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Increase of adhesion of conductive films on dielectric substrates by means of electric field

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Abstract. Films of aluminium and copper produced by vacuum deposition obtained on the glass substrates were investigated. Improve of the efficiency of adhesion of conductive layers was made by the use of ponderomotive forces of an electric field (electroadhesive effects). It is found that thermal and electric treatment of films make possible to increase the strength of the adhesive bond of the film with the dielectric substrate.

1. Introduction

When films are produced by vacuum deposition, the physical contact of the film with the substrate is achieved relatively simply, but the adhesive strength of the compounds obtained in this case is not always satisfactory. An example is the production of film coatings in thin-film technology of the microwave range, where films of materials with thickness 10–15 μm are required, have poor adhesion to substrates, especially in a number of special applications where the adhesion strength of connections have to be particularly high. Improving the adhesion ability can be influenced by the electric field together with the heat treatment of the films [1].

In this paper, we consider ways to improve the efficiency of adhesion of conductive layers on ion based dielectric substrates on the use of ponderomotive forces of an electric field. The theoretical substantiation of the methods and methods for eliminating the electroadhesive effects is given in [2].

Electro-adhesion is the result of the electrostatic (ponderomotive) attraction of electrified bodies, in which charges of different signs are separated by a gap between contacting surfaces or a thin layer of one of the fastened objects depleted of charge carriers and therefore having an increased resistance adjacent to the contact interface. Most of the applied voltage therefore falls on this narrow layer, that is the reason for the appearance of large electrostatic fields and forces. To obtain greater attraction forces at the points of actual contact, the migration polarization observed in ionic dielectrics can be used. Migration polarization is effect of drift of the weakly fixed ions in the dielectric to the corresponding electrode under the action of the electrostatic field forces.

2. Research technique

Copper and aluminium were studied as coating materials. All these materials are widely used, they have different adhesion properties, which is important for a more complete study of the possibilities of the method of increasing adhesion. Films of copper and aluminium were deposited by thermal evaporation in a vacuum. The argon pressure at the time of deposition was of the order of $4 \cdot 10^{-3}$ mm Hg. The film thicknesses were 1.5–2 μm.

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Experiments related to the study of the influence of the electric field on the adhesion of thin metal films were carried out using device for obtaining uncontrolled electroadhesive contacts (figure 1) [3]. To quantify the adhesion, the Krotyova and Deryagin adhesimetr was used. The detachment *A* of the film is found according to the expression [4]

$$A = \frac{mg}{b}(1 - \cos\alpha), \quad (1)$$

where *m* – load mass; *g* – gravity acceleration; *b* – width of the peeled film; α – angle at which separation starts.

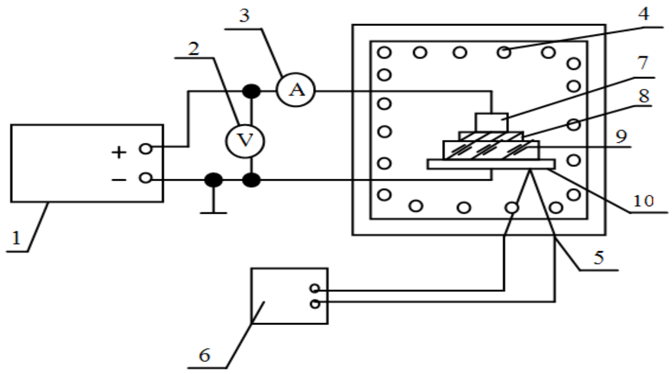

Figure 1. Scheme of installation for the obtaining of an electroadhesive connection: *1* – power supply; *2* – voltmeter; *3* – milliammeter; *4* – muffle furnace; *5* – thermocouple; *6* – potentiometer; *7*, *10* – electrodes; *8* – metal (semiconductor); *9* – insulator.

With high adhesion of the film to the substrate, only a partial peeling of the film from the substrate during measurements was observed. In this case, the relative share of the waste area was calculated based on the results of visual observations and the tear-off work calculated according to (1) was divided by this coefficient. Due to the fact that the value $k < 1$, the value obtained by the detachment was more than by (1). Thus, the detachment work was determined by the formula

$$A = \frac{mg}{b}(1 - \cos\alpha)\frac{S_0}{S_{sep}}, \quad (2)$$

where S_0 – total tear-off area, i.e. area of adhesive tape; S_{sep} – actually tearing off film area.

The possibility of improving the adhesion of films directly in the process of their condensation is of great interest. One of the measures used to increase the adhesion of films during their condensation is the heating of the substrate. However, this measure is in some cases insufficient. In some methods of applying film coatings, for example, ion-plasma sputtering “with displacement” presupposes the supply of a negative potential to the substrate relative to the plasma. Positive plasma ions bombard the substrate throughout the film deposition process, which allows higher adhesion values. The disadvantage of the method is that the negative potential prevents the formation of a transition oxide layer, which in some cases leads to insufficient adhesion [5]. By feeding a small positive potential at the first stages of film formation, it is possible to circumvent these difficulties. It can be seen that in this method, the potential difference is created between the plasma and the substrate, and not at the interface between the film and the substrate, and therefore is not achieved in all cases of the required adhesion value. Therefore, in the developed method, during the vacuum deposition of the film, a positive potential is supplied directly to the surface on which the film is deposited. To do this, a small contact spot must be made on this surface in advance, to which it is possible to connect a pressure contact with a positive potential with respect to the opposite surface of the substrate. The experiments were performed according to the scheme shown in figure 2.

3. Experimental results

The deposition of the films was carried out from a tungsten evaporator in a vacuum at a pressure of $\sim 10^{-5}$ mm Hg. With a speed of ~0.015 μm / s. The thickness of the films was about 0.2 μm. The glass was used as the substrate material.

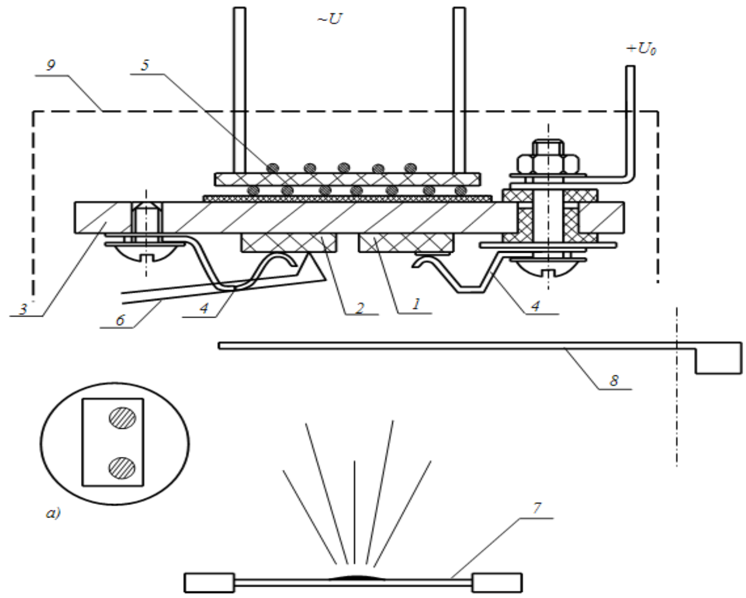

Figure 2. Tooling for the use of electro-adhesive forces in the process of vacuum film deposition: *1*, *2* – substrates; *3* – heat equalizing base; *4* – spring; *5* – heater; *6* – thermocouple; *7* – evaporator; *8* – damper; *9* – heat shield.

As an example, figure 3 shows some dependencies demonstrating the possibility of increasing adhesion by the proposed method. Adhesion of the films was measured at room temperature.

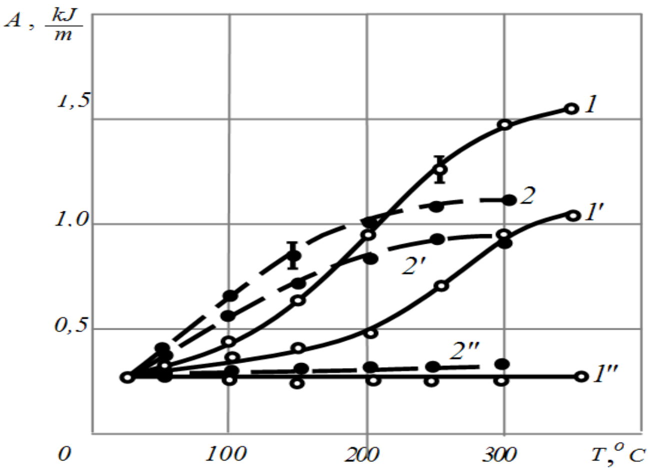

Figure 3. Dependence of the separation of copper (dashed) and aluminium (solid lines) films on the pane of glass from the temperature of the electroadhesion treatment. Holding time t = 10 min – *1*, *2* (U = 300 V) and *1*", *2*" (U_0 = 0 V); t = = 5 min – *1*', *2*' (U_0 = 300 V).

The increase in the stress applied to the film and substrate, as can be seen from figure 4, leads to a significant increase in the adhesion of the films to which the field was applied, with respect to those samples that experienced only heating and, in practice, did not change their adhesion.

The effect of the electric field on the formation of the film-substrate adhesion is determined by the same factors that affect the adhesion of the already applied films, the appearance of a large mechanical pressure at the film-substrate interface, due to the peculiarities of the migration polarization of the glass and the formation of an intermediate oxide layer between the film and a substrate was studied. However, the effect of the electric field on adhesion at the moment of film condensation turned out to be more significant than on the adhesion of already applied films. Confirmation of this fact was carried out as follows: the voltage was applied to the film after condensation under the same conditions (vacuum, temperature, voltage), before removing the substrate and breaking the vacuum. The increase in the adhesion of the film to the substrate in this case was much less than for the samples, the condensation of the film on which was produced in an electric field. The imposition of an electric field upon condensation of the film apparently leads to an additional activation of the surface of the substrate and, thus, to the appearance of a large number of chemical bonds between the adsorbed metal atoms and the substrate material. Electro-adhesive forces cause metal atoms to be attracted to the substrate more efficiently and occupy places with a minimum of potential energy, that is, deeper potential wells, and thereby increase the strength of the film-substrate joints.

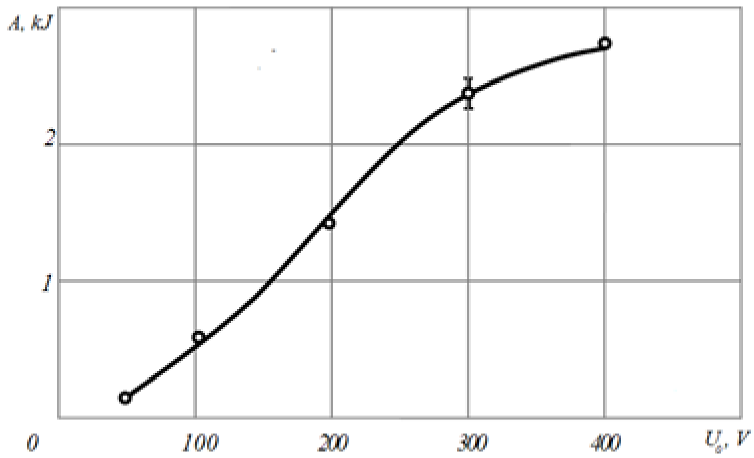

Figure 4. Dependence of the adhesion of an aluminium film on voltage under electroadhesive treatment. Substrate temperature *T* = 120 °C.

4. Conclusions

Thermal treatment of films in combination with the impact of an electric field makes it possible to increase or, if necessary, reduce the strength of the adhesive bond of the film with the dielectric substrate. Change the adhesion of films can be both – after application, and during the process of condensation of the film on the substrate.

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