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Abstract

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CATHODE SPUTTERING OF TUNGSTEN BY POTASSIUM IONS

The main difficulty in studying questions connected with the laws of cathode sputtering is that the sputtered surface is usually covered with a layer of gas atoms sorbed from the volume of the apparatus. These atoms may be held by ordinary sorption forces or may form chemical compounds with the material under study. On the other hand, the beam of ions incident on the target inevitably contaminates the surface with the substance used to obtain the ions. Thus, the sputtered surface is always covered with a layer that hinders the sputtering of the basic material.

In a number of communications (1–3), results are given for an analysis of the composition of products leaving the bombarded target. By the method of mass spectrometry the authors established that the following fly off from the surface: particles of the target material; particles corresponding to the incident ions and to adsorbed gases; and products of interaction of the target material with sorbed gases. It was shown (4) that sputtering of the target material in the form of chemical compounds of the latter type may constitute a considerable fraction of the total sputtering. These results lead to the necessity of analyzing simultaneously occurring processes: 1) sputtering directly of the material of the bombarded target and 2) ejection of the target material in the form of its chemical compound with sorbed gases. We set ourselves the task of elucidating the laws governing the sputtering of tungsten in the form of its chemical compounds and of finding conditions under which data for a clean tungsten surface can be obtained.

To record the amount of sputtered substance we used the method of radioactive indicators. Polycrystalline tungsten targets with induced activity ($^{184}_{74}$W) were subjected to ion bombardment. The activities used in the experiments made it possible to bring the sensitivity of the measurements to $1 \cdot 10^{-9}$ g. The experimental apparatus is described in detail in communication (4).

Fig. 1 and Fig. 2

Figure 1: Fig. 1 and Fig. 2

In order to estimate the role of sputtering of the material in the form of its chemical compounds, experiments were carried out in which a potential difference V_k of different sign relative to the target was applied between the target and the collector. In the case of positive values of the collector potential relative to the target, $V_k > 0$, no difference in sputtering was observed in comparison with the case $V_k = 0$; i.e., we did not detect sputtering of the material in the form of positive ions. On the contrary, at $V_k = -300$ V the amount of sputtered material received by the collector decreased appreciably. This shows that a considerable part of the sputtering of tungsten consists of negative ions.

A large number of negative ions can be connected only with the sputtering of tungsten-containing molecules of the surface contamination. The yield of negative ions from a metallic surface bombarded by positive ions increases considerably if a film of an alkali metal is present on the surface ([3], [5]). In our experiments such a film is formed by the ion beam itself.

Figure 1 shows the energy dependences of the sputtering coefficient of tungsten under the conditions $V_k = 0$ (curve *I*) and $V_k = -300$ V (curve *II*). Curve *II* characterizes the neutral part of the sputtering both of tungsten atoms and of its chemical compounds. Curve *III* shows the fraction δ of the total sputtering accounted for by sputtering of tungsten in the form of negative ions. The absolute values of the coefficient N^- for sputtering in the form of negative ions are shown in Fig. 2.

Fig. 1. *I*—dependence of the cathode sputtering coefficient of W on the energy of K^+ ions at $V_k = 0$; *II*—the same dependence at $V_k = -300$ V; *III*—dependence of the fraction of the total sputtering of W accounted for by the negative ionic component on the energy of K^+ ions

Fig. 2. Energy dependence of the coefficient for sputtering of W in the form of negative ions

In preparation for the experiments described, the target was degassed by heating in vacuum at temperatures up to $T \sim 2000^\circ$ K. During the measurements the target was at room temperature. Consequently, we may assume that the sputtering in the form of negative ions described by the curve in Fig. 2 is due mainly to adsorption of gas from the volume of the apparatus, the residual pressure in which during the experiments was usually $2 \cdot 10^{-6}$ mm Hg.

The quantities δ and N^- determine only the ionic component of the sputtering of tungsten in the form of its chemical compounds. Apparently, the total sputtering in the form of neutral and charged particles constitutes an even larger fraction of the total amount of sputtered material.

The presence of sputtering of this type may serve as a convenient criterion for

Fig. 3. Temperature dependence of the sputtering coefficient of W by K^+ ions with energy $E_p = 1600$ eV

Figure 2: Fig. 3. Temperature dependence of the sputtering coefficient of W by K^+ ions with energy $E_p = 1600$ eV

the state of the bombarded surface. Detection of negative ions indicates that the data obtained under such experimental conditions cannot be attributed to sputtering of pure tungsten. In order to exclude the sputtering of tungsten-containing compounds, it is necessary to reduce to a minimum the amount of "dirt" adsorbed on the target surface. This requirement can be fulfilled at a high temperature of the bombarded target.

It is natural to expect that sputtering of tungsten-containing compounds should depend on the target temperature. At sufficiently high target temperatures, part of the alkali coating evaporates, the work function of the surface increases, and the ejection of negative ions should practically cease. These considerations are very well confirmed by experiment. This does not mean that the ejection of tungsten-containing molecules ceases; the latter leave the surface in the form of neutral particles. A clear illustration is given by Fig. 3, which shows the temperature dependence of the cathode sputtering coefficient. Evidently, such a course of the process cannot describe sputtering of the base material. The presence of a maximum in the curve is due to the temperature dependence of the sputtering of tungsten-containing contaminants. The decrease in the sputtering coefficient at $T > 1200^\circ$ K characterizes partial cleaning of the target surface.

At higher temperatures, nonequilibrium evaporation of tungsten begins, preventing measurement of the amount of sputtered material. Therefore, the study of cathode sputtering at temperatures above 1300° K

was carried out on an experimental apparatus that made it possible to measure separately the results of the simultaneously occurring processes of evaporation and sputtering. Further experiments showed that, for a well-degassed target at temperatures $T > 1600^\circ$ K, the cathode sputtering coefficient ceases to depend on temperature. This means that under such conditions sputtering of tungsten-containing compounds is practically absent. Apparently, it may be assumed that the results obtained under such experimental conditions will characterize the sputtering of a pure metallic surface.

Fig. 3. Temperature dependence of the sputtering coefficient of W by K^+ ions with energy
$E_p = 1600$ eV

Fig. 4. Energy dependence of the sputtering coefficient of a clean surface of polycrystalline tungsten under bombardment by K^+ ions

Figure 4 shows the energy dependence of the cathode sputtering coefficient of a

Fig. 4. Energy dependence of the sputtering coefficient of a clean surface of polycrystalline tungsten under bombardment by K^+ ions

Figure 3: Fig. 4. Energy dependence of the sputtering coefficient of a clean surface of polycrystalline tungsten under bombardment by K^+ ions

tungsten target at a temperature $T \sim 1800^\circ$ K. In accordance with what was said above, these data refer to sputtering of a clean tungsten surface. Comparison of the curve in Fig. 4 with curve I in Fig. 1 makes it possible to conclude that, when the surface contamination is removed, both a strong increase in the cathode sputtering coefficient and a change in the form of its energy dependence occur.

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