Hybrid plasma system for magnetron deposition of coatings with ion assistance

K V Vavilin[1], E A Kralkina[a, 1], P A Nekludova[1], A. K Petrov[1], A M Nikonov[1], V B Pavlov[b, (1)]

A A Airapetov[2], V V Odinokov[2], G Ya Pavlov[2], V A Sologub[2]

[1] Faculty of physics, Lomonosov MSU, Moscow, 119991, Leninskie Gory 1, build. 2
[2] PJSC “Research institute of precision machine manufacturing”, Russia. 124469, Moscow, Zelenograd, Panfilovsky avenue 10

[a] ekralkina@mail.ru , [b] vb_pavlov@mail.ru

Abstract. The results of the study of the plasma hybrid system based on the combined magnetron discharge and high-frequency inductive discharge located in the external magnetic field is presented. Magnetron discharge provides the generation of atoms and ions of the target materials while the flow of accelerated ions used for the ion assistance is provided by the RF inductive discharge. An external magnetic field is used to optimize the power input to the discharge, to increase the ion current density in the realm of substrate and to enhance the area of uniform plasma. The joint operation of magnetron and RF inductive discharge leads to a substantial increase (not equal to the sum of the parameters obtained under separate operation of two hybrid system channels) of the ion current density and intensity of sputtered material spectral lines radiation. Optimal mode of the hybrid plasma system operation provides uniform ion current density on the diameter of at least 150mm at 0.7PA argon pressure. The optimal values of the magnetic fields in the region of the substrate location lie in the range 2-8 mTl, while in the region of the RF input power unit lie in the range 0.5-25 mTl.

1. Introduction

The creation of innovative products in electronics, mechanical engineering, medical technology and other fields is related usually to the use of new composite and multicomponent materials. In general, a multifunctional thin film layers must be deposited by the low cost, environmentally friendly, technically accessible and safe methods. In the last decade a set of methods for the coating of complex shape surfaces has been intensively developed [1,2]. Among them the scientific and technological preconditions have been established for the practical utilization of clean and safe vacuum plasma processes. Ion sputtering of the solid targets in gas discharge plasma is the multipurpose and efficient method of the target material atoms and ions generation. So, it is sputtering vacuum-plasma magnetron and vacuum arc gas discharges systems that are widely used for the film deposition. However, the simple usage of the sputtering systems does not allow to control with necessary accuracy the nanostructure and chemical composition of the deposited layers. This requires the introduction of the assisting ion bombardment of the substrate simultaneously with the film deposition [3,4], i.e. one needs to develop a hybrid plasma system, where in addition to the magnetron or vacuum arc device the source of the accelerated ions with the flux density matched with the deposition system rate is present. This paper presents the first results of a study of the hybrid plasma system, where in addition to magnetron the RF inductive discharge placed in an external magnetic field is used for generation of accelerated ions flow for ion assistance.

2. Construction of the hybrid plasma system

The design of the hybrid plasma system (HPS) is shown on Figures 1 and 2.

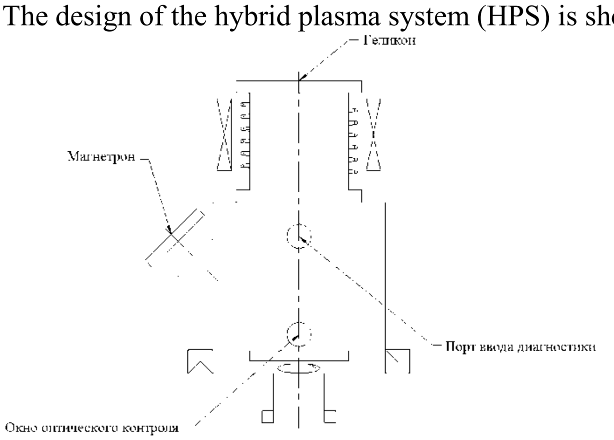

Figure 1. Schematic view of the Hybrid plasma system.

Figure 2. Photograph of the Hybrid plasma system.

The HPS consists of two parts. The main part is a steel cylindrical chamber with a diameter of 500 mm and a height of 350 mm. At the bottom of the chamber the rotatable table for placing the processed samples is assembled. During tests and optimization of the technological regimes of HPS a system of probes for monitoring plasma parameters was mounted on the table. A special port is mounted on the side surface of the chamber for output of the signals from probes to the recording equipment. To carry out spectrometric studies of plasma parameters in the area near the table two windows strictly arranged against each other are assembled. On the side surface of the chamber a magnetron is installed. Below the main chamber an electromagnet, which yields an external magnetic field induction near the table in the range 0 -150Gs is situated.

Above the main chamber quartz cylindrical plasma source with a length of 250 mm and a diameter of 220mm is mounted. On the top the source is closed by glass flange and at the bottom - by the metal flange with an opening providing plasma access to the main plasma chamber. The magnetic field in the upper chamber in the range of 0 -300Gs is provided by electromagnet. To ignite and maintain the discharge the helical antenna is used. The antenna ends are connected via a matching system to the RF power supply with the operating frequency 13.56MHz and output power up to 1000W.

To investigate the plasma uniformity in the region of the substrate the 25 flat probes are mounted on the table. 13 probes are parallel to the symmetry axis of the magnetron (the x axis) and 12 probes are perpendicular thereto (hereinafter referred to axis y). To measure the ion saturation current the potential -60V with respect to the walls of the main chamber is applied to the probes. The plasma radiation via optical fiber is sent to the monochromator MDR – 40 at which output the photomultiplier is located. The signal from the photomultiplier is amplified and registered by computer. Scanning the spectrum is carried out in the range of 400-700nm.

3. Results of the operating regimes of the HPS study

Note that in the above range of external magnetic fields and RF power supply power, the inequality is valid [5]:

$$\omega_{Li} << \omega << \Omega_e << \omega_{Le},$$

where ω_{Li}, ω, Ω_e, ω_{Le} are ion Langmuir, operating, electron cyclotron and electron Langmuir frequency. The range of plasma parameters satisfying the inequality corresponds to an area where resonant excitation of linked helicon and oblique Langmuir waves is possible. Under conditions of resonance the energy input to plasma is optimized. In addition, the penetration of the RF field into the plasma under conditions of resonance provides the possibility to organize extensive area of long and uniform plasma. Below RF inductive discharge placed in an external magnetic field, the induction of which corresponds to the conditions of resonance excitation of helicon and oblique Langmuir waves will be called helicon one

Experimental study of the discharge in the GPS has shown that the imposition of a uniform magnetic field leads to significant changes in the length of the discharge. In the absence of a magnetic field the discharge is concentrated in the top quartz chamber. Increase of the magnetic field strength first leads to a plasma appearance in the upper part of the main steel chamber, then the length of the portion of discharge with the high intensity of radiation in the main chamber begins to grow, and finally, the discharge is closed to the table and form an extended plasma column. Thus, optimization of magnetic field value gives the possibility to increase ion current density near the substrate from 0.5 to 3mA/cm^2 at the RF power generator power 500W. The diameter of the plasma column is approximately equal to the diameter of the top quartz chamber.

Experiments have demnstrated the mutual influence of the magnetron and helicon discharge. Figures 3 and 4 shows the results of radial ion saturation current distribution measurements along the x and y axes, obtained under operation of the helicon discharge and magnetron individually, and under their simultaneous operation.

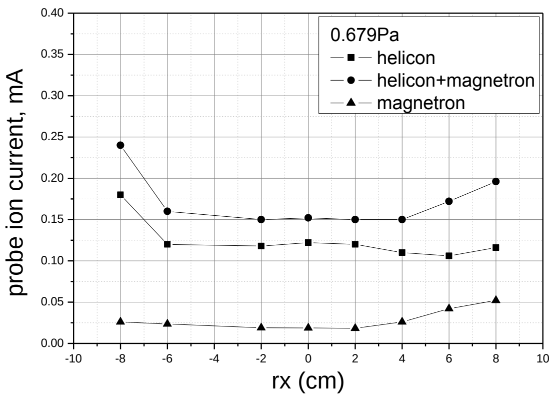

Figure 3. Radial dependence of saturation current along *x* axis

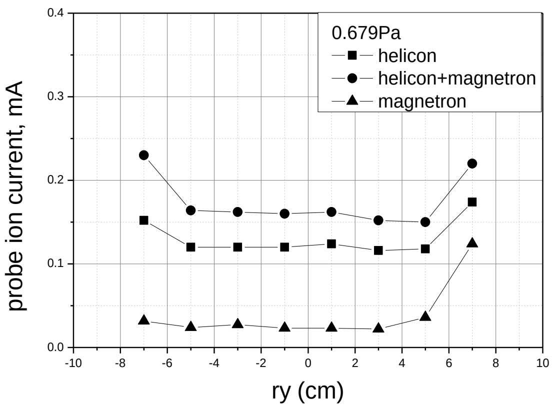

Figure 4. Radial dependence of saturation current along *y* axis

As can be seen, the joint implementation of the two discharges leads to a significant increase in the values of the ionic current. It is higher than the sum of the values measured under separate operation of helicon discharge and magnetron. This conclusion is valid for all the considered experimental conditions. The growth of Ar pressure from 0.3 to 0.7Pa, as experiments have shown, leads to a significant improvement of the radial distribution uniformity of the ion current, however, the absolute value of the ion current falls. A further increase in the pressure to 1 Pa leads to a further drop in the values of the ionic current.

The results presented above indicate the impact of the magnetron discharge on the parameters of the hybrid system. Influence of the helicon plasma source on the magnetron with a titanium target operation can be seen on the basis of the plasma spectral studies. Figure 3 shows a part of the plasma radiation spectrum, where the intensive TiI spectral lines are localized, measured at a pressure 0.3Pa in the case of the separate magnetron operation and joint helicon and magnetron operation.

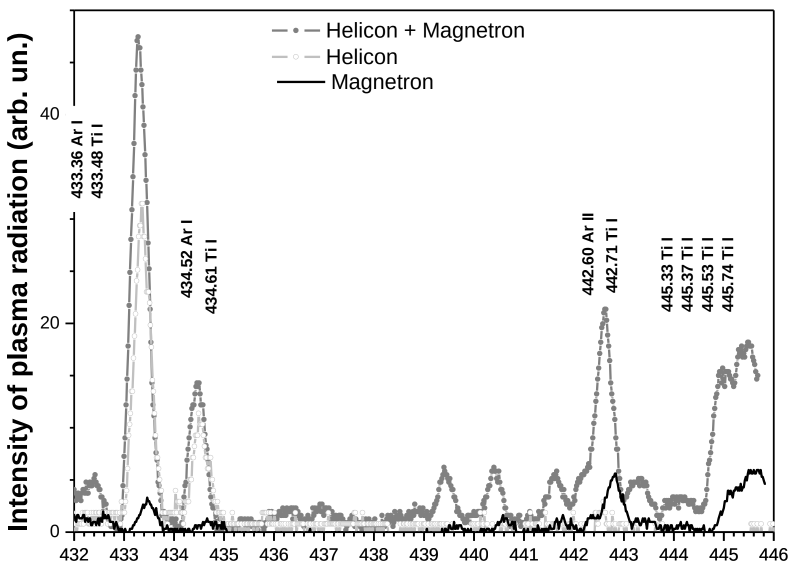

Figure 3. Part of the radiation spectra with high intensity TiI lines.

Experiments have shown that under conditions of separate magnetron operation The TiI spectral lines can be hardly identified due to the small number of Ti atoms in the discharge. However, under joint operation of the devices the intensity of TiI spectral increase, indicating the growth of titanium atoms concentration. In addition it was found that the intensity of the TiI lines in the region of the substrate was slightly less than the intensity in the region of the magnetron location.

Optimal mode of the hybrid plasma system operation has been found to provide uniform ion current density on the diameter of at least 150mm at 0.7PA argon pressure. The optimal values of the magnetic fields in the region of the substrate location lie in the range 2-8 mTl, while in the region of the RF input power unit lie in the range 0.5 – 25 mTl.

References

[1] Donald M. Mattox 2003 *The foundation of vacuum coating technology* N.Y.: Noyes publications.

[2] Zhurin V V 2012 *Industrial ion sources. Broad beam Gridless Ion Source Technology* N.Y.: Wiley-VCH Verlag & Co.

[3] John S. Colligon 2004 Ion-assisted sputter deposition *Phil. Trans. R. Soc. Lond. A* **362**, 103-16.

[4] Winters H et al. 1998 Influence of energy reflected from the target on thin film characteristics *J.Vac.Sci.Technol. A* **11** 657-63.

[5] Alexandrov A.F., Bogdankevich L.S., Rukhadze A.A. *Principles of Plasma Electrodynamics,* Heidelberg: Springer Verlag, 1984.