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Formation of Nanosized Coatings in Hybrid Plasma Reactor Combining Magnetron or Arc Deposition with RF Plasma Assistance

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Abstract. The hybrid plasma reactor is based on the combined magnetron or arc discharge and radio-frequency inductive discharge located in the external magnetic field. Magnetron or arc 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 high value of the ion flow bombarding the substrate gives the possibility to organize the effective ion assistance to the films growth in case of high rate deposition by the arc sources.

The deposition of Ti, Al, Si and permalloy films showed that the presence of ion assistance leads to the substantial change of the films structure and properties.

Introduction

Creation of innovative products in electronics, mechanical engineering, medical technology and other fields, is usually associated with the use of new composite and multi-component materials. In the last decade, the physical-chemical methods of coating of surfaces of complex shapes are intensively developed, scientific and technological prerequisites for the practical use of environmentally friendly and safe vacuum plasma processes in the production of the complex film structures are created. Vacuum plasma systems based on magnetron and vacuum-arc discharge are widespread. However, the simple use of sputtering sources for deposition of different materials doesn't allows flexible control of nanostructure and chemical composition of the deposited layer. Optimization of technological processes requires the introduction of the assisting ion bombardment of the substrate simultaneously with the deposition of the films, what is more the flow of assisting ions should be matched with the flow of sputtered atoms. In [1] the results of numerous experiments in the field of coatings with the assisting ion beam are analyzed. It is shown that the most significant changes in the properties of the deposited films occur if every deposited atom receives additional energy in the range from 1.0 to 100 eV. The greatest deposition rate is achieved using a vacuum-arc sources. In [2] for ionic stimulation of vacuum-arc deposition (creation of ion flow, the value of which corresponds to the deposition rate), it is proposed to use an inductive RF discharge, placed in an external magnetic field with the induction corresponding to the resonance conditions of excitation of helicon waves.

This paper presents the results of optimization and utilization of the plasma reactor combining magnetron deposition of thin films with the assistance by ion flow generated in inductive RF discharge with external magnetic field.

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Experimental Procedure

The scheme of the plasma reactor is shown on Fig.1. It consists of two parts. The main part is a processing metal chamber of the cylindrical shape with a diameter of 500 mm and a height of 350 mm. On the sides of the chamber a magnetron and a vacuum arc source are installed. In the upper part of the processing chamber a cylindrical quartz gas discharge chamber with a length of 250 mm and a diameter of 220 mm is mounted. Above the volume of the chamber is closed by a hollow glass flange and by metal flange with an opening providing access to the main plasma chamber at the bottom. Two electromagnets provide a magnetic field in the processing chamber. For excitation of the discharge, a solenoidal antenna placed on the outside of the quartz chamber is used. The ends of the antenna are connected through the matching system to the RF generator with an operating frequency of 13.56 MHz and an output power of 1000 W. Probe and spectroscopic methods are used for plasma diagnostics. To study the plasma homogeneity in the substrate movable Langmuire probe is used. To measure the ion saturation current, a potential of 60 V negative in relation to the main chamber walls is supplied to the probe. The plasma radiation is transmitted through the light guide to the input of the MDR-41 monochromator, at the output of which the photomultiplier FEU-100 is placed. A signal from the photomultiplier tube is amplified and fed to the ADC connected with the computer. The spectrum is scanned in the range of 400-700 nm. Measurements were carried out in the argon environment at pressures ranging from 0.2 Pa to 1.5 Pa. Ti, Al, Si+10%Al, and permalloy targets were utilized for thin films deposition.

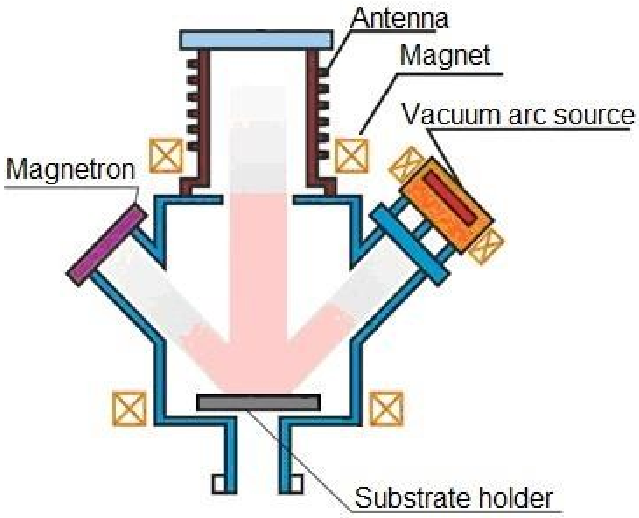

Fig.1. The scheme of the plasma reactor.

Characterization of the Operation Modes of Plasma Reactor

Experimental investigations of the discharge in hybrid plasma reactor showed that the superposition of an external magnetic field leads to significant changes in the length of the discharge. Whit a magnetic field of about 40 Gauss, the discharge closes on the bottom flange, forming a long plasma column. The diameter of the plasma column is approximately equal to 20 cm. Fig.2 shows the results of measurement of radial distribution of ion saturation current along the substrate in dependence on the current flowing through the electromagnet located on the upper part of the processing chamber I_{top}. As can be seen, the most homogeneous distribution can be obtained at the I_{top}, corresponding to the conditions preceding resonance increase of the plasma density in the central parts of processing chamber related to the excitation of helicon and Tivelpiece –Gold waves [3–5]. The increase of the ion current value here can be achieved by the increase of the current I_{bot} flowing through the electromagnet located at the bottom of the processing chamber. In case if RF power source power is equal to 1000 W the ion current density can be changed within 1 – 3mA/cm^2.

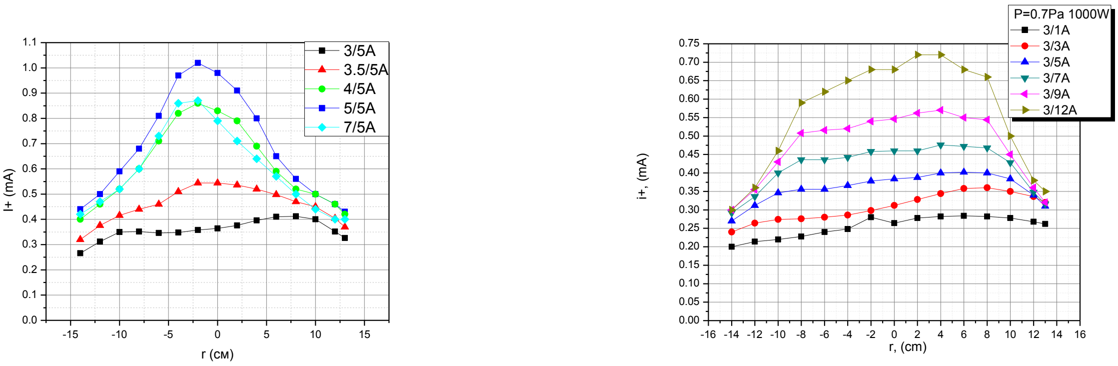

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Fig.2. Radial dependence of probe ion current in dependence on I_{top} (a) and I_{bot} (b).

Experiments showed that joint work of the two discharges leads to a substantial increase of ion current whose value is higher than the sum of the values measured in separate modes for inductive RF source and the magnetron. Growth of the pressure from 0.3 to 0.7 Pa, as shown by the experiments, leads to substantial improvement in the uniformity of the radial distribution of ion current, however, its absolute value declines. Increasing of pressure to 1 Pa leads to a further decrease of ion current.

Results of Coatings Deposition in Hybrid Plasma Reactor Combining Magnetron or Arc Deposition with Helicon Plasma Assistance

Figs. 3,4 show SEM pictures of the Al and Si films deposited during the operation only of the magnetron and during of the simultaneous operation of the magnetron and RF discharge.

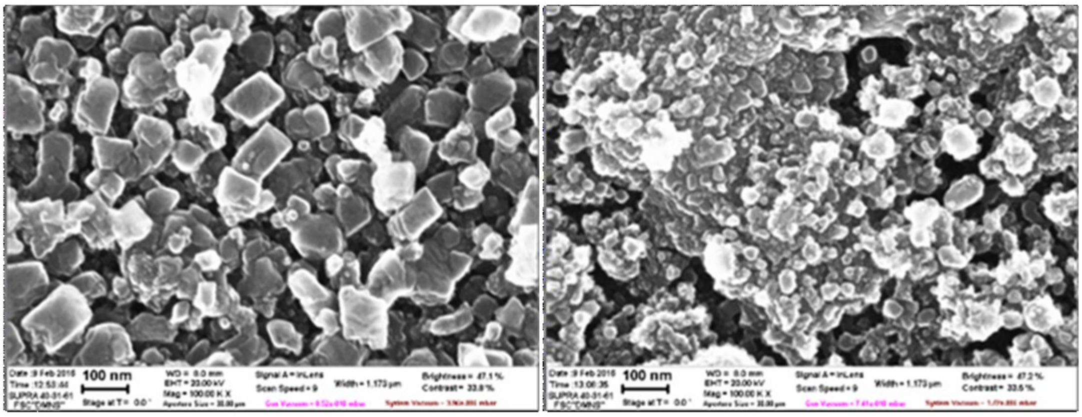

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Fig.3. SEM pictures of Al films deposited during the operation only of the magnetron and during of the simultaneous operation of the magnetron and RF discharge.

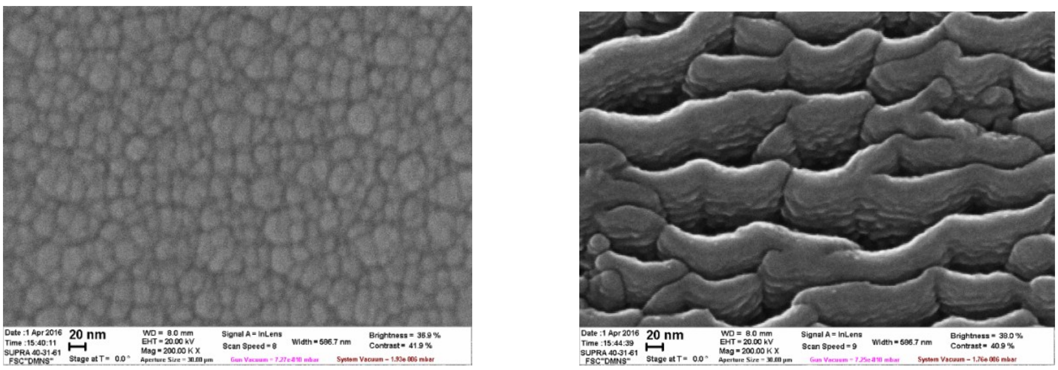

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Fig. 4. SEM pictures films deposited during the operation only of the magnetron with Si+10% target and during of the simultaneous operation of the magnetron and RF discharge.

Table. 1 shows the results of experiments with permalloy films Fe / Ni = 20/80, in the processes of magnetron sputtering with and without ion assistance by the ion flow generated in the RF discharge with power coupled to plasma 500 and 1000W.

Summing up the results one can see that experiments carried out with the hybrid plasma reactor showed its efficiency in the engineering of deposited films structure and properties.

Table 1. The values of the magnetic and electrical characteristics of permalloy films, deposited without and with ion assistance.

Permalloy fil	The film permalloy coercive force [Oersted]	magnitude of the anisotropy field, [Oersted]	Electrical resistivity, [mkOhm cm]	surface resistance, [Ohm / sq]
Without ion assistance	22.9	Isotrpopic	1.67	55.7
With ion assistance 500W	18.8	Isotrpopic	1.11	36.9
With ion assistance 1000W	6.1	9.2	0.47	15.8

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