CONTROLLING PARAMETERS DETERMINING TECHNOLOGICAL PROPERTIES OF A HELICON DISCHARGE SYSTEM

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In experiments on two helicon sources driven by a planar antenna, it is shown that the plasma density in the drift chamber and the energies and density of the ion flux onto the substrate holder can be effectively controlled by changing the local magnetic field and the holder potential.

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INTRODUCTION

Helicon sources, which are based on a magnetic field assisted rf inductive discharge, produce dense plasmas and, for this reason, can serve as efficient plasma tools for various technologies. Except for materials processing [1], recent helicon source applications include space propulsion in both high and low thrust schemes (e.g., [2 - 4]) and nanomaterials production (e.g., [5, 6]). These sources can be used either alone, or as units of hybrid discharge systems for performing specific technological operations, e.g., in thin film formation using the PECVD process [7].

For technological purposes, a compact design of the source with a planar driving antenna located behind a flat dielectric window seems to be preferable (e.g., [8]). Our previous experiments on the research [8] and technological [9] sources of this type have shown that their characteristics depend considerably on both the strength and configuration of the magnetic field. This factor, in combination with other discharge control methods, can be used for developing the flexible technological tools. In this paper, we study how the plasma flux parameters can be controlled under combined action of various external factors, such as the magnetic configuration, bottom electrode (substrate holder) potential, rf power, and working gas pressure. To draw some universal regularities, we performed the experiments using two helicon sources mentioned above.

EXPERIMENTS ON THE RESEARCH SOURCE

The discharge chamber of the research source (Fig. 1) is a 20-cm-diam, 30-cm-long grounded metal cylinder closed on top by a quartz window. A 11.5-cm-diam double-turn planar antenna supplied from an rf generator of frequency 13.56 MHz and up to 2 kW power is located above the window. The chamber is confined from below by a 15-cm-diam metal electrode (substrate holder) that was either at a floating potential, or negatively biased down to −100 V. The magnetic field of various configurations and maximum strength up to 250 G was produced by three solenoids with independent power supplies. The working gas was argon at pressures 1…10 mTorr. The parameters of plasma and ion fluxes were measured by two movable probes inserted into the chamber in its upper (below the antenna) and lower (above the bottom electrode) parts, and by a five-electrode ion energy analyzer with a 12-mm-diam case and a 6-mm-diam entrance aperture. The analyzers resolution was about 3 eV.

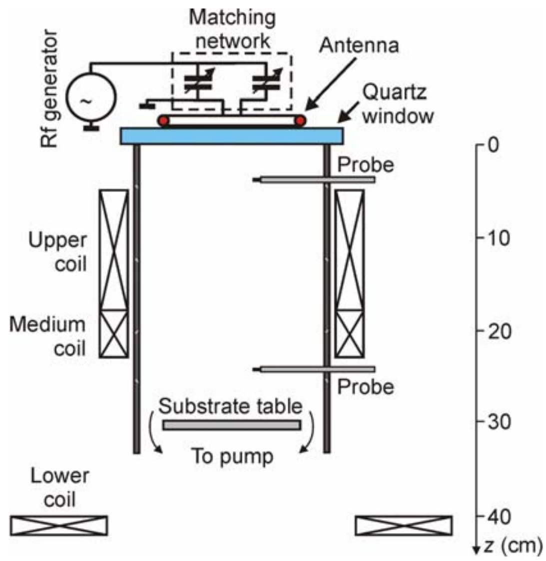

Fig. 1. A scheme of the research source

It was found that, over the whole examined range, the bottom electrode floating potential possessed negative values, $U_{\text{float}} = -5$ to -20 V, and decreased with magnetic field increase. Such a behavior is in qualitative agreement with that of a local floating potential in the discharge volume, as was formerly ascertain from the probe measurements [10], and is apparently determined by presence in plasma volume of a population of energetic non-maxwellian electrons detected previously using the probe with a low-frequency bias potential modulation [10].

Measured with the lower probe (see Fig. 1) dependences of ion saturation current on the magnetic field, which was varied by proportional current changing in all the solenoids, is shown in Fig. 2, under conditions when the bottom electrode was either grounded of floating. As seen, the electrode grounding decreases the plasma density, especially in the range of lower magnetic fields. Positive electrode biasing resulted in the discharge disruption. The discontinuous dependences in Fig. 2 evidence that the way to control plasma parameters by changing the magnetic field over the whole discharge volume is problematic for the technological processes.

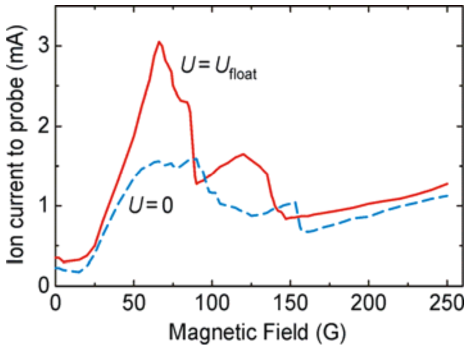

Fig. 2. Dependences of ion current onto the probe on magnetic field, at floating (solid curve) and ground (broken curve) substrate holder potentials

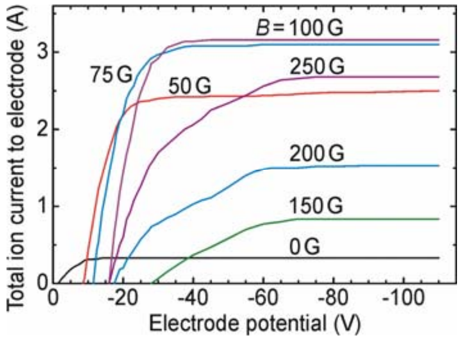

Fig. 3. Volt-ampere characteristics of the substrate holder, at various magnetic fields

For controlling the ion flux energy onto the electrode (substrate holder), the range of its negative biases is most interesting. Fig. 3 shows the volt-ampere characteristics of the electrode with a bias in the range from the floating potentials down to −120 V, at various magnetic fields related to different discharge regimes (see Fig. 2). As seen, the ion current onto the electrode increases with decreasing bias potential and then saturates at a level that depends non-monotonically on the magnetic field. In most intense discharge regimes, the ion current onto the electrode reaches 3 A.

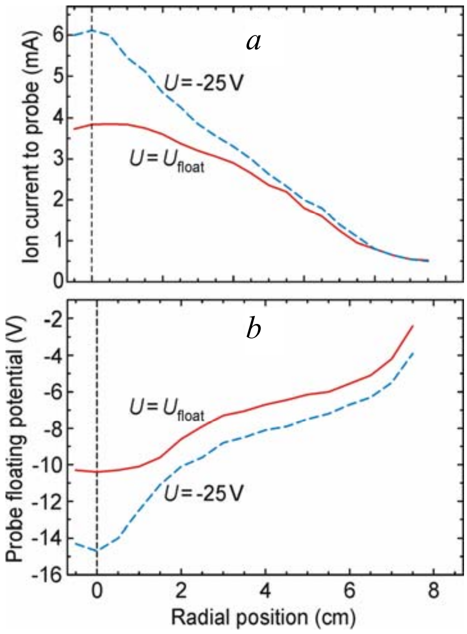

Fig. 4. Radial profiles of (a) ion current onto the probe and (b) probe floating potential

Negative electrode biasing gives rise to substantial plasma density increase (Fig. 4,a), especially around the axis, where a floating potential sags (Fig. 4,b). As long as a population of energetic electrons exists just in this region, it is natural to interpret the density increase as a result of that the negative potential reflects the energetic electrons back to the discharge volume thus increasing the ionization efficiency.

EXPERIMENTS ON THE TECHNOLOGICAL SOURCE

The technological device (Fig. 5) consists of a helicon source discharge chamber, 20 cm in diameter and length, and an adjoint drift chamber, 35 cm in diameter and 25 cm long. The discharge in argon at a pressure 7…8 mTorr was excited by a 11-cm-diam single-turn planar antenna fed from an rf generator of frequency 13.56 MHz and up to 1 kW power. The magnetic field is created by a set of solenoids. A solenoid surrounding the discharge chamber generates the main field that provides the helicon discharge operation in the required mode. One more solenoid with independent power feed (not shown in Fig. 5) is located below the substrate holder and generates the control field which extends only into the drift chamber and has no substantial influence on the main field in the discharge chamber. In the lower part of the drift chamber, there is a subdivided electrode (substrate holder) of 25-cm total diameter. Plasma parameters were measured by two cylindrical probes, the upper (15 cm below the antenna) and the lower (5 cm above the substrate holder) ones.

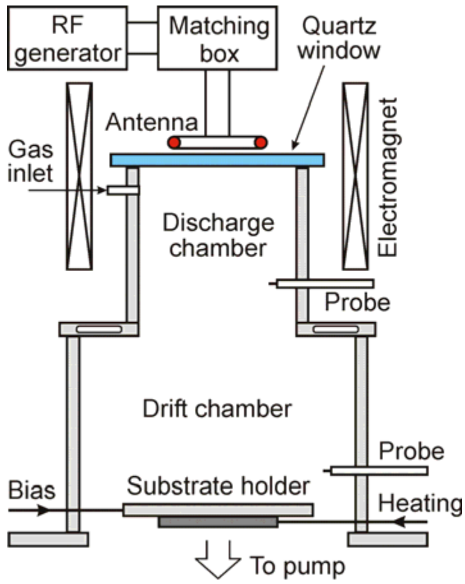

Fig. 5. A scheme of the technological source

Fig. 6 shows the radial profiles of the ion saturation current onto the upper probe. Curves *1* and *2* were taken with no control magnetic field and relate, respectively, to the rf power of 300 and 600 W. Curve *3* was also taken with 600 W power, but with control field turned on. It is seen from this figure that the plasma density in the discharge chamber is approximately proportional to the rf power, and that the control magnetic field has a minor influence upon the conditions in the discharge chamber.

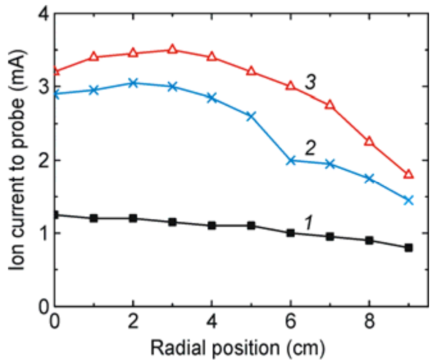

Fig. 6. Radial profiles of ion current onto the upper probe, at rf power of 300W (curve 1) and 600 W (curves 2 and 3)

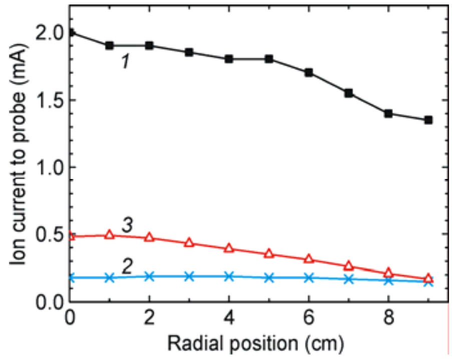

Fig. 7. Radial profiles of ion current onto the upper (curve 1) and lower (curves 2 and 3) probes, at rf power of 500W

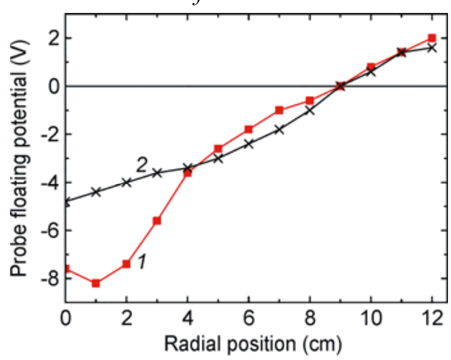

Fig. 8. Radial profiles of the probe floating potential with (curve 1) and without (curve 2) the control magnetic field

Fig. 7 shows the radial profiles of the ion saturation current onto the lower probe measured without and with the control magnetic field (curves *2* and *3*, respectively), at the rf power of 500 W. The profile measured by the upper probe with no control field is also shown there (curve *1*). As seen from comparison of curves *1* and *2*, the plasma density drops an order of magnitude to the drift chamber bottom, apparently, as a result of strong plasma flux flaring in a divergent magnetic field of the upper solenoid. With the control field turned on, the plasma density rises by 2.5 times near the axis, but its profile becomes nonuniform (cf. curves *2* and *3*). This effect is thought to result from improved plasma transportation from the discharge chamber to the substrate holder and, probably, from spreading of the helicon discharge into the drift chamber.

With the pressure increase, the density drop at the substrate holder increases, whereas the radial density profiles smooth over.

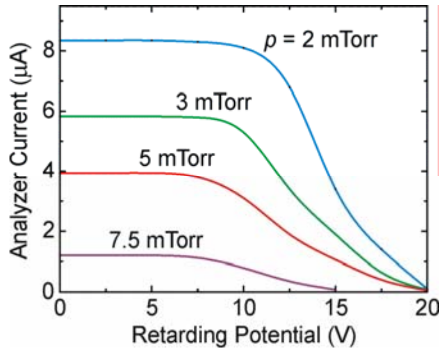

Fig. 9. Retarding characteristics of the energy analyzer, at various Ar pressures. Rf power 450 W, main and control coils currents I_m = 1.5 A and I_c = 1 A

In the presence of the control field, the density increase in the central part of the drift chamber is accompanied by a considerable decrease there of the floating probe potential (Fig. 8). This effect arises, apparently, due to increase in this region of the number of energetic electrons that were detected earlier in experiments on the research source [8] and are thought to exist in the technological source as well.

An important technological characteristic of the source, along with the plasma density, is the ion flux energy. In the helicon sources, it is possible to combine high density plasma production with independent ion energy control, which makes these sources well suitable for various applications. Fig. 9 shows retarding characteristics of the ion energy analyzer, $I(U)$, for various argon pressures, at a fixed input rf power of 450 W. As seen, the plasma potential, which is determined from maximum of dI/dU, changes only slightly in the pressure range. In general, the helicon source operating range was found to extend up to 40…50 mTorr; the ion flux density drops drastically at higher pressures. An optimal pressure range, as seen from Fig. 9, lies within 1…5 mTorr.

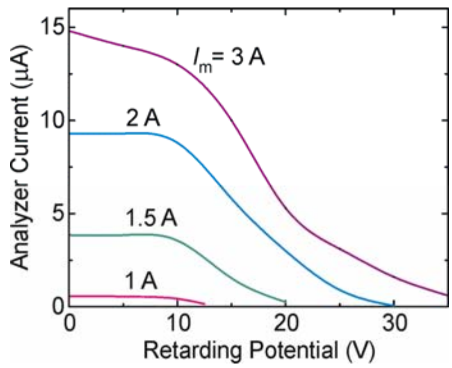

Fig. 10. The same as in Fig. 9, but at various main coil currents. Rf power 525 W, Ar pressure 5 mTorr and I_c = 1 A

Fig. 10 shows analyzer characteristics measured at argon pressure of 5 mTorr and input rf power of 525 W, at various currents in the main field solenoid surrounding the discharge chamber. (Its magnetic field is evaluated as 15 G/A). With the main field increase, the discharge grows in intensity and extends further from the antenna, which results in the analyzer current increase. The retardation curves related to lower pressures in Fig. 10 evidence the presence of a fast ion “tail” extending up to 30…35 eV.

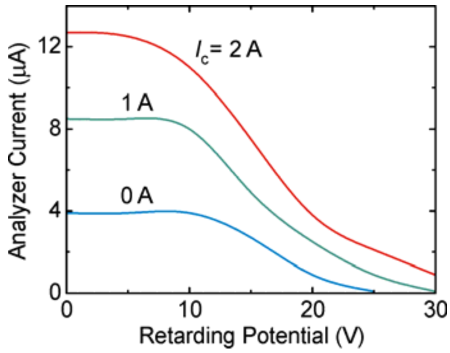

Fig. 11. The same as in Fig. 9, but at various control coil currents. Rf power 525 W, Ar pressure 5 mTorr and I_m = 1.5 A

The effect of the control magnetic field on the ion current is shown in Fig. 11 taken at various control coil currents (the magnetic field is evaluated as 25 G/A) and the same other parameters. The data comparison in Figs. 10 and 11 evidences that the increase of the control field gives rise to ion current increase whereas the ion flux energy distribution changes only slightly. When the plasma density increases with the rf power, the content of energetic ions in the flux grows.

CONCLUSIONS

In experiments on two helicon sources driven by a planar antenna, it was found that the magnetic system, which is placed nearby the substrate holder and varies the magnetic field only locally, can effectively control the magnitude and profile of the ion current onto the substrate holder whereas the ion energy spectrum changes only slightly. At that, the conditions in the discharge chamber do not change considerably which permits to eliminate the discharge regimes jumps that arise when the magnetic field changes globally, on the scale of the whole system. By changing the substrate holder potential, one can not only control the ion flux energies but also control the ion flux current through changing the plasma density around the substrate holder. The latter effect is thought to arise from energetic electrons whose reflection back to the discharge volume increases the ionization efficiency.

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УПРАВЛЕНИЕ ПАРАМЕТРАМИ, ОПРЕДЕЛЯЮЩИМИ ТЕХНОЛОГИЧЕСКИЕ СВОЙСТВА ГЕЛИКОННОЙ РАЗРЯДНОЙ СИСТЕМЫ

В.Ф. Семенюк, В.Ф. Вирко, И.В. Короташ, Л.С. Осипов, Д.Ю. Полоцкий, Э.М. Руденко, В.М. Слободян, К.П. Шамрай

Экспериментами на двух геликонных источниках с плоской возбуждающей антенной показано, что плотностью плазмы в дрейфовой камере и энергиями и плотностью ионного потока на подложкодержатель можно эффективно управлять изменением локального магнитного поля и потенциала держателя.

КЕРУВАННЯ ПАРАМЕТРАМИ, ЩО ВИЗНАЧАЮТЬ ТЕХНОЛОГІЧНІ ВЛАСТИВОСТІ ГЕЛИКОННОЇ РОЗРЯДНОЇ СИСТЕМИ

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Експериментами на двох геліконних джерелах з плоскою збуджуючою антеною показано, что густиною плазми в дрейфовій камері та енергіями і густиною іонного потоку на підкладинкотримач можна ефективно керувати зміненням локального магнітного поля і потенциалу тримача.