UDC 620.1

STUDY OF INTERNAL STRESSES IN ALUMINUM LAYERS EVAPORATED ON DIELECTRIC SURFACES

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Abstract. Analysis of internal stresses in evaporated aluminum layers formed at various sputtering regimes is demonstrated. Dependences of internal stresses on the thickness of aluminum films deposited at various substrate temperatures and evaporation rates are studied.

Keywords: internal stresses, aluminum layer, deposition, sputtering regimes, modulus of elasticity.

Introduction. To form aluminum films for the production of the interconnection systems, the number of problems should be solved such as the ensuring aluminum adhesion to the conventional dielectric substrates (glassceramics, polycor), the selection of the evaporation method with controlled regimes, the reproduction of the films structure, electrical conductivity and etc.

Experiments and results. The available literature on the internal stresses in the evaporated films considers only low films thicknesses and a narrow range of temperatures and evaporation rates for the deposition [1-6]. The internal stresses in aluminum films up to 30 μm in thickness deposited with the modern evaporating systems are of practical interest. 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:

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

where E is a modulus of elasticity (Young modulus) for the substrate; d is a substrate thickness; x is a flexure of the free end; l is a substrate length; h is a thickness of the evaporated film; μ is a 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:

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

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

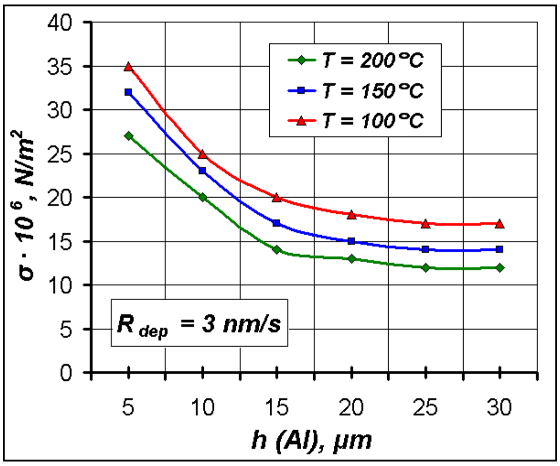

Figure 1 – Dependence of the internal stresses on the thickness of the aluminum films at various substrate temperatures

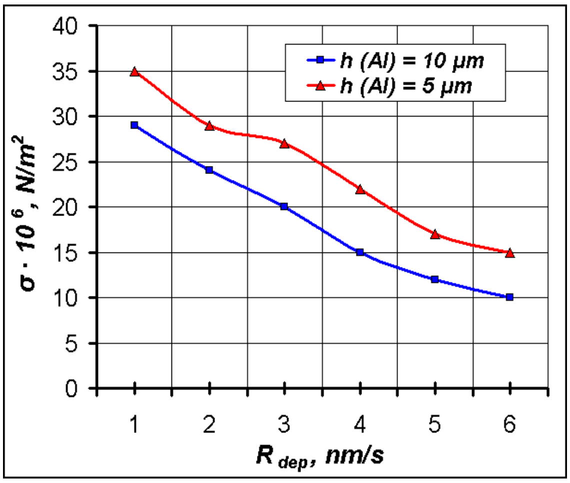

Figure 2 – Dependence of the internal stresses on the deposition rate of the aluminum films

Referring to Figure 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 Figure 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:

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

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 μ = 0.348 and σ_T = (2-3)·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.

Conclusion. Thus, in this paper the analysis of the internal stresses in evaporated 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.

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