CHARACTERISTICS OF THE PLASMA CREATED BY ECR PLASMA SOURCE FOR THIN FILMS DEPOSITION

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The construction of planar ECR plasma source with multipolar magnetic field is described and the distribution of plasma parameters is measured. Plasma density and electron temperature at the distance 2,5 cm from the magnet surface achieve 5×10^{10} cm^{-3} and 22,5 eV accordingly and they linearly decreased with the moving off from ECR zone. The possibility of homogeneous and dense films deposition for both pure metals and alloys is shown.

PACS: 52.50.Dg; 81.15.Jj

1. INTRODUCTION

Development of the plasma assisted PVD and CVD processes is accompanied by active elaboration and investigation of the plasma sources of different kinds including ECR type[1-7]. The planar ECR plasma sources are of interest because they can be produced in the form of assembling of separate moderate in size modules with various space configurations depending on the requirements of specific experiments.

In this work the plasma parameters of planar rectangular ECR plasma source with multipolar magnetic field were measured and explored. Preliminary experiments on thin film deposition of pure metals and NdFeB alloy were performed also.

2. THE PLANAR ECR PLASMA SOURCE DESIGN

Scheme of the plasma source and experimental setup are shown in Fig.1. The magnetic system of the planar plasma source consists of 5 parallel rows of rectangular magnetic bars with the length of 9cm each, disposed with a gap of 1cm. Each magnetic bar consists of 3 $Nd_2Fe_{14}B$ permanent magnets of 1× 1,2cm in cross section and 3cm in length. The base of the magnet is the plane of 1×3cm. The magnetic bars are magnetized in perpendicular to base direction i.e. in direction of 1,2 cm. The e magnetic field on the magnet surface is 3 kG. The permanent magnets are jointed butt (plane 1×1,2cm to plane 1×1,2cm) with alternating polarities. The rows of the magnetic bars are installed by such a way that the magnetic field direction in each cross section is identical (see Fig.1).

The electromagnetic wave with frequency of 2,45GHz is exited in the magnetic system by two-slot antenna, which represents two rectangular copper channels fastened to the copper basis of the plasma source. The channel length is equal to the wavelength (12,5cm). The width of the channel slot is 0,3cm and the height is equal to a quarter of the wavelength. The antenna is installed so as the slot channels are between magnetic bars on both sides from the central bar. The channel output is aflush with upper plane of the magnetic system (z=0).

The microwave power in the antenna is exited by the loop on the terminal of the coaxial line. The coaxial line is used also as the holder of all plasma source construction. Second output of the coaxial line been situated outside of the vacuum chamber is attached to a lateral wall of the rectangular waveguide piece in which the microwave power is launched by magnetron M105/1 attached to the opposite lateral wall of the waveguide. Total power of the magnetron is 600W. In Fig.1 the axis x of Cartesian coordinates is in perpendicular to drawing direction, axis y – along the drawing from left to right, axis z – in vertical direction upward.

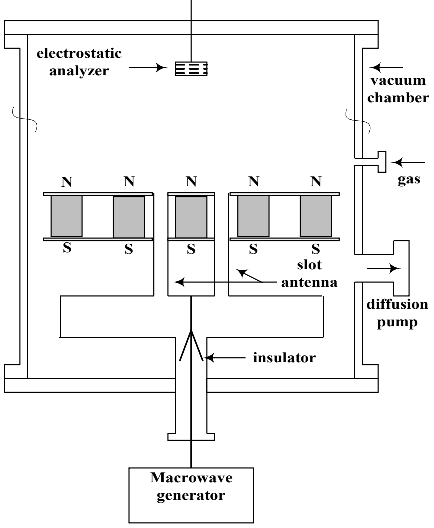

Fig.1. Experimental set-up

With switching on the magnetron an electron cyclotron resonance zone is formed above the slots. ECR condition is reached in the region with magnetic field intensity of 875 G where the electrons resonate at the microwave frequency of 2,45 GHz. Part of the fast electrons are trapped on magnetic field line and oscillated between the magnetic cusps (mirror points of the multipolar magnetic field). At the same time trapped electrons undergo the electrical and gradient drift motion and they are distributed along all magnetic structure surface. The existence of the areas with minimum B in longitudinal direction (axis x) promotes to the reduction of fast electron losses to the wall of the chamber and the construction elements. Thus the multipolar magnetic field should increase the lifetime of fast electrons in the resonance zone and thereby increase the ionization probability by inelastic collisions with neutrals. The ECR plasma source was introduced through the face flange into the vacuum chamber with diameter of 20cm and length of 30cm. The vacuum chamber was pumped to background pressure of 10^{-5} torr. Then the continuous flow of the working gas was initiated with needle valve and a pressure was reduced to a value of $1\div2\times10^{-3}$torr (the working pressure). Pure Ar, He, Kr were used as working gases in these experiments.

Measurements of the plasma parameter were performed by single and double Langmuir probes. All the probes were able to move in z direction. Measurements of the plasma potential, the energy distribution of ions and ion temperature were carried out by two-grid electrostatic analyzer with retarding field.

3. EXPERIMENTAL RESULTS

Preliminary experiments demonstrated that plasma density value and uniformity of created plasma layer are defined by the location of the resonance zone with respect to the magnetic structure plane (z=0). In optimal case when the distance between magnet bars is 1cm and the interface gap between magnets in the each magnet bars is 0,2 cm, the resonance zone (B_z=875G) is disposed maximally above the magnetic plane (z=1cm). At such configuration of the magnetic structure the primary electrons are accelerated in the resonance zone, trapped on the magnetic field lines and oscillated between successive cusps getting over gradually to the rest of the cusps and thus filling the all region of the magnetic field. The created plasma is diffusively extended under the action of the pressure gradient in perpendicular to the magnet plane direction (z direction). With better plasma confinement in the multipolar magnetic field a higher density and electron temperature of the formed plasma are observed and higher uniformity of plasma distribution in the plane of magnetic structure is achieved. Visual observation of the ECR discharge showed the homogeneous plasma luminescence over the all plasma source sections. At the same time the discharge was stable and the consumable high frequency power did not change.

In these experiments all measurements were carried out for z range from 2.5cm to 9cm from the magnet plane. At the distance less than 2,5cm the electric probe disturbed ECR discharge. The working pressure was varied in the range from 1×10^{-3} to 3×10^{-3} torr. Transverse size of the plasma with the uniform density is about 6x6 cm^2 at the pressure 2×10^{-3}torr and at position z=5cm. Electron density n_e for different working gases (Ar, He, Kr) vs. the distance from the magnet plane is represented in Fig.2. The curves for Ar and Kr are obtained at pressure of 1×10^{-3} torr. For He the pressure was 3×10^{-3} torr. As it is seen the plasma density decreases practically linearly with increasing the distance from ECR zone. It is characteristic that the electron temperature behavior is similar. At the distance z=2,5cm the electron temperature is 22÷23eV practically for all gases and it decreases less than two times moving away from magnet plane to 7,5cm. Linear character of plasma density decreasing with the distance from the resonance zone testifies to the diffusive expansion of the plasma layer.

Analysis of the magnetic field structure shows that the main magnetic field component is z-component ($H_z\approx$ 346Oe, $H_y\approx$4,3Oe, $H_x\approx$0,11Oe) already at the distance of 2,5 cm from the magnet plane i.e. the diffusive plasma flows directly along the magnetic field. In this case the diffusion coefficient along magnetic field coincides with coefficient of ambipolar diffusion. The plasma diffusion in the transverse direction was restricted due to magnetization of electrons. Larmor radius of electrons at 2,5cm from the magnetic plane was estimated as 0,046cm while the mean free path of electrons is much longer than the size of experimental setup. Relatively slow decreasing of electron temperature with moving away from the resonance zone is explained by restriction of the diffusive expansion of plasma in cross direction. On the other hand the measured I-V characteristics show that floating potential of the single Langmuir probe reaches up to 6V and it has a positive polarity. The current density to the probe at zero applied voltage is +3,5 mA/cm^2. The appearance of such current to the probe signifies that the ion stream propagate from the resonance zone in z direction. The value ion current does not changed practically in the region of z=2,5- 9cm.

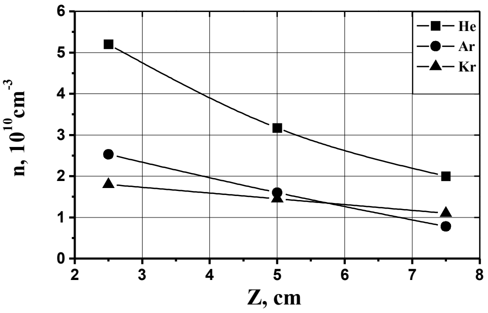

Fig.2. Electron density vs. the distance from the magnetic structure plane

The plasma potential and the energy characteristics of ion component of diffusive plasma flow are measured with electrostatic analyzer [8-10]. The I-V characteristic of analyzer measured for different gases at the distance of z=5cm are shown in Fig.3. The potential, at which characteristic knee is arisen, determines the plasma potential with high accuracy [10,11]. For example Ar plasma potential is about 40V and it decreases with moving away from the resonance zone. So at z=9cm the plasma potential is as low as 20V. According to [12] the plasma potential is defined as: $U_p=U_{fl}+(kT_e/e)Ln(0,77m_i/m_e)^{1/2}$, where U_p-the plasma potential, U_{fl}-the floating potential, m_i- ion mass (in our case Ar), m_e-the electron mass. The estimations made on the base of I-V characteristics give the values of U_p that are in agreement with electric probe measurements within 0,5V. When the analyzer is moved away from the resonance zone the electron temperature decreases and, as a consequence, the plasma potential falls too. Higher ionization potential of working gas leads to smaller plasma potential in the ECR discharge (Fig.3).

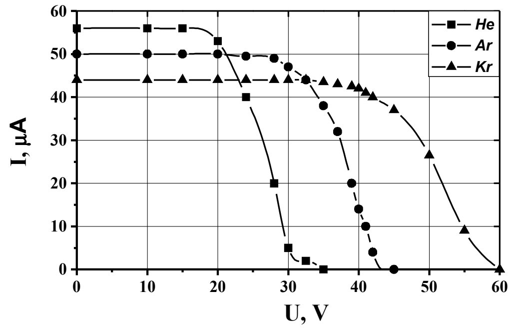

Fig.3. I-V characteristics for different gases

The function of the ion energy distribution along z direction can be received by numerical differentiation of the I-V characteristic [8]:

$$f(v)=Am_i/e(-dI/dE)=m_i/e^2(-dI/dV),$$

where A is a constant depending on the aperture and geometry of the analyzer, I- collector current, U- retarding potential, E- energy ions in eV. Calculated from I-V characteristic the energy of Ar ions is ~ 20 eV. Assuming Maxwellian distribution function, the ion temperature is $kT_i=-e/d\ln I(U)/dU$, where I is collector current. At the distance of 3cm from the magnet plane the ion temperature is estimated to be 3÷3,5eV.

4. THIN FILM DEPOSITION

In these experiments the target and the substrate were inclined with respect to plasma layer and with each other. The plate target (pure tungsten with the size of 5×5cm^2) was arranged at the angle of 45^0 and at the distance of 5cm from the magnet plane. The substrate was placed at the distance of 3cm from the target and it was practically perpendicular to the magnet plane. The negative bias of the target could be varied in wide range. The potential of the substrate (copper sample treated with diamond lathe tool) could be changed too. Roughness of the sample was 0.1μm. Deposition process was realized after ultrasonic washing and ion etching. For comparison 2 regimes of deposition were realized at the same amplitude of the accelerating voltage (900V): with direct current bias supplied to the target and with pulsating voltage with the frequency of 100Hz (full-wave rectification).

Surface analysis of the deposited films shows that the film produced in the pulsating regime is more homogeneous. A small positive bias to the substrate still more improve the quality of the film. The droplet fraction is not observed. The structure of the tungsten film is not visible even at the magnification 1000 of the optical microscope that indicates fine crystalline structure of the deposited film. The film thickness measured by the optical interferometer is 2μm

In trial experiments on magnetic film deposition by sputtering of $Nd_8Fe_{86}B_6$ alloy target the surface analysis also shows high quality of the deposited film, its uniformity and cleanness. At the magnification of 1000 any droplets and fractions are completely absent. XRD shows that the deposited magnetic film has the amorphous structure.

5. CONCLUSIONS

ECR plasma source assigned for studying the different cycles of plasma technology (cleaning and ion etching, deposition of various materials including multiphase alloy films) has been designed and investigated.

At the distance of 5cm from the magnet plane the plasma density is up to 2,5×10^{10}cm^{-3}, the electron temperature achieves 22÷23eV. Argon ion flux of 3,5mA/cm^2 is obtained with ion energy of about 20eV. The homogeneous range of this plasma flow is about 6× 6cm^2.

The test experiments show the possibility of the deposition of high quality coatings of different materials including magnetic films on the base of the rare earth compounds.

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ХАРКТЕРИСТИКИ ПЛАЗМЫ, СОЗДАННОЙ ЭЦР ПЛАЗМЕННЫМ ИСТОЧНИКОМ ДЛЯ НАНЕСЕНИЯ ТОНКИХ ПЛЕНОК

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В работе описана конструкция планарного ЭЦР плазменного источника с мультипольным магнитным полем и измерены распределения параметров создаваемой плазмы. На расстоянии 2,5 см от поверхности магнитов плотность плазмы и электронная температура 5*10^{10} см$^{-3}$ и 22,5 еВ соответственно, которые линейно спадают при удалении от ЭЦР зоны. Показана возможность напыления однородных и плотных пленок, как чистых металлов, так и сплавов.

ХАРАКТЕРИСТИКИ ПЛАЗМИ СТВОРЕНОЇ ЕЦР ПЛАЗМОВИМ ДЖЕРЕЛОМ ДЛЯ НАНЕСЕННЯ ТОНКИХ ПЛІВОК

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В роботі розглянута конструкція планарного ЕЦР плазмового джерела з мультипольним магнітним полем та виміряно розподіл параметрів створюваної плазми. На відстані 2,5 см від поверхні магнітів густина плазми та електронна температура 5 *10^{10} см$^{-3}$ та 22,5 еВ відповідно, які лінійно зменшуються при віддаленні від ЕЦР зони. Показана можливість нанесення однорідних та щільних плівок, як чистих металів, так і сплавів.