Mechanical stresses in aluminum nitride films formed by magnetron sputtering

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Abstract. The results of studies of the dependence of the mechanical stresses of aluminum nitride (AlN) films obtained by direct current magnetron sputtering on the formation modes: substrate temperature, discharge power, ratio of nitrogen and argon fluxes at a pressure of 0.07 Pa are presented. It is shown that the minimum mechanical stresses are observed at a substrate temperature of 573-613 K, a power of 900 W and a gas ratio of 4/5 - 5/5, and are (15-22) * 10^8 N / m2.

1. Introduction

The key elements of acoustoelectronic devices are SMR BAW resonators, the principle of operation of which is to excite a longitudinal volume acoustic wave in a thin piezoelectric film, for example, AlN [1,2]. A thin-film electro-acoustic transducer is formed on the surface of the Bragg reflector (Fig. 1), which provides acoustic insulation of the transducer from the substrate. The number of layers of thin films in this design of the resonator reaches 15, and the total thickness is 5-7 micrometers, depending on the operation frequency of the resonator. The Bragg reflector acoustically isolates the piezoelectric transducer and determines the mechanical strength of the entire structure. Each layer has mechanical stresses and with each subsequent layer the mechanical stresses add up.

![Figure 1. Design of a resonator with an acoustic Bragg reflector: 1 – upper electrode; 2 – a piezoelectric film; 3 – base electrode; 4 – substrate; 5 – film layers of the Bragg reflector.](image)

Low adhesion between the film layers of the Bragg reflector worsens the acoustic contact at their boundary, which leads to an increase in attenuation of the longitudinal acoustic wave and a decrease in the quality factor of the resonator. One of the reasons for the decrease in the adhesion of
thin-film layers is high mechanical stresses ($\sigma$) [3]. By the time of formation of the piezoelectric AlN film, 10-12 layers of thin films are already on the substrate. An AlN film also has mechanical stresses that can affect the characteristics of the resonator as a whole, such as:

- resonator Q factor
- effective electromechanical coupling factor
- insertion loss
- the level of "spurious" resonances [4].

The aim of the work is to determine the optimal technological modes of magnetron formation of aluminum nitride films with minimal mechanical stresses.

2. Experimental technique

In work, the installation of applying multicomponent coatings STEMS116-01 was used. Aluminum nitride films were formed by direct current magnetron sputtering of a target in an atmosphere of argon and nitrogen. An aluminum target (99.999%) with a diameter of 150 mm and a thickness of 8 mm was attached to the water-cooled cathode through a heat-conducting paste. Before the formation of the film, the target was cleaned from impurities and oxides by magnetron sputtering for 3 minutes. The vacuum chamber was previously pumped out by a turbomolecular pump to a pressure of not more than $2 \cdot 10^{-4}$ Pa. The substrate was preliminarily heated by IR radiation to a predetermined temperature (573-673K) and maintained using a PID controller. The distance from the target to the glass substrates is 100 mm. A sensor based on a quartz resonator with a sensitivity of 0.5 nm / s controls the thickness and rate of deposition of AlN films. The AlN film thickness and the radius of curvature of the ceramic substrate before and after the deposition of the aluminum nitride film were measured using an MII-4 microinterferometer. Based on the results of measuring the film thickness and the radius of curvature of the substrate, the value of mechanical stresses in molybdenum films was calculated using the Stoney formula [5].

3. Experiment Results and Discussion

It is known that films formed by magnetron sputtering of a target in vacuum are in a state of mechanical stresses. This is due both to the difference in the temperature coefficients of the linear expansion of the substrate and the film, and to the structural properties of the film itself in terms of conjugation with the substrate. The structure of the AlN film is formed depending on the substrate temperature, the number and energy of AlN atoms bonding in the argon atmosphere, nitrogen atoms and aluminum atoms entering the substrate and their spatial distribution in the sprayed zone. Therefore, it is important to find out the dependence of mechanical stresses in aluminum nitride films formed by magnetron sputtering on the substrate temperature, deposition rate, argon and nitrogen gas flow in a vacuum chamber.
Fig. 2 shows the dependence of the change in mechanical stresses in aluminum nitride films on the substrate temperature. The effect of substrate temperature during deposition on the value of mechanical stresses in AlN films is shown in Fig. 1. As the substrate temperature increases, the mechanical stresses increase, and at the same time they have a minimum value, with the substrate temperature values $T_s = 573-613$ K. With a further increase in the temperature of the substrate, compressive mechanical stresses increase. This may be due to the formation of a fine-grained structure, which leads to an increase in mechanical stresses.

Fig. 3 shows the dependence of the change in the mechanical stresses of aluminum nitride films on the power supplied to the target.

**Figure 2** The dependence of mechanical stresses on the substrate temperature.

Mechanical Stresses, $\sigma \times 10^8$ Pa

Substrate temperature, K

Fig. 3 shows the dependence of the change in the mechanical stresses of aluminum nitride depending on the power supplied to the target.

**Figure 3**. The dependence of the mechanical stresses of aluminum nitride depending on the power supplied to the target.
In a wide range of power values, mechanical stresses are compressive in nature. An increase in power leads to a decrease in mechanical stresses, this may be due to the fact that with an increase in power leads to an increase in the concentration of Al, in relative units. This leads to an excess of aluminum and leads to the appearance of a phase different from aluminum nitride-AlxNy.

Fig. 4 shows the dependence of the mechanical stresses of aluminum nitride films on the amount of gas supplied to the chamber.

![Figure 4](image)

**Figure 4.** The dependence of the mechanical stresses of aluminum nitride films on the amount of gas supplied to the chamber

A small amount of argon leads to a decrease in the concentration of aluminum atoms, which critically affects both mechanical stresses and the appearance of the AlxNy phase, and with an increase in the argon flux, the relative nitrogen content in the chamber decreases, thereby leading to an increase in the aluminum concentration in relative units, which also leads to an excess of aluminum and leads to the occurrence of a phase differing in AlN.

**Conclusions**

1. The obtained dependences show that the mechanical stresses of aluminum nitride films formed by direct current magnetron sputtering are compressive.

2. It was determined that with increasing temperature, compressive mechanical stresses increase. This may be due to the formation of a fine-grained structure, which leads to an increase in mechanical stresses.

3. It is shown that with increasing power and increasing argon concentration in the chamber, the relative nitrogen content in the chamber decreases, which leads to an increase in aluminum concentration in relative units, i.e., creates an excess of aluminum relative to the stoichiometric composition of aluminum nitride.
References

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