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Internal Stress in Aluminum Layers Deposited on Dielectric Substrates

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Summary: The analysis of the internal stress in deposited aluminum layers is demonstrated and dependences of the internal stresses on the thickness of the aluminum films deposited at various substrate temperatures and evaporation rates are studied. The study may be applied to fabricate the nanoporous alumina coatings for different kinds of high-sensitive sensors.

Keywords: Anodic alumina, Membrane, Light scattering, Light propagation.

1. Introduction

In recent years, there is an intensive development of sensor technology that reaches a new level of sensitivity. Electrochemical, acoustic, optical sensors and biosensors are developed. Among the optical sensors, it should be noted the devices on the surface plasmon resonance (SPR), reflectometric spectroscopy sensors, waveguide sensors, including waveguide sensors on a metal underlayer (WSMP). WSMP which is a thin film structure consisted of a waveguide layer of porous anodic aluminum oxide on the aluminum sublayer is of particular interest. Technology of coatings based on anodic alumina for sensor applications (SPR- sensors and WSMP) includes the following stages: the vacuum deposition of aluminum films on the dielectric substrate; the one-step anodic oxidation for the formation of the alumina film and a translucent aluminum film; the chemical etching for widening of pores with controlled optical parameters of nanostructured coatings. So, control of mechanical stress of the film on the basis of which the device is formed is very important for designing devices with required parameters [1-5].

2. Experimental

Electron-beam evaporation was used for the aluminum deposition on the 165 µm thick rectangular glass strips in the length-to-width ratio of 10:1 to measure stresses by the console method as the simplest and easy-to-use method for the vacuum evaporated films. The stress σ was calculated by the Stoney's formula:

$$\sigma = \frac{Ed^2 x}{3l^2 h(1-\mu)}, \qquad (1)$$

where E is the modulus of elasticity (Young modulus) for the substrate; d is the substrate thickness; x is the flexure of the free end; l is the substrate length; h is the thickness of the evaporated film; μ is the Poisson's ratio.

The modulus of elasticity for the substrate was measured by hanging of a plummet to the console end and determining of the glass flexure. This was calculated by the formula:

$$E = \frac{4Gl^3}{wd^3 x}, \qquad (2)$$

where G is the plummet weight, and w is the substrate width.

Young modulus was equal to $5 \cdot 10^{10}$ N/m^2.

The aluminum evaporation was made at various substrate temperatures and deposition rates. The flexure values x were measured at the room temperature when the samples were taken out of the vacuum chamber.

3. Results and Discussion

Figs. 1-2 show dependences of the internal stresses calculated by the Eq. (1) on the thickness of the aluminum films deposited at various substrate temperatures and evaporation rates.

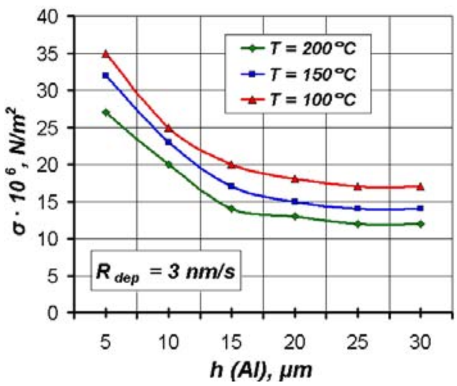

Fig. 1. Dependence of the internal stresses on the thickness of the aluminum films at various substrate temperatures.

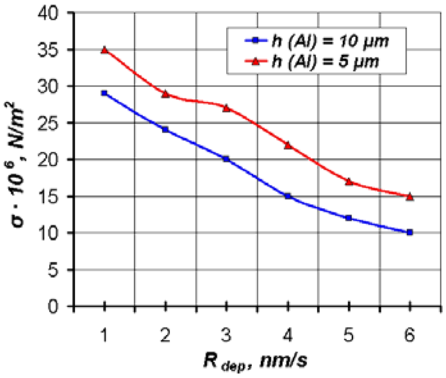

Fig. 2. Dependence of the internal stresses on the deposition rate of the aluminum films.

Referring to Fig. 1, in the aluminum films the internal stresses are reduced with the increase in the film thickness and the substrate temperature. The glass substrate flexes towards the deposited film. This is indicative of the tensile stress presence in the aluminum film. In contrast to thin films, in more than 1 μm thick aluminum films the tensile stresses are reduced when the deposition rate increases, as shown in Fig. 2. The tensile stresses values are equal to $(1.0\text{-}3.5)\cdot 10^7$ N/m^2 to be comparable with the aluminum yield point ($2.3\cdot 10^7$ N/m^2).

It is clear that stresses measured are characteristic of residual stresses including thermal stresses resulted from the difference in the linear expansion coefficients of aluminum and the substrate material. Thermal stresses are calculated by the formula:

$$\sigma_T = \Delta d \cdot \Delta T \cdot E / (1 - \mu)\,, \qquad (3)$$

where Δd is the difference in the linear expansion coefficients of aluminum and glass; ΔT is the difference between the condensation point and the room temperature; μ is a Poisson's ratio.

For aluminum $\mu = 0.348$ and $\sigma_T = (2\text{-}3)\cdot 10^8$ N/m^2 to be 10 times higher than residual stresses. This is evidence of high ability of the aluminum films to a stress relaxation by means of a plastic deformation.

Thus, the aluminum films are plastically deformed. So they have a developed dislocation arrangement up to the structure typical of the afterflow stage when a splitting of the initial aluminum grains is possible due to the net of dislocation clusters. However, to all appearance such the structure is not characteristic of the whole thickness of the aluminum film. The reduction of the internal stresses in the film-substrate system with the aluminum thickness and the deposition rate, as discussed above, testifies that in this case not a two-layer system but at the least a three-layer one consisting of the substrate, a transition plastically deformed aluminum layer, and an outer elastically stressed aluminum layer should be considered. Then the stress reduction with the film thickness can be explained by the expansion of the transition layer. With thin aluminum films, the aluminum yield point increases almost by the order and therefore the relaxation of the stresses is difficult.

4. Conclusions

Thus, in this paper the analysis of the internal stresses in deposited aluminum layers is demonstrated and dependences of the internal stresses on the thickness of the aluminum films deposited at various substrate temperatures and evaporation rates are studied. The study may be applied to fabricate the nanoporous alumina coatings for different kinds of high-sensitive sensors.

Acknowledgements

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