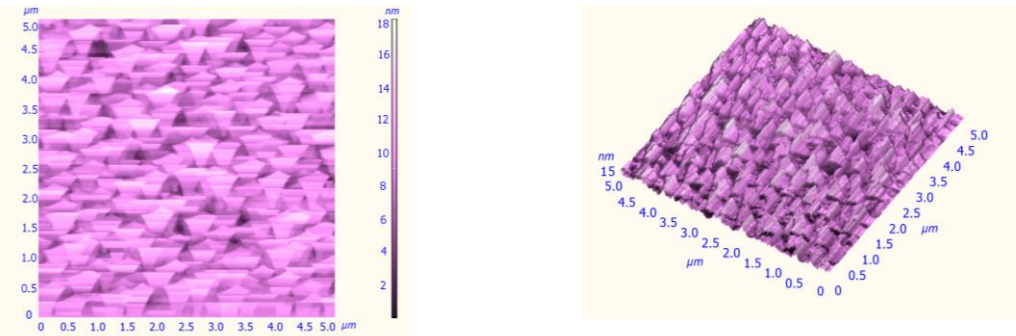
a b

Figure 2: Morphology of AlN nanolayer on the sapphire substrate obtained at 1000 K. (a – AFM tapping mode image, b – 3D AFM imaging) Scan size is 3×3 μm. Ten point height: 99.6117 nm.



a b

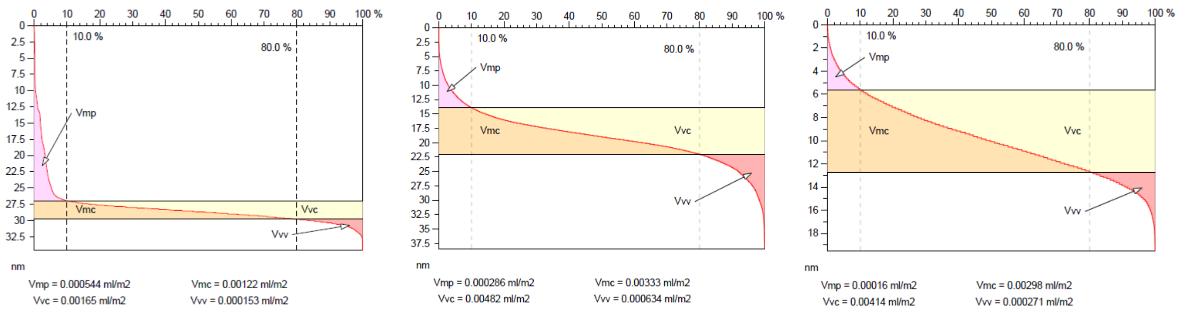
Figure 3: Morphology of AlN layer on the sapphire substrate obtained at 1300 K. (a – AFM tapping mode image, b – 3D AFM imaging) Scan size is 7.5×7.5 μm. Ten point height: 102.894 nm.



a b

Figure 4: Morphology of AlN layer on the sapphire substrate obtained at 1500 K. (a – AFM tapping mode image, b – 3D AFM imaging) Scan size is 5×5 μm. Ten point height: 12.4285 nm.

The graphical study of volume parameters (surface): peak material volume (Vmp), core void volume (Vvc), core material volume (Vmc) and pit void volume (Vvv) parameters based upon the Abbott curve calculated on the surface associated with Figures 2-4, are shown in Figure 5.



a b c

Figure 5: Graphical study of volume parameters (surface): Vmp, Vvc, Vmc and Vvv parameters based upon the Abbott curve calculated on the surface. Two bearing ratio thresholds are defined (using the vertical bars that are drawn with dotted lines). By default, these thresholds are set at bearing ratios of 10 % and 80 %. The first threshold, p1 (default: 10 %), is used to define the cut level c1 (and p2 defines c2, respectively). AlN epilayer on the sapphire substrate obtained at: a) 1000 K, b) 1300 K and c) 1500 K.

The curve of the material share provides important information about the condition of the surface in terms of its operational suitability. It is known that for the optimal functionality of the surface, it is required to be progressive or progressive-regressive.

3. CONCLUSION

Atomic force microscopy, scanning electron microscopy and statistical analysis are employed to characterize the films morphology. Our results suggest that the AlN thin film surface morphology gets better with the increase in temperature of Al_2O_3 substrate and can be tailored to feature unusual properties. The results show that there is an interdependence between the temperature of the substrate during deposition process and films morphology. Also there is a connection between surface roughness parameters and the film texture. The presence of the nitridization sapphire layer provides a good condition for consequent growth of AlN epilayers in the (0001) plane. The AlN epilayers on the sapphire substrate surface of all samples appeared relatively smooth, with very fine nano-asperities spread on the surface due to the preparation processes. AFM and surface statistical parameters analysis are powerful tools that are important for developing AlN thin films with improved surface characteristics.

The topography of the AlN epilayers on the sapphire substrate can open a new perspective and allows new interesting research on electro-physical, mechanical, and thermal properties, for the future expansion, both in breadth and depth. The functional properties of the AlN epilayers should be targeted for relatively low cost of the applications with respect to equivalent products fabricated using standard technologies.

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