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Mini Review

Texture of Thin Films of Aluminum Nitride Produced by Magnetron Sputtering

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Abstract

The results of the study of the texture of thin films of aluminum nitride obtained by magnetron sputtering are presented. The dependence of the sizes and degree of preferential orientation of crystallites on the conditions of formation of thin films (pressure, discharge power, composition of the plasma-forming gas) is investigated.

Introduction

Recently, thin films of Aluminum Nitride (AlN) have been widely used in microelectronics due to their excellent acoustic properties [1,2].

Various methods of thin film production are widely used in modern science and industry, for example, ion plasma, ion beam, and thermal vacuum deposition methods [3,4]. One of the most effective methods for producing thin films is the magnetron sputtering method [5].

However, the physical properties of piezoelectric AlN films are significantly affected by the parameters and conditions of their deposition [6], since they determine the arrangement of aluminum and nitrogen atoms on the substrate, and, consequently, the microstructure of the formed film.

Despite numerous studies devoted to the formation of thin films of aluminum nitride by magnetron sputtering, the relationship between the deposition parameters and the physical properties of the resulting film has not been established. The scientific novelty of this work is to identify the dependence of the structural features and texture of aluminum nitride films formed by magnetron sputtering for specific technological modes.

The structural and morphological properties fully determine the possibility of using thin films of aluminum nitride in a particular type of device. In particular, for use in devices powered by surface acoustic waves (surfactants), thin AlN films must have a smooth surface and a preferential orientation (002), since the piezoelectric properties strongly depend on the crystallographic orientation of the film [6]. The aim of the work is to conduct research aimed at determining the effect of the ratio of gas flows, pressure in the chamber, and the power of the magnetron discharge on the texture of aluminum nitride films formed by magnetron sputtering.

The experimental part

The studied Aluminum Nitride (AlN) films were formed on citallic substrates by magnetron sputtering of an Al (99.99%) target in an Ar/N_2 reactive medium at a multi-component coating application facility.

Before spraying, the substrates were first chemically treated, then the substrates were placed in a vacuum chamber, where, to further purify the target from possible oxides before the film formation process, the target was sprayed in an argon medium with the substrate closed and the power supplied to the target exceeding 10% -15% the power when forming aluminum nitride films.

The studied Aluminum Nitride (AlN) films were formed under the following technological conditions: Ar/N2 fluxes ranged from 4 sccm/5 sccm, and 4 sccm/10 sccm. The power supplied to the target ranged from 400 to 900 Watts, the substrate temperature was 350 K and the pressure varied from 0.07 to 0.1 Pa. The distance from the target to the substrate was 100 mm.

Diffractometric analysis of the structural parameters of thin films of aluminum nitride was performed on an XRD-6000 diffractometer using CuKa radiation. The surface areas were studied on a scale (5x5 microns) and with a resolution of 512 x 512 dots.

The results and their discussion

Figure 1 shows the dependence of the coherent scattering region (RCS) on the power of a magnetron discharge. Figure 1 shows that with increasing power, the size of the RCS increases. With an increase in the power of the magnetron discharge, the energy of adatoms and their surface mobility increases, which leads to the formation of larger crystallites [7].

Figures 2,3 show the dependence of the size of the RCS on the gas pressure. For films obtained at a nitrogen concentration of 10 sccm in a gas mixture, the RCS decreases with increasing pressure (Figure 2), while the inverse relationship is observed at a nitrogen concentration of 5 sccm. This is explained by the fact that with a higher concentration of nitrogen atoms in the plasma of the working gas (10 sccm), the number of high-energy aluminum atoms hitting the substrate decreases, in parallel with this factor, an increase in the pressure of the working gas also leads to the scattering of atomized aluminum atoms due to their collision with argon atoms. The result of the influence of these two factors is a decrease in the migration ability of aluminum atoms deposited on the substrate, which leads to a decrease in the size of the crystallites. At lower nitrogen concentrations (5 sccm), an increase in the size of crystallites is observed with an increase in the pressure of the working gas, which is associated with an acceleration of the diffusion process of aluminum atoms adsorbed on the substrate surface and the absorption of small crystallites by larger ones [7].

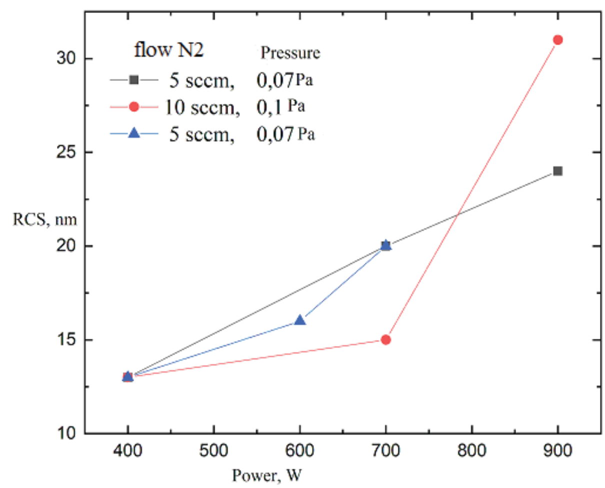

Figure 1: Dependence of the size of the RCS on the discharge power.

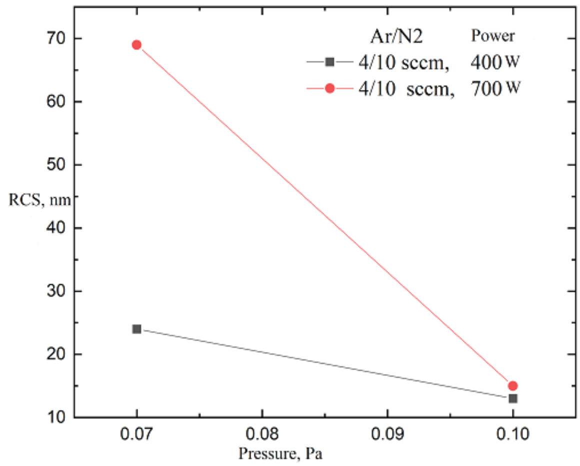

Figure 2: Dependence of the size of the RCS on the gas pressure at a nitrogen concentration of 10 sccm.

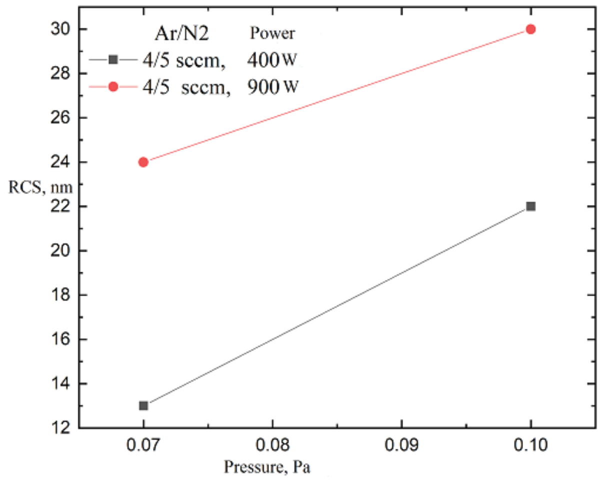

Figure 3: Dependence of the size of the OCR on the gas pressure at a nitrogen concentration of 5 sccm.

Figure 4 shows the dependence of the degree of preferential orientation (002) on the power of the magnetron discharge.

An increase in the power of the magnetron discharge leads to an increase in the deposition rate. Thin films deposited at low discharge power have a low degree of orientation along the plane (002), which may be due to the fact that atoms sprayed in the direction of the substrate do not have the necessary energy to form a well-oriented structure. The subsequent increase in power leads to a change in the microstructure and the formation of a textured film with grains misoriented relative to each other since an increase in the deposition rate leads to a decrease in surface diffusion. Based on the analysis of experimental data, the optimal power of a magnetron discharge, at which crystallites are formed with the highest degree of preferential orientation, is 700 watts.

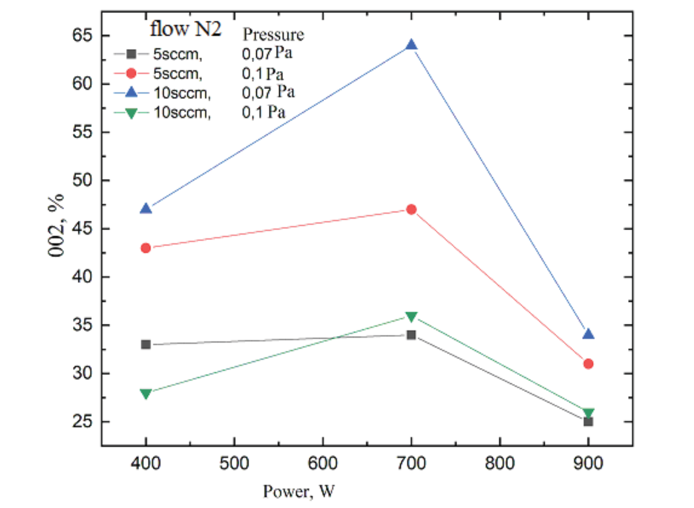

Figure 4: Dependence of the degree of preferential orientation (002) on the discharge power.

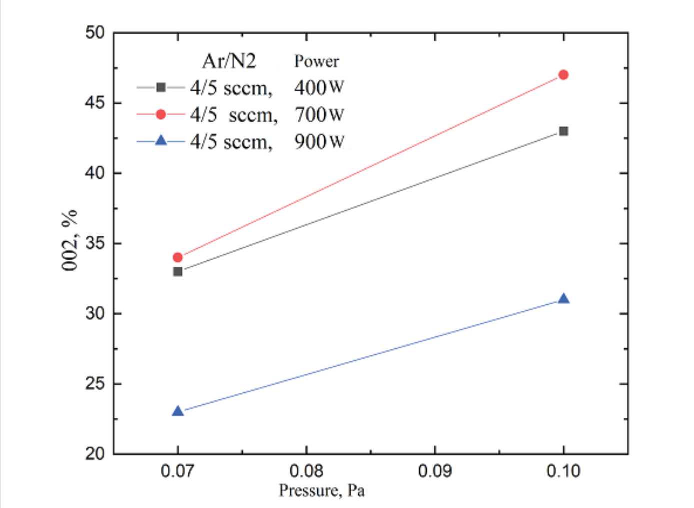

Figure 6: Dependence of the degree of orientation (002) on the gas pressure at a nitrogen concentration of 5 sccm.

Figures 5,6 show the dependence of the degree of preferential orientation (002) on the gas pressure. For films obtained at a nitrogen concentration of 10 sccm, the degree of orientation along (002) decreases with increasing pressure, and for films obtained at a nitrogen concentration of (5 sccm), an increase in the degree of orientation along (002) is observed with increasing pressure. This is explained by the fact that argon ions have a higher atomic mass and, consequently, if they predominate in the gas mixture when they bombard the target, a larger number of aluminum atoms with higher kinetic energy will be knocked out, which, falling on the substrate, will form a plane (002). The energy of formation of the densely packed (002) AlN plane is greater than that of planes with other orientations, therefore, the high energy of the atomized aluminum atoms will contribute to the growth of the (002) plane. With an increase in nitrogen concentration, the number of collisions of atomized aluminum atoms with nitrogen atoms increases, which leads to a loss of energy and a decrease in the number of high-energy aluminum atoms hitting the substrate and participating in the creation of a densely packed plane (002) [7].

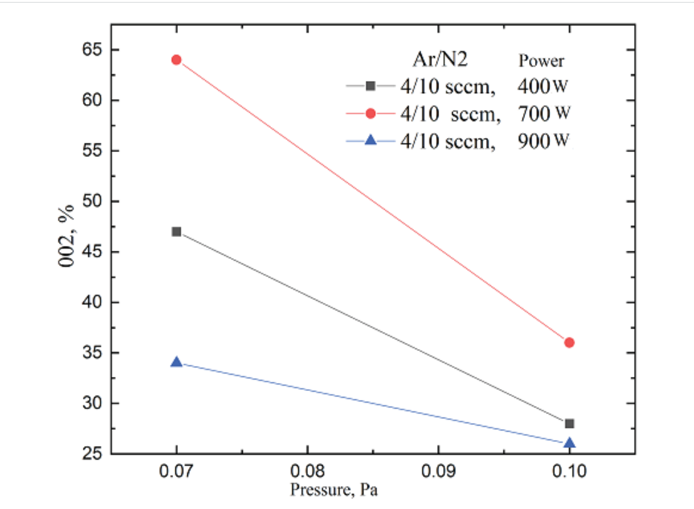

Figure 5: Dependence of the degree of orientation (002) on the gas pressure at a nitrogen concentration of 10 sccm.

Thus, the paper presents the results of a study of the texture of thin films of aluminum nitride, depending on the conditions of their formation. The dependence of the size of the OCD and the degree of preferential orientation (002) on the pressure, power, and composition of the plasma-forming gas was studied.

Conclusion

It was found that with the ratio of gas flows in standard cubic centimeters per minute (sccm) Ar/N2=4/5, the AlN phase with the preferred orientation (002) and the size of crystallites increases with increasing pressure, and with the ratio of gas flows Ar/N2=4/10, the inverse relationship is observed. The size of the OCD and the degree of preferential orientation increase with increasing power of the magnetron discharge, however, starting from a certain power value, the proportion of crystallites with a preferential orientation decreases (002). Based on the analysis of experimental data, the optimal power of the magnetron discharge, at which crystallites are formed with the highest degree of preferential orientation (002), is 700 watts.

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