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VACUUM ARC DEPOSITION OF Mo COATINGS

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ABSTRACT

Mo films have been deposited on different substrates with the aid of the vacuum arc technology. The deposition rate, surface morphology and microstructure of the coatings have been studied with the aid of light microscopy, profilometry, and scanning electron microscopy. The deposition rate increases with increasing deposition current. It decreases with increasing distance from the cathode slower than in case of magnetron sputtering. The fractional coverage of the substrate with microparticles has been studied in dependence on the deposition time, current and distance from the cathode. Microparticles are gradually incorporated into the columnar grain structure of the growing coating during the deposition process. The contribution of the particles to the total deposition rate decreases with increasing distance from the cathode and increases with increasing discharge current.

1. INTRODUCTION

Vacuum arc deposition is a promising technology for high-rate deposition of thick coatings. The most successful applications of the vacuum arc technology are titanium nitride coatings for machining tools and diamond-like coatings [1–3]. The evaporation of the target in the arc discharge, which burns in the vapour of the cathode material itself, excludes the dependence of the deposition rate on the sputter coefficient [1]. It makes the sputtering rate high and practically independent on the type of the cathode material. Therefore, high deposition rates of metals like Mo can be achieved [4]. The peculiarity of vacuum arc deposition most important for its application is the possibility for changing the properties of the substrate surface and growing film with the aid of a combined flux of multiple charged ions and microparticles. It is widely believed that microparticles have a deteriorating effect on the properties of the deposited layers [5]. However, in many applications the roughness of the film caused by the incorporated microparticles has either no effect or can be even useful. Therefore, the role of microparticles in the formation of a coating should be studied more thoroughly.

2. EXPERIMENTAL

Mo coatings have been deposited onto polished copper and silica glass substrates in a vacuum arc apparatus described elsewhere [4]. The cathode of diameter D = 60 mm was made of 99.95% Mo. It was produced by high-vacuum electron beam multiple melting in specially designed water-cooled copper molds [6]. The facilities for magnetic filtering of macroparticles were not used in this study. The substrates were placed at different distances L from the surface of the cathode. For each distance two substrates were positioned, one substrate parallel ($\theta = 0°$) and one

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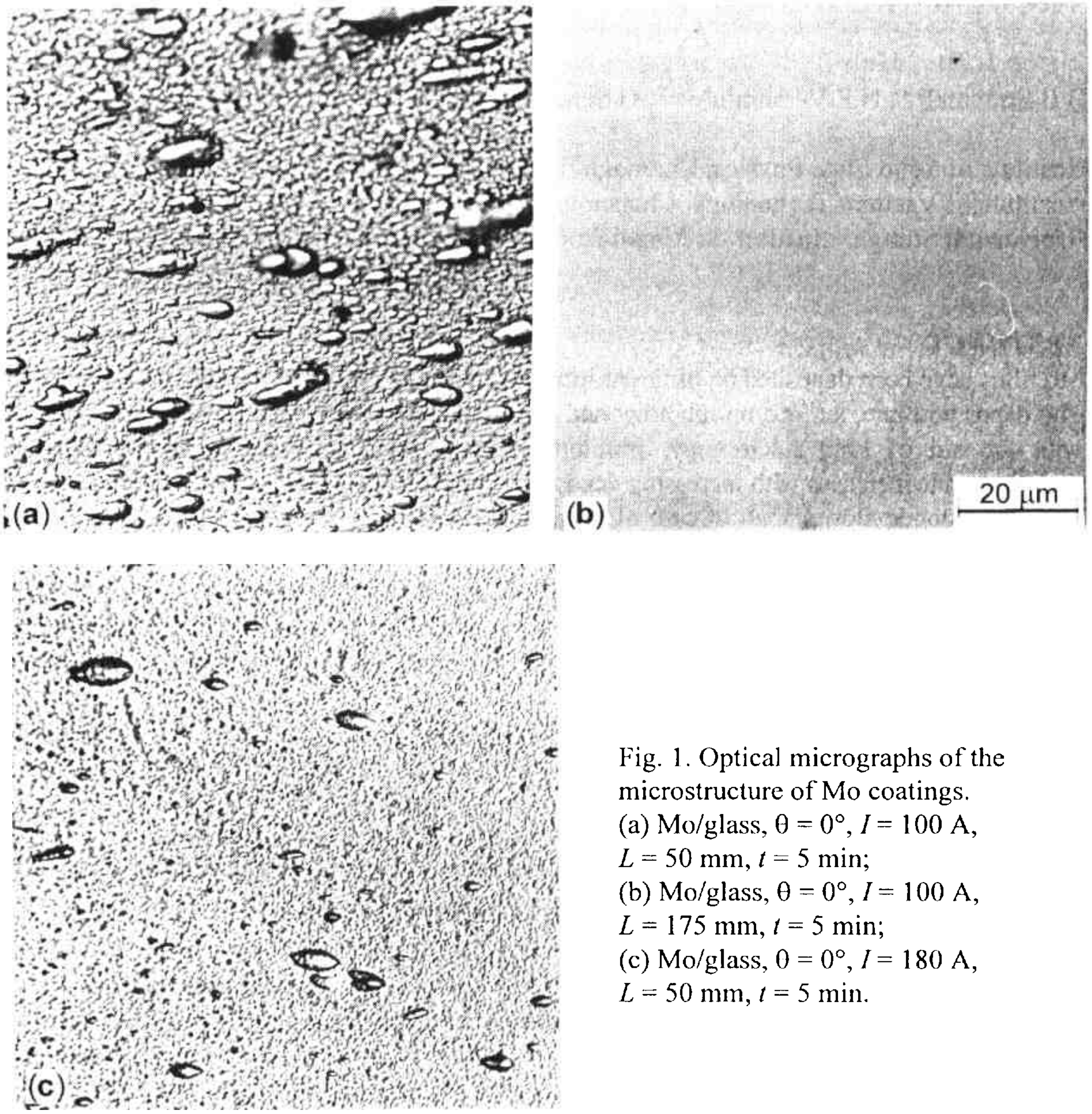

Fig. 1. Optical micrographs of the microstructure of Mo coatings.
(a) Mo/glass, $\theta = 0°$, $I = 100$ A, $L = 50$ mm, $t = 5$ min;
(b) Mo/glass, $\theta = 0°$, $I = 100$ A, $L = 175$ mm, $t = 5$ min;
(c) Mo/glass, $\theta = 0°$, $I = 180$ A, $L = 50$ mm, $t = 5$ min.

perpendicular ($\theta = 90°$) to the plasma flow coming axially from the cathode (θ is the angle between the direction of plasma flow and the surface of the substrate). The vacuum arc source voltage was constant ($U = 31$ V), and the discharge current I was varied from 80 to 180 A. The strength of the stabilizing magnetic field on the cathode surface ranged from 60 to 70 G. No bias was applied to the substrates. The coating time t was varied from 5 to 40 min. In order to avoid an overheating of the substrates the coating process was interrupted (in vacuum) every 2.5 min for 2.5 to 3 min. The thickness of the coatings d was measured with the aid of a "Polystep" profilometer and an optical microscope. The sizes of the microparticles were measured with the aid of a scanning electron microscope (JEOL 6400) and a Zeiss Axiophot optical microscope possessing contrast accessories which allow a resolution as low as 0.2 to 0.4 µm. The area S occupied by individual particles was determined to be $S = \pi r^2$ for round particles and $S = \pi ab/4$ for elliptical particles, where a and b are the axes of the ellipse. The fractional coverage, $\Sigma S/S_t$, was determined to be the ratio of the total area of all particles counted, ΣS, to the total projected area on the substrate for all analysed rectangles S_t ($S_t = nS_c$, where S_c is the square of one counting area, typically 2500 µm^2, and n is the number of rectangles counted (about 500)).

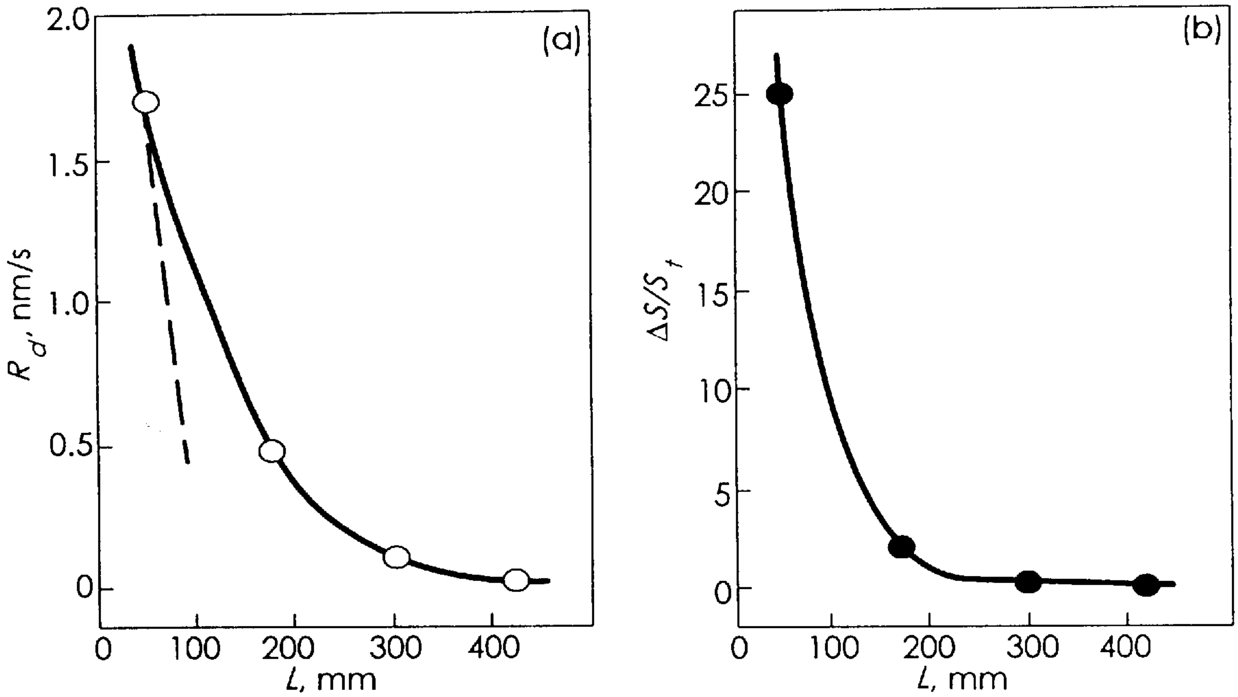

Fig. 2. Dependence of the deposition rate R_d (**a**) and fractional coverage $\Delta S/S_t$ (**b**) on the distance L between cathode and substrate. Mo/Cu (**a**) and Mo/glass (**b**). $\theta = 0°$, $I = 100$ A, $t = 5$ min.

3. RESULTS AND DISCUSSION

Optical micrographs of of the microstructure of Mo coatings are shown in Fig. 1. The number of microparticles decreases rapidly with increasing L (see also Fig. 2b). The aspect ratio a/b of microparticles is about 2.5 and does not depend on their dimension. With increasing thickness the particles are gradually incorporated into the growing film. The grain size of the particles is the same as in the rest of the film [7]. In Fig. 2a the dependence of the deposition rate R_d is shown on the distance L between cathode and substrate for substrates oriented parallel to the plasma flow coming from the cathode for a discharge power $P = 3.1$ kW. For $\theta = 0°$ at $L = 50$ mm the value $R_d = 15$ nm/s has been reached [4]. The broken line shows the slope of the R_d (L) dependence for the Mo magnetron sputter deposition taken from [8] for the same discharge power and comparable L/D ratios, D being the diameter of the cathode. Normally, only the R_d values for $L/D < 1$ can be found in the literature for the magnetron sputter deposition, because reasonable deposition rates can be reached only if the substrates are positioned close to the target. If the distance L exceeds the diameter of the magnetic ring behind the target the deposition rate decreases with increasing L even faster as it is shown in Fig. 2. It is obvious that R_d for vacuum arc deposition decreases with increasing L *much slower than in the case of magnetron sputter deposition.* It can be also clearly seen that the vacuum arc deposition permits to obtain R_d values which are *higher than* R_d *values reached with the aid of magnetron sputter depositio*n at the same values of P, L/D and θ. The R_d values on the substrates perpendicular to the plasma flow ($\theta = 90°$) are higher than for $\theta = 0°$ [4]. But this difference decreases with increasing L/D [4]. A slow decrease of R_d with increasing L/D and comparable values for normal and tangential incidence make easy *the coating of non-planar and three-dimensional parts with the aid of vacuum arc deposition.* The comparison of Figs. 2a and b definetely shows that R_d decreases with the increasing L slower than the fractional coverage. Therefore, the microparticles gradually

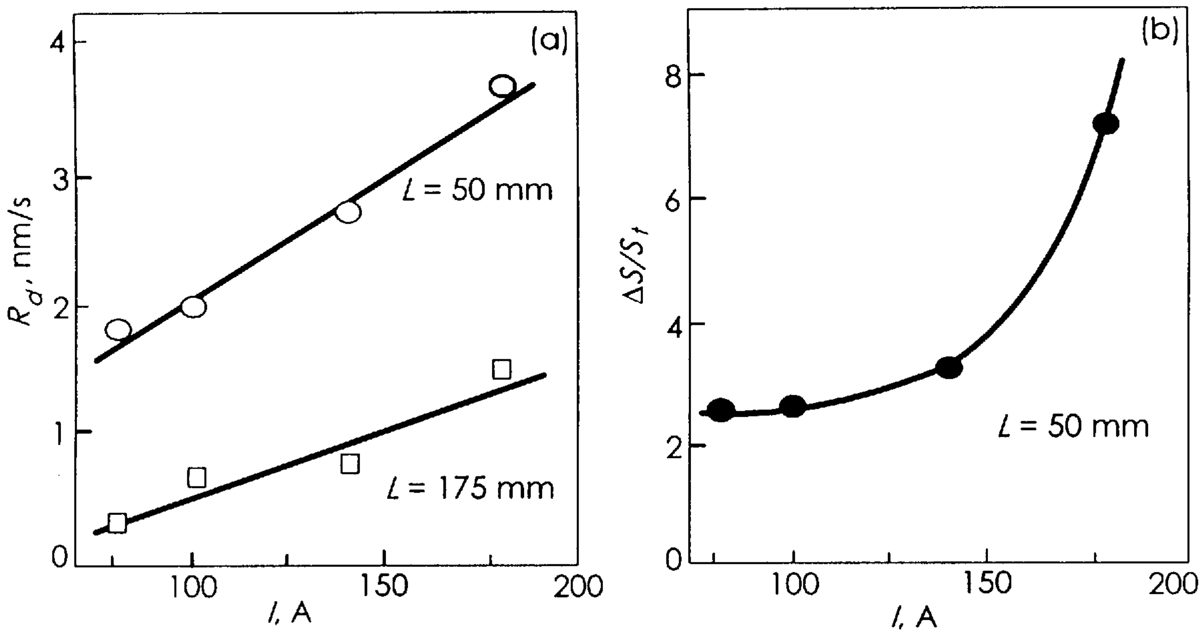

Fig. 3. Dependence of the deposition rate R_d (**a**) and fractional coverage $\Delta S/S_t$ (**b**) on the discharge current I. Mo/Cu (**a**) and Mo/glass (**b**). $\theta = 0°$, $t = 5$ min.

disappear from the plasma flow and *the contribution of the particles to the total deposition rate decreases with increasing distance from the cathode.* Figure 3 shows the dependence of the deposition rate R_d and fractional coverage $\Delta S/S_t$ on the discharge current I for four different distances L of substrates positioned perpendicular to the cathode surface. The deposition rate increases almost linearly with increasing discharge current. Close to the cathode this increase is most pronounced. The fractional coverage increases parabolically with increasing I. The comparison of Figs. 3a and b definetely shows that R_d increases with increasing I slower than the fractional coverage. Therefore, *the contribution of the particles to the total deposition rate increases with increasing discharge current.* It can be seen also from a comparison of micrographs 1a and c. This fact can be explained by the increase of the cathode temperature with increasing I because it is known that an increase of the cathode temperature makes easier the formation of microdroplets in the cathode spot [1].

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