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The role of magnetic energy on plasma localization during the glow discharge under reduced pressure

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Abstract. In this work, we present the first results of our research on the synergy of fields, electric and magnetic, in the initiation and development of glow discharge under reduced pressure. In the two-electrode system under reduced pressure, the breakdown voltage characterizes a minimum energy input of the electric field to initiate and sustain the glow discharge. The glow discharge enhanced by the magnetic field applied just above the surface of the cathode influences the breakdown voltage decreasing its value. The idea of the experiment was to verify whether the contribution of potential energy of the magnetic field applied around the cathode is sufficiently effective to locate the plasma of glow discharge to the grounded cathode, which, in fact, is the part of a vacuum chamber wall (the anode is positively biased in this case). In our studies, we used the grounded magnetron unit with positively biased anode in order to achieve favorable conditions for the deposition of thin films on fibrous substrates such as fabrics for metallization, assuming that locally applied magnetic field can effectively locate plasma. The results of our studies (Paschen curve with the participation of the magnetic field) seem to confirm the validity of the research assumption. What is the most spectacular – the glow discharge was initiated between introduced into the chamber anode and the grounded cathode of magnetron 'assisted' by the magnetic field (discharge did not include the area of the anode, which is a part of the magnetron construction).

Key words: glow discharge • grounded magnetron • magnetron sputtering

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Introduction

In the two-electrode system under reduced pressure, the breakdown voltage characterizes a minimum energy input of the electric field to initiate and sustain the glow discharge. Physical conditions of glow discharge initiation are determined by the Paschen's law [1], which binds the discharge initiation voltage V_B with the vapor pressure p and the distance between the electrodes d. The $V_B = f(p*d)$ relation is a curve indicating a specific minimum. Considering the mechanism of vapors ionization by Townsend regime, that is avalanche ionization due to inelastic collisions of the primary electrons with neutral gas molecules and wherein the generation of subsequent electrons occurs [2]. The increase of the breakdown voltage at the left side of the Paschen curve minimum is due to an increase of the electrons' free path in relation to reducing the dimension of the distance between electrodes where electrons move. Under conditions of relatively large interelectrode distance and the short free path (right side of the Paschen curve), the probability of collision is so high that, in macroscopic terms, the system needs more power to sustain discharge, since the accelerated in an electric field electrons rapidly precipitate its energy by collisions with neutral molecules.

It is known that glow discharge enhanced by the magnetic field applied just above the surface of the cathode influences the breakdown voltage decreasing its value, both the magnetic field oriented parallel with respect to the electric field [3], as in the case of their perpendicular orientation [4, 5]. The magnetic field was used to increase the efficiency of a glow discharge in the gas under reduced pressure in the construction of one of the most important sources of plasma among the plasma surface engineering methods – the magnetron sputtering. In the standard magnetron unit, the anode is grounded with the vacuum chamber and the cathode, as a source of vapor, is negatively biased.

The idea of the experiment was to verify whether the contribution of potential energy of the magnetic field applied around the cathode is sufficiently effective to locate the plasma of glow discharge to the grounded cathode, which, in fact, is the part of a vacuum chamber wall (the anode is positively biased in this case).

Experimental studies

In our experiments, we used a typical circular WMK-50 magnetron and specially prepared anode in the form of a ring made from copper. The anode was connected to the positive potential of the DSP power supply [6], while the whole construction of magnetron was grounded with the vacuum chamber.

Figure 1 shows a schematic arrangement of anode and cathode (the cathode was on the ground potential). The anode was placed in a magnetron axis, in distance *d* equal to 4 and 12 cm. The magnetron was equipped with targets made of different materials with different thicknesses *g*, to obtain a magnetic field of varying intensity at the target surface. In the experiments, we used three types of targets: iron with a thickness *g* equals 5 and 12 mm in order to trap the magnetic field in the body of the magnetron and the two targets, which were made of titanium with a thickness *g* equaling 5 and 3 mm, respectively. The discharges were initiated at different pressures from 1 to 7 Pa, for different values of breakdown voltage in the range of 0–800 V for all value of the working gas pressure.

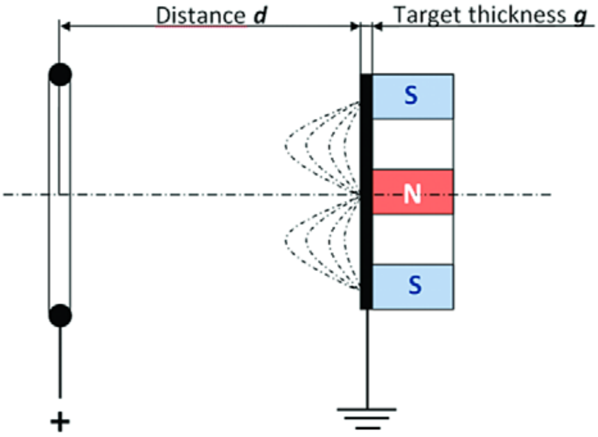

Fig. 1. Schematic arrangement of the experiment.

The measurement of magnetic field was made by using a magnetic field sensor ASONIK SMS-102. The measurements were made at the surface and 10 mm from the surface of the magnetron.

Experimental results and discussion

The main aim of our study was to convince if locally applied magnetic field can effectively locate the plasma of glow discharge. For this purpose, we have assembled the titanium and iron targets with variable thickness *g* to the grounded magnetron unit. By installing iron target, we wanted to effectively close the magnetic field lines inside the body of magnetron unit, just below the iron target. The thickness of iron target was sufficiently large so magnetic field strength measured on the target surface showed a value of zero, thereby preventing the grounded surface from the effect of magnetic field during the experiment. It has appeared that the initiation of discharge in such a conditions was impossible – the 800 V voltage applied to the anode was insufficient to initiate a discharge.

In the next stage of our experiment, the two targets made of titanium with a thickness of 5 and 3 mm were used. After installing them in the magnetron unit, we have obtained the different intensities of magnetic field. The measurements of the intensity distribution of a magnetic field showed that at the surface of the 3 mm thick target the magnetic field is more than twice intensive than at the target surface with a thickness of 5 mm (Fig. 2). In both cases, the glow discharge was initiated, which illustrate how effectively magnetic field supports the discharge. What is the most spectacular – the glow discharge was initiated between introduced into the chamber, positively biased anode and the grounded cathode of magnetron 'assisted' by the magnetic field (discharge did not include the area of the anode, which is part of the magnetron construction!), which proves the rightness of the adopted assumption.

In the last stage of the experiment, we intended to demonstrate quantitative impact of energy of magnetic field in a glow discharge, which would show the measurements of breakdown voltage V_B as a function of pressure and the distance between the two electrodes for two target thicknesses. We believe that an effort to interpret the relation between breakdown voltage V_B and pressure p, at the constant distance d_{const}, is satisfactory at this preliminary stage of our research. The results obtained from the performed measurements are shown in Fig. 3.

The lowest values of breakdown voltage were recorded for cases in which the glow discharge was supported by magnetic field of relatively higher intensity. This effect is particularly pronounced for left side of the Paschen curves, where exist the conditions of a relatively long free path. The effect of magnetic field on the measured characteristics emphasizes with the influence on the motion of electrons of discharge plasma. Under the conditions of the magnetic field, the electrons are trapped and gyrate around magnetic field lines, which is

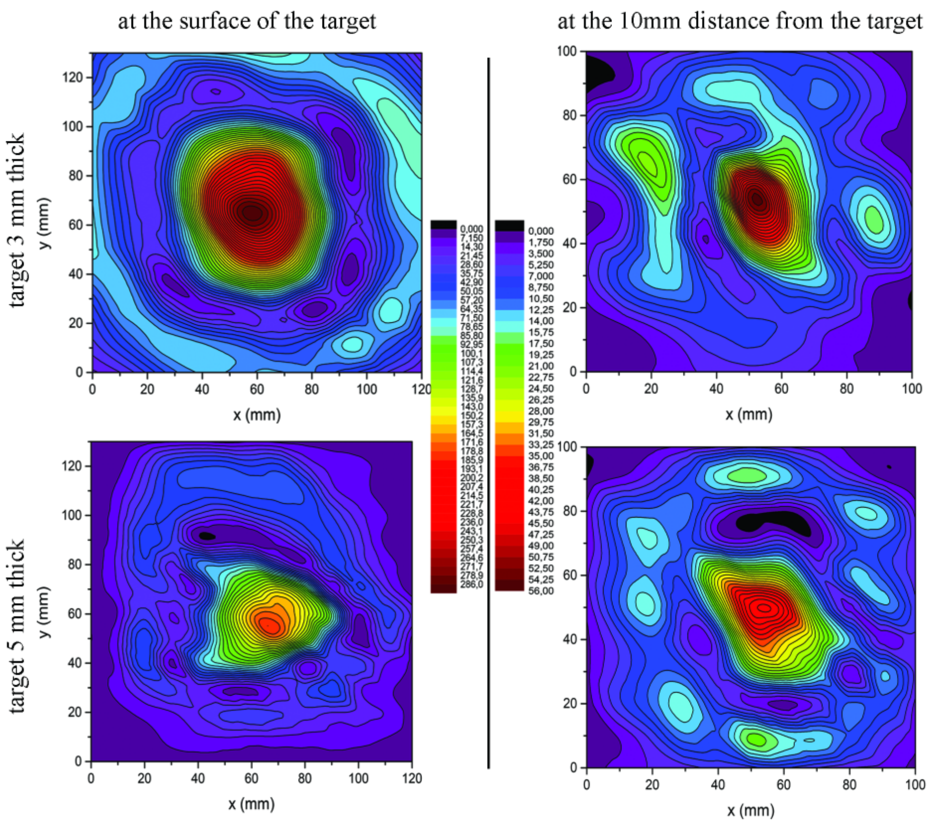

Fig. 2. Magnetic field strength distributions on the targets surface (left), and on the distance of 10 mm from the surface (right).

defined by the Larmor radius. The consequence of helical trajectory of plasma electrons motion is the increasing the probability of occurrence ionization by inelastic collisions. This effect comes from decreasing the Larmor radius with increasing the magnetic induction [7]. Stronger occurrence of ionization events make concentration of electrons in plasma higher (generation of SE electrons), increasing the conductivity and the degree of ionization of plasma components. These phenomena illustrate in a principled way contribution of the magnetic field energy at the expense of the electric field energy input in the course of the glow discharge. The element of novelty of our work is not in itself to demonstrate the contribution of the magnetic field energy in supporting the glow discharge because the literature in this area provides sufficient information [3–5], but to demonstrate his role as a factor for localization of plasma at the electrically grounded element of vacuum apparatus and, in addition, giving it the status of the electrical cathode, which can undergo phenomena characteristic to magnetron sputtering. The presented results are the preliminary results showing a phenomenon that we believe is of great importance for one of the plasma surface engineering method, the magnetron sputtering method, due to the opportunity of simplifying the construction of the magnetron as a source of vapors. In our future work, we consider to make a wider diagnostics of glow discharge generation in the conditions of the 'grounded cathode' and develop a technological system using our solution to the synthesis of coatings of materials.

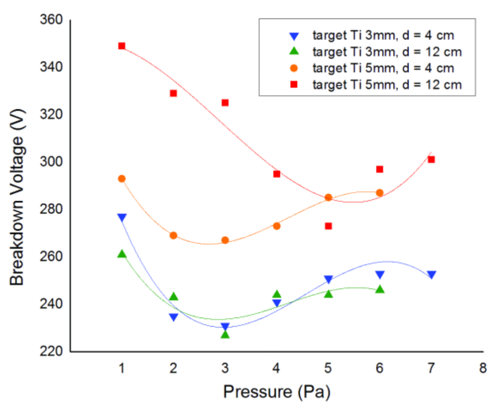

Fig. 3. The dependence of breakdown voltage as a function of working pressure for two thicknesses of the titanium targets and two distances between the electrodes (the curves have been inserted for presentation purpose only).

Conclusions

The results of our preliminary studies concerning the participation of the magnetic field in glow discharge proved our assumption that energy of magnetic field applied locally at the surface of grounded vacuum chamber wall can locate the discharge plasma in this specific region. The energetic input of magnetic field into glow discharge was demonstrated by measured Paschen curves for discharges supplied by fields of different intensities – the stronger magnetic field was, the lower breakdown voltage of discharge was measured. We believe that continuation of our study can simplify the construction of plasma sources in magnetron sputtering methods by using the grounded cathode.

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