# Influence of Sputter Atoms on Magnetron Discharge

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**Abstract – Ionization phenomena going in plasma of magnetron discharge are localized in the area which is several millimeters above the target surface. The self-target atoms play the role in the discharge mechanism and surface sputtering. There is a critical level of power starting from which the necessity to use working gas disappears.**

## 1. Introduction

It is known that the action of plasma fluxes and charged particle beams to the surface leads to different effects connected to the redistribution and relaxation of energy in the substance. In the context of this work those effects are considered which are conditioned by the inner structure of atoms and ions: behavior of gas discharge plasma at the presence of atoms with various ionization energies (at the example of magnetron discharge) and sputtering of target surface by it, change of potentials of interaction in metals and phenomena associated with it, alteration of interatom interaction at the electron subsystem excitation, strengthening of atom diffusion mobility in the conditions of temperature gradient appearance and concentration at the intense pulsed action.

## 2. Magnetron discharge plasma

Earlier basing on the qualitative (phenomenological) model of magnetron discharge and study of spacious distribution of potential by cathode it was shown that the significant concept on the magnetron discharge mechanism at DC requires further more accurate definition [1, 2]. For this purpose the floating potential of Langmuir probe at the zero current in its circuit has been studies.

Figure 1 shows the group of volt-ampere characteristics of this magnetron (curves *1–3*) and probe potential relatively anode (curves *4–6*) at various distances from the target surface in the area of its maximal etching. The voltage falling to the probe-anode interval (distance by voltage scale between couples of curves corresponding to equal distance of probe from target) was constant within the range of measurement inaccuracy and did not depend on discharge current.

The obtained results testify that the discharge area can be divided into two parts: zone of ion-electron current transportation several millimeters in width joined to the cathode surface and zone of electron current transportation protruding farther to the anode surface. The boundary between these zones is the external area of positive volumetric charge performing as the function of plasma cathode for anode area which does not contain magnetic field so the function of anode emitting positive ions in the cathode area.

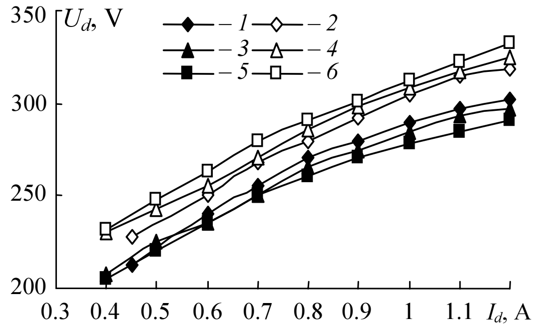


Fig. 1. The volt-ampere characteristics of magnetron (curves *1–3*) and probe potential relative to cathode (curves *4–6*) at various distances from the target surface: *1* and *4* – 14; *2* and *5* – 6; *3* and *6* – 4 mm

The spacious distribution of the probe floating potential in the center of target surface erosion zone was measured at various voltages. It was found out that the main change of electric potential is observed at 1-mm distance from the target surface. The distribution of electric field was in assumption that the probe potential coincides in the discharge gap while the distribution of excess discharge was calculated by the Poisson equation and is presented in Fig. 2.

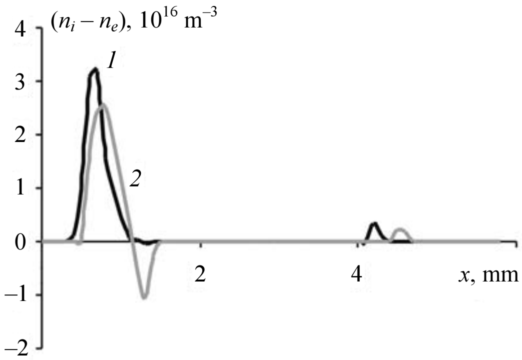


Fig. 2. The spacious distribution of excess charge for various voltages at magnetron: *1* – 225; *2* – 195 V

As it is seen from Fig. 2 there are two areas with the increased positive discharge density at various discharge voltages. The first of them is at the distance of about 1 mm from the target surface. The excess concentration of positive ions in it is about $3 \cdot 10^{16}$ m$^{-3}$

for 225 V voltage. In this area the main drop of electric potential applied to the discharge gap takes place. That is why it is responsible for acceleration of argon ions sputtering the target surface.

The second area is at the distance of about 4 mm from the target. The concentration of excess carriers in it is significantly lower and is about $2.5 \cdot 10^{15}$ m$^{-3}$. It favors the extraction of electrons from the intense zone of working gas ionization. At a lower discharge voltage of 195 V the area of negative excess charge can be observed. As the discharge voltage increases the spacious distribution function of excess charge moves to the left, the positive charge carrier concentration increases, the discharge leans to the target surface.

The method of molecular dynamics was used to calculate the propagation paths of electron motion in the crossed electric and magnetic fields. It is shown that the ionization acts produce electrons of first several generations (not more than 10) which go from the cathode surface not further that to 1.5 mm because only they are able to accumulate the energy exceeding the argon ionization potential at the cycloid height.

In the work the energy distribution of accelerated argon ions at the target surface was obtained. Its maximum was shifted to the side of high-energy particles. This is favorable for target sputtering effectiveness. When using a higher potential the energy of accelerated ions is higher. This leads to the increase of target etching.

Basing on the probe potential dependence on discharge current presented in Fig. 3 and Child-Langmuir equation the typical sizes of intense ionization zone have been obtained.

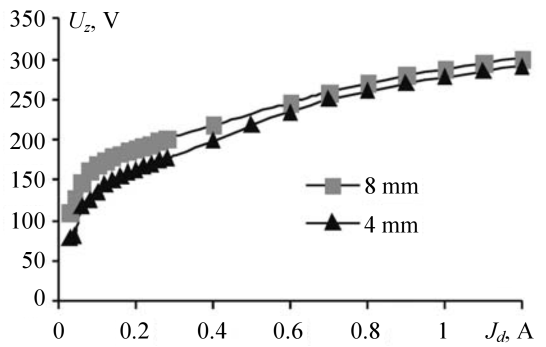


Fig. 3. The dependence of probe potential on discharge current at various distances from the target surface

Figure 4 represent the sizes are presented as discharge voltage function for the case when the probe is at 4-mm distance from the target surface. When the discharge voltage is less than 250 V the width of this zone is units of millimeters, and then become several times smaller with the voltage growth.

This fact testifies the jump-type change of processes going in discharge when the voltage changes. Similar phenomena are often observed visually when at the increase of discharge voltage the glowing zone volume sharply decreases while the glow intensity increases.

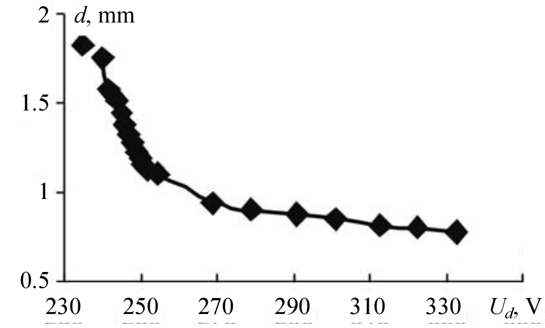


Fig. 4. The dependence of independent discharge zone size on the voltage of magnetron

To our mind the internal structure of magnetron discharge at low voltage reminds glowing discharge. As the current and voltage grow the jump-type transition to discharge which is usually called magnetron one occurs. In this process the sputtered atoms play an important role due to their ionization potential which is lower in comparison to argon. The discharge structure completely changes when the concentration of sputtered atoms increase so much that the process of self-sputtering becomes significant in the target erosion mechanism.

The mode of self-sputtering is a very interesting form of discharge existence. It does not only provide high speeds of deposition and allows getting more pure films but also helps to open new ways of generation and application of low-temperature plasma of metals in various fields of science and technology. In addition to this the action of sputtered atoms and their ions to the plasma formation processes are not often considered.

That is why we developed a construction and studied the process of liquid-phase magnetron transition to the target self-sputtering mode. The time dependences of capsule temperature, voltage and discharge current are presented. Fig. 5 shows the dependence of film growth speed on discharge current for copper target.

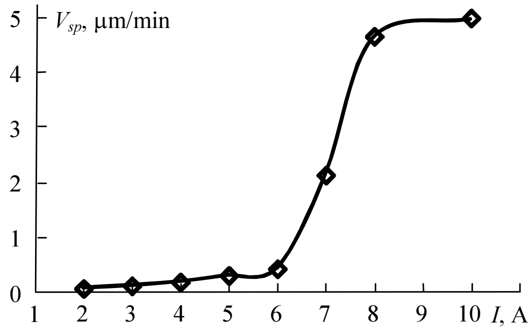


Fig. 5. The dependence of film growth speed on discharge current for copper target

At the initial period of time when the target is in the solid state as well as right after its melting (up to $I = 6$ A) the insignificant growth of deposition speed is observed. This is related to the process of target material evaporation. Further there is a section of sharp increase of deposition speed and its release to saturation. When a definite current value is reached the curve goes to plateau (approximately 8 A) starting from this value, and the magnetron transfers to self-sputtering mode. After that it is possible to stop the argon introduction to the working chamber. The temperature of melt in such mode is not lower than 1250 °C what corresponds to the pressure of saturated copper vapor of 0.13 Pa.

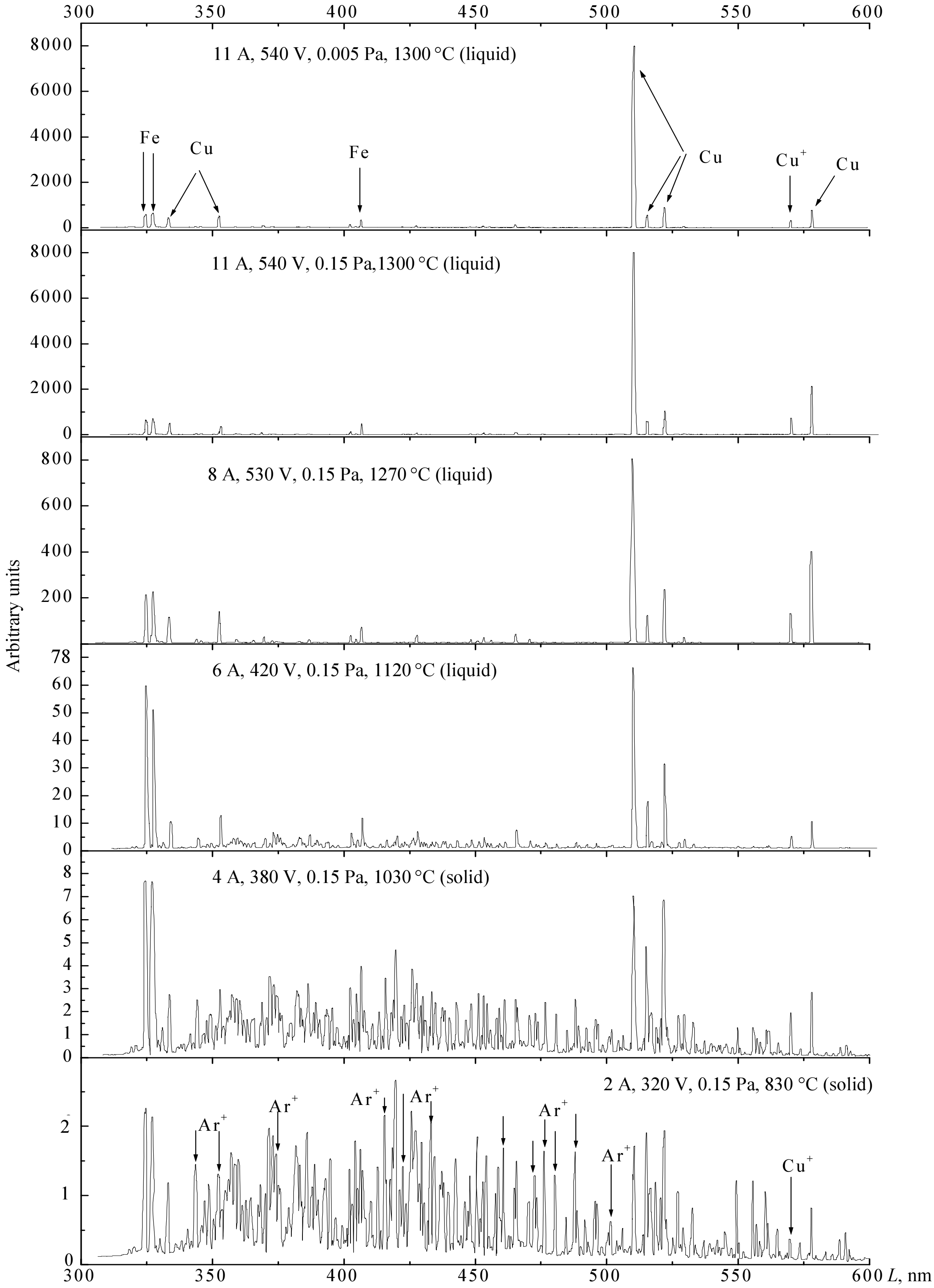


Fig. 6. Optical spectrum of the magnetron discharge plasma

This is comparable to the working pressures of argon of magnetron with solid-body target.

The optical spectrums of magnetron discharge plasma are presented in Fig. 6 together with the data on magnetron operation modes: discharge currents, voltages, pressures of working gas and capsule temperatures. The sign “+” in brackets points to the fact that the line corresponds to ion, sign “0” – to atom. In the diagrams in addition to lines of main elements there are lines of atomic iron. This is related to the magnetron body sputtering. Relatively small height of $Cu^+$ lines is conditioned by a low sensitivity of photo electron multiplier in this area of wavelength. A sharp increase of target ion concentration was observed in plasma when the discharge parameters were close to self-sputtering mode.

## 3. Conclusion

Considering the fact that argon ionization potential is significantly higher than that of the sputtered substance it is possible to conclude that the presence of inert gas is important only at the stage of discharge ignition and while operating at low power level. When working at higher power level with a rather high value of saturated vapor pressure of the sputtered material the redistribution of cathode potential occurs in such way that Hall electrons do not reach the energy required for argon atom ionization when moving along cycloid. To the favor of this statement the fact testifies that volt-ampere characteristics of magnetron operating in the self-sputtering mode become insensitive to the argon presence. Thus, starting from some critical level of power the target sputtering is performed mainly by its own ions [3–5].

## References

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