The dependence of the surface roughness of aluminum nitride films on the processing methods when magnetron sputtering is used.

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Abstract. The paper investigates the dependence of the surface roughness of aluminum nitride films on the modes of magnetron deposition. The paper shows the difference between the surfaces of polycrystalline aluminum nitride films on ceramized glass and silicon substrates grown under the same conditions. Atomic force microscopy was used to compare the surface roughness parameters of aluminum nitride obtained at different substrate temperatures and the power dissipation in the target. The optimal conditions for forming aluminum nitride films through magnetron sputtering have been determined.

1. Introduction
The paper considers the conditions for formation and their effect on the surface relief of aluminum nitride films obtained through magnetron sputtering of an aluminum target in argon and nitrogen atmosphere. Aluminum nitride films are widely used in the design and manufacture of microelectronic piezoelectric films of the devices for generating and selecting microwave signals [1].

In modern thin film technology, magnetron sputtering systems have become widely used due to a number of advantages. These are control of deposition processes, the possibility of obtaining materials of various properties, high quality coatings [2].

This method enables us to achieve relatively high deposition rates and obtain uniform thickness films on large area substrates. High sputtering rates allow us to reduce the contamination of sputtered films by foreign impurities. The possibility of processing in a reactive medium of dilute gas makes it possible to obtain films of nitrides, carbides, oxides and other compounds [3]. On the other hand, the magnetron method of forming aluminum nitride films with specified characteristics is a multiparameter process task of mutually consistent processes that determine the interrelation between film properties, namely, the elemental and phase composition, the texture and the structure of crystallites, surface morphology, electromechanical coupling coefficient, with such main operating parameters of magnetron sputtering systems as electrode voltage, discharge current, target current density, specific capacity, working gas composition, actuation gas pressure, substrate temperature.

One of the key characteristics of the film quality is the surface roughness, which determines the frequency and resonant properties of BAW resonators.
The aim of the paper is to reduce the degree of surface roughness of aluminum nitride films by determining the interrelation between the process conditions of film formation and their properties, and to determine the optimal sputtering conditions.

2. The experimental procedure

A production magnetron installation for applying multicomponent coatings STEMS116-01 was used to form the films. The deposition of aluminum nitride films was carried out on silicon and ceramized glass substrates. The pressure of the Ar:N₂ gas mixture during sputtering provided a collisionless motion of aluminum atoms between the sputtered target and the substrate (a distance of 100 mm), and it was equal to 0.07 Pa. Aluminum nitride films were formed at the substrate temperatures of 300-400 ºC and with the capacity of 400-900 watts supplied to the target.

Magnetron sputtering of an aluminum target is performed by kinetic impact of positively charged Ar ions with an energy of 300-500 eV. Argon ions are generated during the processes of ionization of argon atoms by an electron impact occurring in the cathode region of a glow discharge plasma, DC or AC. A mixed stream of ions and atoms enters the target of inert (Ar) and reactive (N₂) gases. Chemically active atoms and ions during the bombardment of the target do not only participate in its sputtering, but also react with the target atoms forming compounds on the surface, in particular, AlN. In this case, atomization of both pure target material (Al) and its compounds (AlN) is possible. The atoms sputtered off from the target are transported to the substrate, while their interaction with plasma particles and actuation gas atoms, including the formation of chemical bonds, remains possible. The ratio of argon and nitrogen was considered as 4:5.

The surface morphology was examined through atomic force microscopy (AFM), the dependences of the surface roughness of aluminum nitride films obtained by magnetron sputtering on the temperature of the substrate and the power dissipated in the target were investigated [4].

The films were measured at the Analytical and Technological Research Center "High Technology and New Materials" (ATRC HT NM) of Novosibirsk State University. To study the morphology of the film surface and compare the values of roughness on silicon and ceramized glass substrates, the topographies of samples were measured with atomic force microscopy (AFM) on an NT-MDT Solver Next microscope. The sections of the surface were photographed with a scale of 5x5 microns, and a resolution of 512x512 points for different substrates. Fig. 1 shows 2D topographies of the surface of the samples.

With the two-dimensional image of the surface relief of the films taken into consideration, it is possible to estimate the grain sizes, their uniform distribution over the surface, the uniformity of their shape and size.

The samples were flat surfaces. In the images of scanning probe microscopy (SPM), the particles of various diameters and small furrows are distinguishable; the furrows have a depth of only about a few nanometers. The surface appears to be a granular structure, the bases of the columnar structure are visible, a nano-crystalline surface has grains of 50-100 nm in size, the nanopits height is 8 nm.

The values of Ra of the average roughness along the profile (along the line) and Rq of the RMS roughness along the profile (along the line) were calculated in the SPM data processing program "ImageAnalysis 3.2.4 10128".
3. The experimental procedure

When the films grown under the same conditions (actuation gas pressure, substrate temperature, target capacity, etc.) were compared, it turned out that the roughness of the film and the dimensions of AlN polycrystallites in AFM images on a silicon substrate were smaller than those of the films on a ceramized glass substrate. This is due to the fact that the surface of the silicon substrate itself is smoother; its roughness was about 0.35 nm, the roughness of the ceramized glass substrate was 2.2 nm. The thickness of the sputtered films is about 1 micron, so the roughness of the substrate affected the roughness of the film.

Figure 2 shows the results of measurements of Ra and Rq roughness of the films depending on the substrate temperature at a target capacity of 650 watts. The minimum roughness of both Ra and Rq corresponds to a temperature of 300 °C. As the substrate temperature increases, the roughness increases from 8 to 18 nm too.

The substrate temperature is a parameter that determines the mobility of adsorbed atoms. When the temperature of the substrate increases, the surface diffusion coefficient of the adsorbed atoms increases too, which contributes to their mobility. The adsorbed atoms on the surface of the growing film acquire sufficient mobility to regroup into grains with the lowest value of surface energy. The merging of grains is accompanied by their enlargement resulting in an increase in the roughness of the surface of the film due to the formation of deep intergranular cavities on the surface of the film.
Next, the effect of the power dissipation in the target on the surface roughness was investigated, the dependences were obtained for substrate temperatures of 300 °C and 350 °C.

![Figure 2](image_url)  
**Figure 2.** Dependence of the roughness of aluminum nitride films on the substrate temperature

Figure 3 shows a diagram of the dependence of roughness on the capacity at a temperature of 300 °C.

![Figure 3](image_url)  
**Figure 3.** Dependences of the roughness of aluminum nitride films on the target capacity at a substrate temperature of 300 °C.

Figure 4 shows a diagram of the dependence of roughness on the capacity at a temperature of 350 °C.

![Figure 4](image_url)
Figure 4. Dependences of the roughness of aluminum nitride films on the target capacity at a substrate temperature of 350 °C.

When the power increases, the values of Ra and Rq roughness also increase from 13 to 32 nm at a substrate temperature of 350 °C, and from 6 to 11 nm at a substrate temperature of 300 °C. For substrates with a higher temperature, the values of roughness at the same capacities are higher. The increase in capacity contributes to more argon ions affecting the target. As a result, there is an increase in the number of aluminum atoms moving to the substrate per unit of time. Thus, when the power increases, the deposition rate of films increases too. An increase in the deposition rate leads to a higher roughness of the film surface. The atom adsorbed on the substrate can remain stationary or move along the substrate due to the surface diffusion. An increase in the deposition rate makes the surface diffusion more difficult.

Thus, we have proven that the most optimal condition for forming aluminum nitride films with minimal surface roughness is a substrate temperature of 300 °C and a target capacity of 400 watts.

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