Investigation of Magnetron Sputtering System with Electromagnetic Coil

A.A. Soloviev, N.F. Kovsharov, and N.S. Sochugov

Institute of High-Current Electronics SB RAS, 2/3, Academichesky ave., Tomsk, 634055, Russia
Tel.: +7(3822) 49-16-51, Fax: +7(3822) 49-14-10, E-mail: andrewsol@mail.ru

Abstract – The aim of the present work was development and investigation of characteristics of the magnetron sputtering system equipped by the electromagnetic coil. The electromagnetic coil allows generating the magnetic flux in target-substrate region sufficient for fine adjustment of ion flux on substrate surface and thereby influencing on structure and properties of deposited films. The developed magnetron has target diameter 95 mm and has been tested in argon pressure range 0.08–0.3 Pa. The influence of the magnetic field configuration on the shape of discharge was investigated. The possibility of formation both balanced and unbalanced configuration of magnetic field was demonstrated on the same magnetron sputtering system. V–I characteristics of magnetron discharge was researched at different pressures and currents in electromagnetic coil. The radial distributions of ion current densities, plasma potential and floating potential were measured by probe methods.

1. Introduction

Magnetron sputtering systems are widely used in technology of thin films deposition, in particular, in the electronic and optical industry, mechanical engineering. One of the most important aspects in magnetron sputtering is the opportunity to change and control in wide range parameters of plasma during deposition of coatings. So for achievement of optimal structure and properties of coatings it is important to adjust density of an ion current on substrate J_i and energy of bombarding ions E_i. This problem can be solved with the help of the magnetrons equipped by electromagnetic coils which allow controlling value and a configuration of a magnetic field flexibly. However, for today such magnetrons have not received a wide distribution in connection with difficulties of their manufacturing and incomplete understanding about influence of a magnetic field configuration on performance data of the magnetron discharge.

Therefore the main tasks of the present work were development of a magnetron sputtering system design with magnetic system of the combined type on the basis of permanent magnets and the electromagnetic coil allowing over a wide range to change a configuration of a magnetic field, and experimental definition of distributions of plasma characteristics in space between magnetron and a substrate. The main objective of work was finding-out of connection of the received distribution with distribution of an induction of a magnetic field.

2. Experiment

The schematic image of magnetron sputtering system with the electromagnetic coil is shown in Fig. 1.

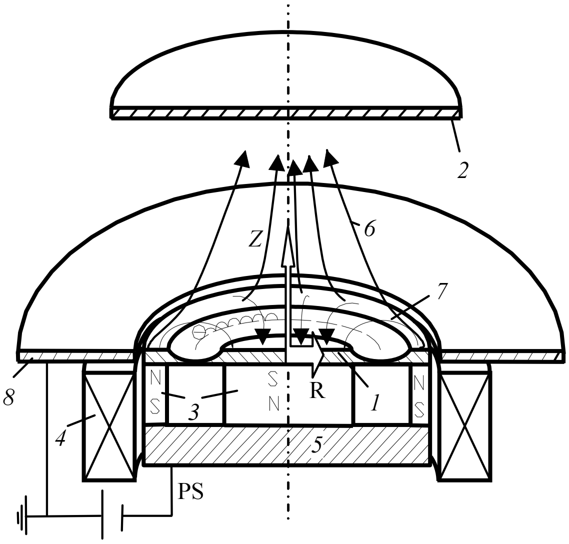

Fig. 1. The simplified scheme of magnetron sputtering system: *1* – sputtered cathode; *2* – substrate; *3* – permanent magnets; *4* – electromagnet; *5* – magnetic circuit; *6* – unbalanced lines of a magnetic field; *7* – balanced lines of a magnetic field; *8* – anode (fixing flange); PS – power supply of a magnetron

The design of a magnetron provides its external installation on the vacuum chamber by means of a fixing flange. Investigations were carried out in the stainless steel vacuum chamber with the size 600×600×600 mm. The cathode of a magnetron represented a Ti disk with diameter of 95 mm and thickness of 6 mm with direct water cooling. The magnetic system of a magnetron has consisted of an internal ring magnet (internal diameter of 15 mm, external diameter of 40 mm, height of 10 mm), an external ring of discrete magnets with trapezoidal forms (height of 10 mm), a magnetic circuit and coaxially-mounted electromagnetic coil having 3500 turns of a Cu wire, designed on flow of a current up to 1 A. The magnetic field created by magnetic system was measured by means of a Hall probe on a surface of the cathode and on an axis of a magnetron in space a magnetron – substrate.

Adjustment of pressure in the vacuum chamber was carried out by change of the working gas flow rate. The gas was filled directly in the chamber. The range of working pressure was from $0.8 \cdot 10^{-1}$ up to $3 \cdot 10^{-1}$ Pa. Power of the discharge changed from 0.5 up to 2 kW. The current in the electromagnetic coil was controlled in limits from 0 up to 1 A. For measurement of an ions flux on a substrate the collector with the area of 330 cm^2 was used. It is located on 23 cm distance from a magnetron. Thus the pulse negative bias with amplitude 100 V with frequency 18 kHz and on-off time ratio of pulses of 50% supplied on it.

For determining of ion current density J_i on a substrate and the floating potential V_{fl} electrical probe measurements with use of a flat probe with a guarding ring have been carried out. The central electrode of a probe made of stainless steel, had diameter of 11.8 mm and has been surrounded with the guarding ring which is under the same potential, for minimization of edge effects [1].

Measurements of plasma potential V_{pl} were carried out with the help of an emissive probe by a known technique [2]. The essence of a method consists in measurement of the floating potential of a probe heated up to a condition in which it is capable to emit enough of electrons. With increase of a heating current, the floating potential of a probe increases so it is not reach value of plasma potential. In this case, the current of electrons from plasma on a probe becomes equal to emission current.

3. Results

In Fig. 2, results of measurement of distributions tangential components of a magnetic field above a surface of the cathode and normal components of a magnetic field along an axis of a magnetron are presented at various currents in electromagnetic coil I_c. Depending on value and a direction of a current in the coil both balanced, and unbalanced (type 1 or 2), according to the standard classification [3], configurations of a magnetic field can be realized above a surface of the cathode.

For generation of ions in the substrate area, the 2nd type of unbalanced configuration of a magnetic field is the most suitable. It is realized in that case when the magnetic field in the solenoid coincides on a direction with a magnetic field created by external magnets of a magnetron (I_c = 1 A).

In this case, a tangential component of a magnetic field above a surface of the cathode it is minimal (550 Gs), and the radius of a sputtering zone is minimal. It is a result of that in strongly unbalanced mode (type 2) the magnetic trap above a surface of the cathode is compressed by unbalanced lines of a magnetic field to its center. It is necessary to note, that the given effect can be used for increase in degree of cathode utilization in case of a supply of the electromagnetic coil by an alternating current.

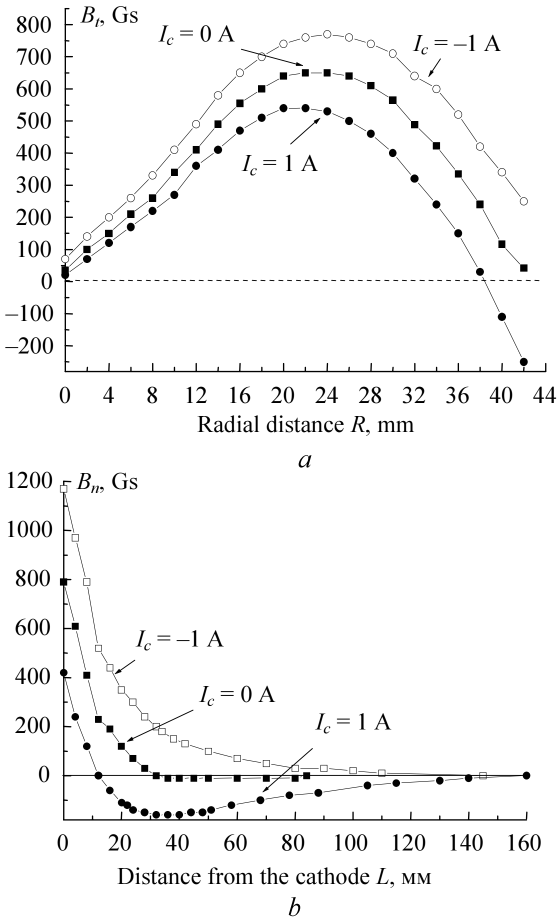

Fig. 2. Distributions of tangential (*a*) and normal (*b*) components of a magnetic field in a radial R (*a*) direction (above a surface of the cathode) and axial L (*b*) direction (in the center of a magnetron) at different currents in the electromagnetic coil

In unbalanced mode of the 1st type (I_c = −1 A) the normal component of a magnetic field on an axis of system exponentially falls down up to 0 (Fig. 2, *b*). At the switched off electromagnetic coil the magnetron works in weakly unbalanced mode (type 2). At increase of a current in the solenoid up to 1 A the degree of unbalance of a magnetic field lines increases, and the maximal value of a magnetic field on an axis of magnetron achieves 180 Gs.

In Fig. 3, the current-voltage characteristics of the discharge measured at various pressure of argon in the chamber are shown.

In a range of the discharge current values from 0.1 up to 5 A the discharge voltages was 300–520 V. With reduction of pressure, current-voltage characteristics are shifted in area of the larger working voltages. At switching on of the electromagnetic coil the discharge voltage increases and current-voltage characteristics of the discharge are shifted in area of the larger working voltages, as well as at reduction of pressure. It is due to that in unbalanced mode (type 2) the form of a magnetic trap at a surface of the cathode is deformed.

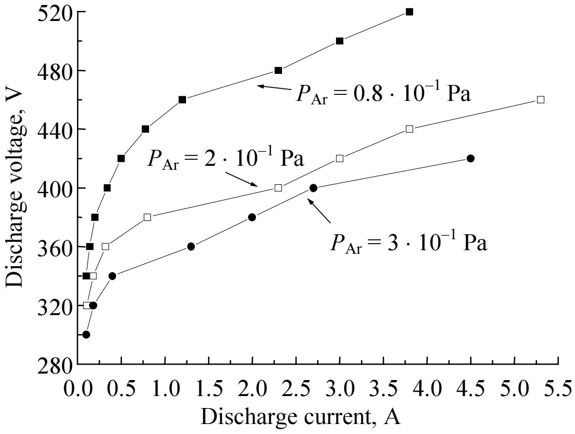

Fig. 3. Current-voltage characteristics of the discharge at various pressure of working gas (the electromagnetic coil is switched off)

At supplying of a pulse negative voltage on a collector the ions start to be extracted on it from plasma. The voltage at which the ion current achieves saturation is about 60 V. At increase of a current of the magnetron discharge from 1 to 4 A there is a proportional increase of an ion current to a collector from 80 to 250 mA.

Switching on of the electromagnetic coil considerably raises the ion current on a collector (Fig. 4).

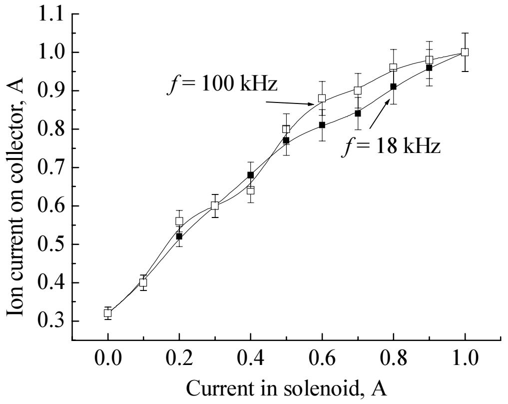

Fig. 4. Dependence of a current on a collector from a current in the electromagnetic coil at frequencies of a negative bias pulses 18 and 100 kHz ($P_{Ar} = 0.3$ Pa, $U_{bias} = -100$ V, discharge power – 2 kW)

It is connected, mainly, to lengthening a trajectory of ionizing electrons in an axial magnetic field.

Results of measurements of an ion current density on a probe, made on distance $L = 150$ mm from the cathode, at different currents in the electromagnetic coil are represented in Fig. 5. Discharge power was supported by a constant and was 0.6 kW.

The increase of a current in the electromagnetic coil is accompanied by substantial growth of density of the ion current, the most expressed on an axis of system. It is a result of increase in a degree of unbalance of a magnetic field which lines, going towards substrates, limit lateral mobility of electrons and force them to move on an axis of system. Thus, electrons move together with ions because of necessity of maintenance of an electro neutrality of plasma [4]. Visually, the increase of a current in the solenoid is accompanied by reduction of radius of glowing area on the cathode and appearance on an axis of system of the plasma flux directed to a substrate.

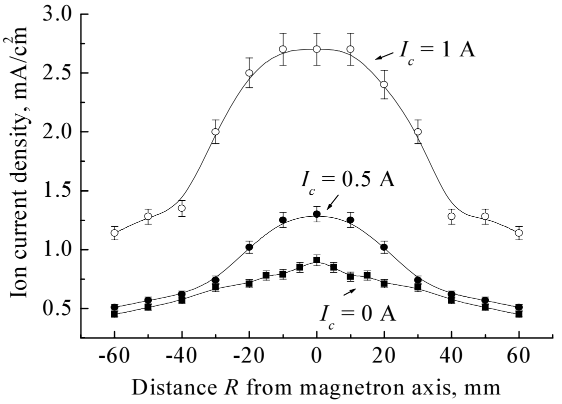

Fig. 5. Radial distributions of an ion current density on distance of 150 mm from the cathode at various currents in the solenoid (discharge power 0.6 kW)

Measurements of the floating potential and plasma potential in very unbalanced mode ($I_c = 1$ A) on different distances from the cathode have shown, that the given parameters spread in space extremely non-uniformly (Figs. 6 and 7). At distance from the cathode radial distributions V_{fl} and V_{pl} become more flat without strongly pronounced peaks on an axis of system.

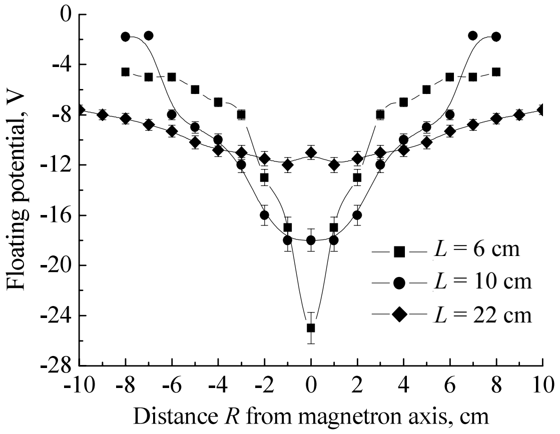

Fig. 6. Radial distributions of the floating potential at different distances from the cathode ($P_{Ar} = 0.2$ Pa, discharge power – 0.5 kW, $I_c = 1$ A)

The largest values of the floating potential are observed near to the cathode and on an axis of system (up to –25 V). At distance from the cathode and axes of system the values of the floating potential decrease up to several volts.

Near to the cathode and on an axis of system superposition of an additional magnetic field lead, first, to reduction of plasma potential due to magnetic confinement of electrons, second, to formation of a radial potential well for the ions, preventing their drift in a radial direction. The negative potential of plasma in the magnetron discharge with unbalanced magnetic field is a result of plasma confinement by magnetic field lines between the cathode which is under negative potential, and a substrate [5].

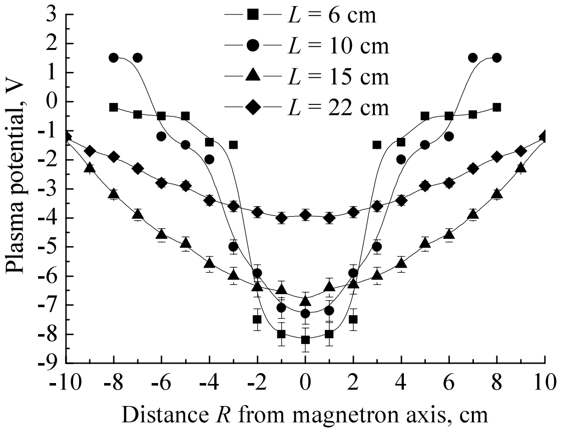

Fig. 7. Radial distributions of plasma potential at different distances from the cathode ($P_{\mathrm{Ar}} = 0.2$ Pa, discharge power – 0.5 kW, $I_c = 1$ A)

On the basis of the received results it is possible to conclude, that the increase in amount of ions in the substrate area in a magnetron with a unbalanced configuration of a magnetic field is caused by necessity of plasmas quasi-neutrality maintenance in conditions of the directed movement of electrons towards the substrate which is caused by a gradient of potential and concentration of electrons, and axially-divergent magnetic field.

4. Conclusion

As a result of the carried out experiments spatial distributions of plasma characteristics in magnetron sputtering system with the electromagnetic coil have been received. Magnetron allows realizing various configurations of a magnetic field above a surface of the cathode. It is shown, that for increase of plasma density in the substrate area it is necessary to create in space between it and a magnetron an axial magnetic field of sufficient value for effective confinement of electrons and prevention of their loss on the chamber walls. In this case electrons as if attached to a magnetic field lines and movement of ions is defined by the electric field created by local charges separation in plasma.

References

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