INFLUENCE OF MULTIPOLAR MAGNETIC FIELD GEOMETRY OF ECR PLANAR PLASMA SOURCE ON PLASMA PARAMETERS

V.D. Fedorchenko, V.V. Chebotarev, I.E. Garkusha, A.V. Medvedev, V.I. Tereshin, B.A. Shevchuk

Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology", 61108 Kharkov, Ukraine

The plasma parameters and its homogeneity were measured in ECR planar plasma source with multipolar magnetic field, which is created by three parallel magnetic bars of 12 cm in length consisted of set of the permanent magnets of 2 cm length. Geometry of the multipolar magnetic field is able to be changed by variation of the polarity and the distance between separate magnets along the bars. For magnetic system with alternative orientation of the magnetic field the plasma density up to 2.8×10^{10} cm^{-3} and the electron temperature about 20–22 eV were measured within the area ~ 75 cm^2 at the distance of 2 cm apart the magnetic structure. The uncompensated ion flow with the energies of 16–18 eV was observed for all configurations of magnetic field.

PACS: 52.50.Dg; 81.15.Jj

1. INTRODUCTION

Development of microelectronic industry demands technological advancements in plasma creation methods to achieve the plasma parameters which would provide high speed ion-plasma etching and thin film deposition on large surfaces of the semiconductor materials. At present, magnetrons, arcs, induction-, RF- and microwave methods of plasma generation for technological use are actively investigated [1-7]. Using permanent magnets on the base of rare earth elements $SmCo_5$ and $Nd_2Fe_{14}B$ gives new possibilities for design of plasma sources as planar systems with different configurations of magnetic field. Such sources are able to provide the treatment of sizeable surfaces to satisfy the requirements of the industry [8,9].

In this paper, the influence of the multipolar magnetic field topology in the ECR (Electron Cyclotron Resonance) planar plasma source on the electron density, electron temperature and the plasma homogeneity in the discharge is investigated.

2. EXPERIMENTAL SETUP

The experiments were carried out with the ECR planar plasma source described in details elsewhere [9]. The key feature of the source is that the multipolar magnetic field has been created by 3 parallel rows of the rectangular magnetic bars. In the gaps between bars the slot antennas were disposed. Each magnetic bar was made of 5 separate permanent magnets of 2 cm in the length. The polarity changes of the magnets determined different topologies of magnetic configuration. The working pressure (1.8 mTorr) and supplied RF power (about 300 W) were not changed in experiments. Plasma parameters were measured by moveable Langmuir and double probes, grid analyzer and flat collectors.

3. EXPERIMENTAL RESULTS AND DISCUSSION

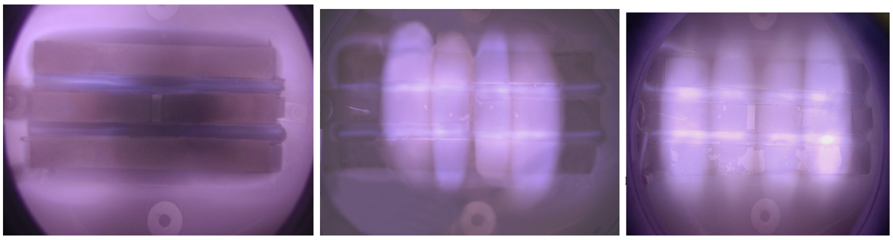
In these experiments we considered following magnetic field configurations at the fixed dimensions of the magnetic system: A- the magnetic field direction was retained along each magnetic bar; B-separate magnets in the bars were installed closely and they had alternate magnetic field direction; C- the separate magnets in the bars were installed with the gaps of 0.8 cm and the magnetic field direction was altered from one magnet to other.

Calculations of magnetic field topography and distribution of its components show that there is the range of resonance magnetic field (875 Oe) where the fast electrons determine evolution of the discharge originated for configuration A. In this range realised at the distance of 0.1 cm from the magnet plane the fast electrons are trapped on magnetic field lines and they oscillated in narrow zone of the magnetic trap with arched geometry of nearby surface of the magnets. At that, considerable part of the electrons is lost on the magnets and antenna wall.

In the case of configurations B and C, an additional area of the resonance magnetic field appears at the distance of 1.2 cm from the magnet plane. This area is important for the discharge development Fast electrons, being trapped in the magnetic traps, oscillate along the field lines which are away on the larger distance from the magnets plane. Ft the same time some electrons passed on the field lines of magnetic traps oriented along the magnetic bars. With increasing the trajectory length of the electrons the probability of the working gas ionization increases too and the plasma layer is formed more effectively.

Due to the curvature and the gradient of multipolar magnetic field the electrons oscillated along the magnetic field line undergo the gradient and the centrifugal drifts that facilitate the plasma distribution along the entire surface of the magnetic system. In the configuration A, the electron drift directs along the magnetic bars and its direction changes with transition from one magnetic trap to other. In the result, the electrons leave on of the magnetic system edge and then loss at the construction elements. As follows from the discharge images the highest intensity is observed along whole area of the magnetic system and it testifies high ionization of the working gas in this range (Fig.1a).

For configurations B and C, the direction of the longitudinal drift changes from one magnet to other and such drift becomes unessential. The appearance of the longitudinal arch magnetic traps drives the transverse electron drift with respect to the magnetic bars direction which changes from one trap to other. Thus the electrons are allocated along all the surface of magnetic system. Comparison of the discharge glow patterns indicates more homogeneous plasma distribution for configuration C. The estimations show that the transverse electron drift is higher namely for it configuration (Fig.1 b and c).



a *b* *c*

Fig.1. The microwave discharge glow for 3 configurations of the multipolar magnetic field: a; b; c- corresponding magnetic configurations

Measurements of the plasma discharge parameters near magnetic structures were performed for these three configurations. The electron density (n_e) and temperature (T_e) were determined from V-I characteristics of the double electric probe located at the magnetic system center. The measurements were conducted for different distances from the magnet surface. Fig.2 shows the distribution of n_e demonstrating that plasma density decreases practically linearly with the distance from the magnet surface. The maximum plasma density up to $2.7\text{-}2.9\times10^{10}\,cm^{-3}$ was measured for the configurations B and C at the distance (z) of 2 cm from the magnet surface.

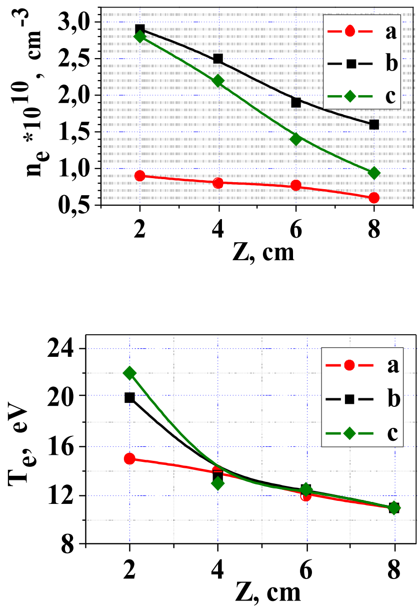


Fig.2. Dependencies of plasma density and electron temperature on the distance from the magnet surface; a , b, c – means corresponding configuration

Lower value of plasma density for configuration A (about $0.9\times10^{10}\,cm^{-3}$) caused by leaving the fast electrons on the periphery of the magnetic system due to longitudinal drift. The pattern of the discharge glow (Fig.1a) confirms this explanation. The difference in the plasma density behavior for configurations B and C can be explained by influence of the transverse electron drift that is in 1.5-1.7 higher for configuration C than for B. Therefore the plasma density in the system centre is a little bit smaller and it decreases faster with increase the distance from the magnet surface.

Electron temperature distribution along distance from magnet system is shown in Fig.2. For A configuration the electron temperature is changed linearly from 15 eV at the distance of 2 cm from the magnet surface down to 11 eV at z = 8 cm. In the case of configurations B and C, the electron temperature decreases rather sharply at the region between z = 2 cm and z = 4 cm. It reaches 14 eV. At the distance more than 4 cm the electron temperature decreases similarly for all configurations. The maximum electron temperature was obtained for configuration C and it amounted to 22 eV. The difference in the values of electron temperature for configurations A, B and C is determined by the trapping properties of the longitudinal and transverse multipolar magnetic traps in these configurations. The estimations of the mirror ratio B_{max}/ B_{min} for those magnetic traps give the maximum magnitude for the longitudinal traps in configuration C. Hence the longer electron lifetime is achieved. This is in agreement with the distribution of the floating potential measured at the different distances from the magnet plane for three configurations (Fig.3). It is obvious that for configuration C the floating potential has the negative value only at the distance from 2 cm to 3.5 cm from the magnet plane. At larger distance the floating potential has the positive value that is the evidence of the electron losses. The maximum floating potential (up to 18 V) was measured at the distance of 4 cm from the magnet plane for configuration B.

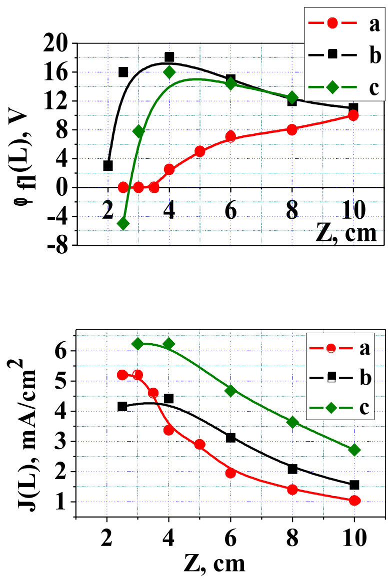


Fig.3. Plasma floating potential and the ion current density vs. the distance from the magnet surface;

a, b, c - indicate corresponding configuration

The measurements of the energy ion distribution by the retarding potential method demonstrated that the directional ion flow with the energy up to 18 eV was formed in the plasma for all magnetic configurations. The ion current density amounted to 2.4 mA/cm^2 at the distance of 4 cm from magnet plane and then it decreased with moving away from the magnet plane for configurations B and C. In configuration A the ion current density increased with moving away from the magnet plane and it amounted to 0.5 mA/cm^2 at the distance of 8 cm.. Such difference in behavior of the ion current density for these magnetic configurations is explained by the magnetic field topology. The magnetic field magnitude is 320 Oe at the distance of 4cm from magnet plane for configuration A whereas it comes to 25 Oe for configurations B and C.

The plasma layer homogeneity was examined by the movable electric probes turned in a circle of different diameter in parallel to magnet plane. It was revealed that the electron density and the temperature were uniform within 10 % in the area of 5 cm in diameter at the distance of 4 cm from the magnet plane for configurations A and B, and ~ 10 cm in diameter for configuration C.

The measurements of emissive ability of the plasma discharge under the negative bias on the collector are illustrated in Fig.4. Maximum value of the ion current density up to 6.23 mA/cm^2 was received at the distance of 4 cm from the magnet plane for configuration C. Ion current density decreased practically linearly with the distance from the magnet plane down to 2.7 mA/cm^{2}and at the distance of 10 cm.

4.CONCLUSIONS

The results of the investigations show that the topology of the multipolar magnetic field essentially effects to the plasma parameters and its homogeneity. For configuration C (separate magnets in the bars were installed with the gaps of 0.8 cm and the magnetic field direction is altered) the uniform distribution of the plasma density about 2.8×10^{10} m^{-3} and the electron temperature up to 22 eV were measured in the area of 75 cm^2. The ion flow with ion energy of 18 eV was measured for all configurations. The maximum ion current density up to 2.4 mA/cm^2 was recorded for configuration C. Under the negative bias about -1 kV at the flat collector the ion current density amounted to 6.23 mA/cm^2 at the distance of 4 cm from the magnet plane. Thus, magnetic configuration C is preferred for the aims of large-area ion-plasma etching and a deposition of thin films.

REFERENCES

1. G.G. Lister //*J.Phys.D: Appl.Phys.* 1992, v. 25, p.1649.
2. J. Hopwood//*Plasma Sources Sci. Technol*. 1992, N1, p.109.
3. R.W.Boswell// *Proc. XXI Int. Conf. Phen. Ion. Gases.* 1993, v.3, p. 118.
4. J. Asmussen// *J. Vac. Sci. Technol. A*. 1989, N 7(3), p. 883.
5. N.Sakudo//*Nucl. Instrum. Methods Phys. Res.* 1987, B21, p.168.
6. T.Shimizu, K.Kato, Y.Li, S.Iizuka, N.Sato// *Thin Solid Films.* 2001, v. 386, p. 248.
7. H.Conrads and M.Schmidt// *Plasma Sources Sci. Technol*. 2000, N 9, p. 441.
8. C.Courteille, J.Bruneteau, F.P.G.Valcloc, Z.Sledziewski and M.Bacal// *Rev.Sci. Instrum*. 1993, v. 64, p. 3265.
9. V.D.Fedorchenko, O.V.Byrka, V.V.Chebotarev, I.E.Garkusha, V.I.Tereshin// *Problems of Atomic Science and Technology*, *Series " Plasma Physics"(11).* 2005, N 1, p. 192.

Article received 23.09.08.

ВЛИЯНИЕ МУЛЬТИПОЛЬНОЙ ГЕОМЕТРИИ МАГНИТНОГО ПОЛЯ ПЛАНАРНОГО ЭЦР-ПЛАЗМЕННОГО ИСТОЧНИКА НА ПАРАМЕТРЫ ПЛАЗМЫ

В.Д. Федорченко, В.В. Чеботарев, И.Е. Гаркуша, А.В. Медведев, В.И. Терешин, Б.А. Шевчук

Измерены параметры плазмы и их однородность в планарном ЭЦР- плазменном источнике с мультипольным магнитным полем, которое создавалось параллельными магнитными стержнями длинной 12 см, состоящих из отдельных постоянных магнитов по 2 см каждый. Геометрия мультипольного магнитного поля изменялась за счет выбора полярности отдельных магнитов и расстояния между ними вдоль магнитного стержня. Для магнитной системы с переменной вдоль стержня ориентацией магнитного поля магнитов и с зазором 0,8 см между ними плотность плазмы составила 2,8×10^{10} см$^{-3}$ и электронная температура 20–22 эВ. Показана однородность параметров плазмы на площади ~ 75 см^2 на расстоянии 2 см от магнитной структуры . Для всех конфигураций магнитного поля наблюдался некомпенсированный поток ионов с энергией 16–18 эВ.

ВПЛИВ МУЛЬТИПОЛЬНОЇ ГЕОМЕТРІЇ МАГНІТНОГО ПОЛЯ ПЛАНАРНОГО ЕЦР-ПЛАЗМОВОГО ДЖЕРЕЛА НА ПАРАМЕТРИ ПЛАЗМИ

В.Д. Федорченко, В.В. Чеботарьов, І.Є. Гаркуша, О.В. Медведєв, В.І. Терешин, Б.О. Шевчук

Параметри плазми та її однорідність були виміряні у планарному ЕЦР- плазмовому джерелі із мультипольним магнітним полем, яке утворювалося паралельними магнітними стрижнями довжиною 12 см, що складались з окремих постійних магнітів по 2 см кожний. Геометрія мультипольного магнітного поля змінювалася за рахунок варіювання полярності окремих магнітів та відстані між ними вздовж стрижня. Для магнітної системи з перемінною орієнтацією магнітного поля магнітів вздовж стрижня та с зазором 0,8 см між ними густина плазми складала 2,8×10^{10} см$^{-3}$ та електронна температура 20–22 еВ. Показана однорідність параметрів плазми на площині ~ 75 см^2 на відстані 2 см від магнітної структури. Для усіх конфігурацій магнітного поля спостерігався некомпенсований потік іонів з енергією 16–18 еВ.