International Journal of Nanoscience
Vol. 18, Nos. 3 & 4 (2019) 1940062 (3 pages)

DOI: 10.1142/S0219581X19400623

Influence of Ion Beam-Assisted Deposition on the Wetting Properties of Al-1.0 at.% Cr Alloy Films

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Received 22 December 2018
Accepted 18 February 2018
Published 13 May 2019

The surface microstructure and wettability of Al-1.0 at.% Cr alloy films obtained by ion-beam-assisted deposition on glass substrates have been investigated using atomic force microscopy, scanning electron microscopy and the sessile drop method. In the passive deposition regime, the surface roughness of the films increased from 8.9 nm to 21.6 nm with an increase in coating time from 3 h to 9 h. A quantitative analysis of the morphology evolution of the films during their growth was performed. The results revealed that Al-1.0 at.% Cr alloy films are hydrophilic. The mechanism of heterogeneous water wetting of Al-1.0 at.% Cr alloy films was considered, when the increasing surface roughness accounts for a decrease of hydrophilicity.

Keywords: Ion beam-assisted deposition; metal film; microstructure; aluminum — chrome; wettability.

1. Introduction

To control the properties of thin metal film coatings during their deposition on a substrate, it is necessary to diagnose the surface micro- and nanostructure of the coating/substrate system. Recently, thin aluminum films and its alloys have been actively investigated in the development of coatings for solar cells components, in particular for outer contacts, and also as a material for various semiconductor devices.[1]

In this paper, ion-beam-assisted deposition (IBAD) was used for fabrication of Al-1.0 at.% Cr alloy films on glass substrates in order to study their water wetting properties depending on formation conditions. The wetting behavior of these films is discussed in terms of determined structural changes.

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2. Experimental

The experiments on IBAD of metal films on glass substrates were carried out using a resonance ion source of vacuum arc plasma (pressure of 10^{-2} Pa) in two modes: without an accelerating voltage and at the voltage (U) of 3 kV. The Al-1.0 at.% Cr alloy was used as electrodes during IBAD. The deposition time was 3 h, 6 h, 9 h ($U = 0$) and 10 h ($U = 3$ kV, current $I = 100$ mA, current density 5.1 mA/cm^2) at the coating deposition rate of ~ 0.1 nm min^{-1}. In accordance with the model proposed by Sigmund,[2] the crystallization rate (cooling of the cascades) was 10^{12}–10^{13} K/s.

The study of the surface topography of the films and measurements of their roughness were performed on an NT-206 atomic force microscope (AFM) with CSC-38 probes with image processing by SurfaceXplorer software. To characterize the surface roughness of the samples, three parameters were selected: two amplitude parameters, R_a (average roughness) and R_z (10-point height R_z (ISO)), and one spacing parameter, S (mean spacing of adjacent local peaks). For the unified estimation of the film surface heterogeneity, the coefficient $k = R_z/S$ was calculated. Additionally, the surface structure was studied by a LEO-1455 VP scanning electron microscope (SEM). As a result of statistical processing of SEM images, the average diameter D of the micro-droplet fraction was measured. The wettability of the thin metal films deposited on glass substrates was characterized by the equilibrium contact angle (ECA) θ measured by the sessile drop method. The drop volume was 9.3 μL. The measurement error of ECA was $\sim 1\%$.

3. Results and Discussion

Figure 1 shows typical AFM images of the thin films deposited without an accelerating voltage (a–c) and at $U = 3$ kV (d) with corresponding histograms of the averaged heights and deepening distribution of the surface relief. All obtained histograms are unimodal. They have a strongly marked maximum and positive asymmetry growth explained by the island mechanism[3] and are well described by the Gauss distribution. According to AFM data, at $U = 0$ an increase in the coating time from 3 h to 9 h leads to an increase of the film roughness from 8.9 nm to 21.6 nm, whereas the histogram maximum decreases with a more uniform distribution of the heights and deepenings. This is explained by the fact that at $t = 3$ h stage, the film surface is characterized by the presence of small islands. Areas between these islands have a low height (Fig. 1(a)). With the increase in the time of coating (6 h and 9 h, Figs. 1(b) and 1(c)), the islands decrease due to the

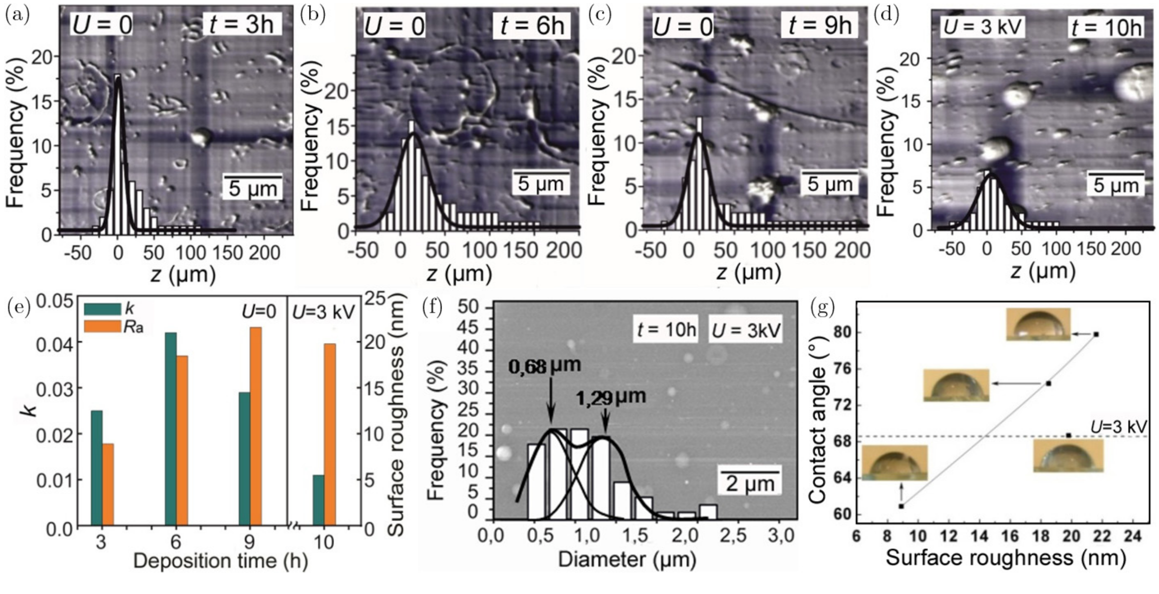

Fig. 1. (a–d) AFM images of thin films of Al-1.0 at.% Cr alloy depending on the deposition conditions and the corresponding histograms of heights and deepening distribution of the surface relief; (e) dependence of the coefficient k and parameter R_a on the time and mode of the coating deposition; (f) SEM image of the surface of thin film of Al-1.0 at.% Cr alloy and the corresponding distribution histogram of the micro-droplet fraction in size groups; (g) dependence of the water contact angle on the surface roughness with corresponding droplet images obtained for Al-1.0 at.% Cr alloy on glass substrates at $U = 0$ and 3 kV.

filling of areas between them with the film material. The data obtained at $U = 3\,\text{kV}$ and $t = 10\,\text{h}$ indicate that the surface heterogeneity decreases significantly at almost constant $R_a = 19.8\,\text{nm}$ (Figs. 1(d) and 1(e)), leading to the minimum value of the parameter $k = 0.011$.

SEM image (Fig. 1(f)) shows that the Al-1.0 at.% Cr alloy film deposited on the glass substrate contains a micro-droplet fraction. Size and density of these droplets depend on the mode and time of deposition. The distribution of their average measured diameters over the size groups is predominantly bimodal and can be described by the superposition of two Gaussian functions. For the films obtained at $U = 0$ this diameter increases in the range of 0.35–0.57 μm with increasing the deposition time from 3 h to 9 h (Figs. 1(a) and 1(c)), whereas for the films deposited 10 h at $U = 3\,\text{kV}$ (Fig. 1(d)) the diameter is $\sim 1.0\,\mu\text{m}$.

Figures 1(a)–1(d) clearly demonstrate the film microstructure evolution depending on coating formation conditions. Initially, with the increase of the coating time deposition, we observe the growth of parameter R_a, but under $U = 3\,\text{kV}$ this parameter decreases although the diameter rises. The obtained results allow us to conclude that the presence of a micro-droplet fraction is not the main factor that affects the film surface roughness.

The increase of the surface roughness from 8.9 nm to 21.6 nm is accompanied by an increase in the contact angle value from 60.9° to 79.8° (Fig. 1(g)). At $U = 3\,\text{kV}$, ECA is 68.7°.

Thus, it was revealed that all Al-Cr alloy films are hydrophilic. Despite the fact that roughness of the films deposited in the voltage-free mode for 9 h and that at $U = 3\,\text{kV}$ for 10 h were close, nevertheless, the hydrophilicity for the samples obtained at accelerating voltage was higher. It was established that the ECA value increases with the increase of the film surface roughness. This behavior of water droplets on the sample surface indicates the heterogeneous wetting and can be explained in the framework of the Cassie-Baxter model.[4] It means that the increase of ECA for the same chemical composition of surface coatings is observed with the decrease of the wetting area fraction. This phenomenon is reasoned by the fact that the liquid phase does not penetrate into surface imperfections and is located on air bubbles inside cavities of the deposited film surface.

4. Conclusion

Evolution of micro- and nanostructure of thin Al-1.0 at.% Cr alloy films deposited on glass substrates by the IBAD technique depending on the deposition conditions has been investigated. It was found that with increasing coating time from 3 h to 9 h, the surface roughness increases from 8.9 nm to 21.6 nm at $U = 0$ and is 19.8 nm at $U = 3\,\text{kV}$ ($t = 10\,\text{h}$). The film surface is characterized by the Gaussian distribution of heights and deepenings. The size of micro-droplet fractions is affected by the applied accelerating voltage and deposition time. The obtained distribution of the average measured diameters of the micro-droplet fractions in size groups is mainly bimodal and well described by the superposition of two Gaussian distributions. The calculated coefficient k allows us to quantify changes in the altitude and longitudinal nanorelief of the deposited film surface depending on conditions of the coating formation. The increase in the surface roughness leads to more values of ECA. The obtained results demonstrate the pathways to control wettability of solidified metal films on glass substrates by changing the mode of IBAD.

Acknowledgment

The work was carried out in the framework of the State Program of Scientific Research for 2016–2020 “Physical Materials Science, New Materials and Technologies”, subprogram “Materials Science and Materials Technologies”, task 1.40, GR No. 20161123.

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