CHARACTERIZATION OF PLASMA AND EMERGENT ION BEAM IN A COMPACT HELICON SOURCE WITH PERMANENT MAGNETS

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A compact helicon source with multi-component changeable magnetic system was studied to gain enhanced parameters of plasma and emergent ion beam. Alteration of the magnetic field configuration was found to be the main instrument for increasing the plasma density and ion beam current. The source efficiency was also critically dependent on the rf antenna position and Ar gas pressure. By optimizing these parameters, plasma outflow was greatly increased and the emergent ion beam of energy above 100 eV was produced.

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1. INTRODUCTION

The helicon source is one of the most efficient types of inductively coupled plasmas. This electrodeless discharge is intensively investigated for different applications including electric propulsion with low [1-3] and high [4] thrust, ion beam probing [5], etc. Helicon sources normally operate with electromagnets, which produce uniform or moderately nonuniform magnetic fields, but the use of permanent magnets is preferable for many applications. The magnetic field produced by permanent magnets is strongly nonuniform. However, just in the nonuniform field the discharge efficiency can be significantly enhanced by positioning the antenna in the region of converging magnetic field [6]. Magnetic field nonuniformity can also result in formation of the current-free double layer accelerating emergent ions [7].

We report on experimental results from the compact source equipped with a two-component, changeable magnetic system. The main idea was to enhance plasma and ion beam characteristics by optimizing the source performance, primarily, the magnetic configuration.

2. EXPERIMENTAL DEVICE AND DIAGNOSTICS

The experimental device consists of two quartz chambers. The discharge chamber of 4.5 cm inner diameter and 32 cm length was attached to a 14.5 cm diameter drift chamber (Fig. 1). The plasma was excited by a tree-turn (m = 0) axially movable antenna powered from an rf generator of frequency 13.56 MHz and power up to 1 kW. Various magnetic configurations were produced by combining the fields of two components of the magnetic system: the 13.5 cm outer diameter, 1.8 cm wide annular ferrite (AF) magnetized axially; and the 12 cm long, 12 cm inner diameter cylindrical array of ferrite bars (CFA) with radial magnetization (Fig. 2). To investigate the effect of the CFA field on discharge performance, we used also more complicated, three-layered CFA that enabled to change the magnetic field strength. Sometimes, an electromagnetic coil (EM) was also used. All components of the magnetic system were movable along the axis. Axial length of the discharge chamber could be changed with use of an axially movable quartz plate (QP). Both the discharge and drift chambers were filled with Ar gas at pressure varying in the range 0.5-5 mTorr. In some experiments, a ceramic diaphragm was installed on the outlet flange, in order to limit the source orifice and to create a pressure drop.

Plasma parameters and the rf field characteristics were measured by axially movable Langmuir, magnetic, and emissive probes. The emergent ion beam was examined with a five-grid retarding field energy analyzers (RFEA). It was positioned in the drift chamber, 7 cm from the outlet and could rotate over the angle of 90°, to face either to the source outlet or to the drift chamber wall.

3. CHARACTERIZATION OF PLASMA AND THE EMERGENT ION BEAM

We examined various magnetic configurations created with use of the single AF, the single CFA, and a combination of the AF with the CFA (Figs. 3 and 4).

3.1. CONFIGURATION WITH THE SINGLE AF

Axial profile of the magnetic field of the single AF has two null points (cusps). It was found that both cusps result in reduction of the efficiency of plasma production and ejection. The left cusp (between the AF and the drift chamber) prevents plasma penetration from the discharge chamber into the drift chamber (Fig. 5).

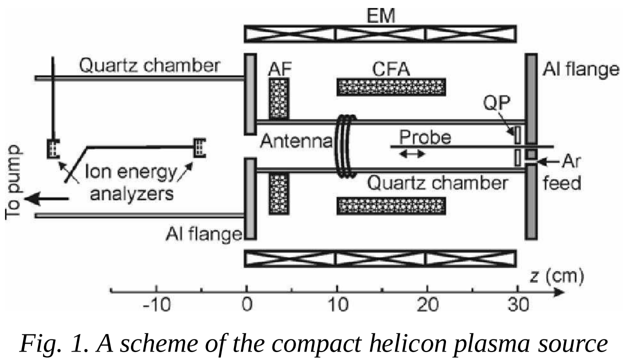

Fig. 1. A scheme of the compact helicon plasma source

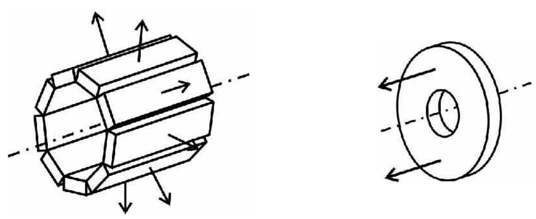

Fig. 2.The single-layer CFA (left) and the AF (right), with magnetization directions shown by the arrows

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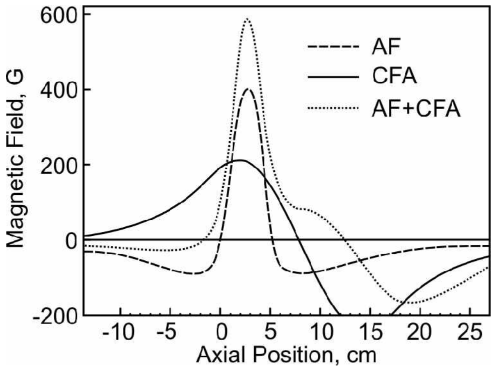

Fig. 3. Magnetic field profiles for various configuration

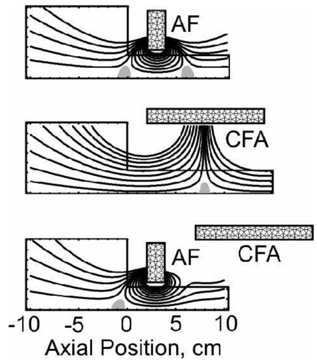

Fig. 4. The shapes of magnetic field lines

Maximum plasma density was found under the antenna, it is 2×10^{12} cm^{-3} at high pressures p_{Ar} = 3-5 mTorr, and twice smaller at lower pressure of 0.7 mTorr. Electron temperature was 6-8 eV and 14-18 eV, whereas plasma potential in the drift chamber 30 and 60 V, for Ar pressures of 5 and 0.7 mTorr, respectively. Characteristics of the RFEA facing either to the source outlet or in perpendicular direction are similar, which implies weak plasma ejection and the lack of accelerated ions.

3.2. CONFIGURATION WITH THE AF AND THE CFA

Adding the magnetic field of the CFA to that of the AF eliminates the cusp between the area of maximum magnetic field and the antenna (Fig. 3), and the magnetic field in the discharge chamber becomes growing from the antenna towards the outlet, which is favorable for enhanced plasma production [7]. Indeed, plasma density becomes higher, especially near the outlet (Fig. 5), owing to more efficient rf power injection into the region of strong magnetic field. The electron temperature is 9 and 15 eV, at Ar pressures of 5 and 0.7 mTorr, respectively.

The RFEA characteristics show that ion flow intensity becomes higher by several times, as compared with the previous configuration. Plasma potential in the discharge chamber grows with decreasing Ar pressure, up to 120 V at 0.37 mTorr (top Fig. 6). The plasma potential has maximum near the entry to the AF, decreases towards the source outlet, and makes 30–70 V in the drift chamber, depending on pressure. The maximum energy of accelerated ions, relative to the grounded RFEA , is equal approximately to the maximum value of the potential in the discharge chamber (top Fig. 7).

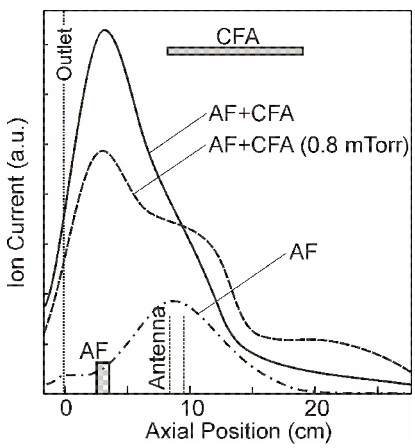

Fig. 5. Profiles of ion saturation current onto the probe

3.3. CONFIGURATION WITH THE SINGLE CFA

In this configuration, plasma flux is much more intense, as long as magnetic lines are diverging gradually into the drift chamber. The source efficiency depends critically on the antenna position, whose optimum was found at the left of the cusp, i.e., in the region of converging magnetic lines (Fig. 8).

The axial distribution of the potential is, in general, similar to that in the case with the AF and CFA; it also grows with decreasing pressure and amounts to 110 V inside the discharge chamber, at a pressure of 0.42 mTorr (bottom Fig. 6). However, for reason yet unclear, the ions with such the high energies (~100 V) do not come to the grounded RFEA (bottom Fig. 7).

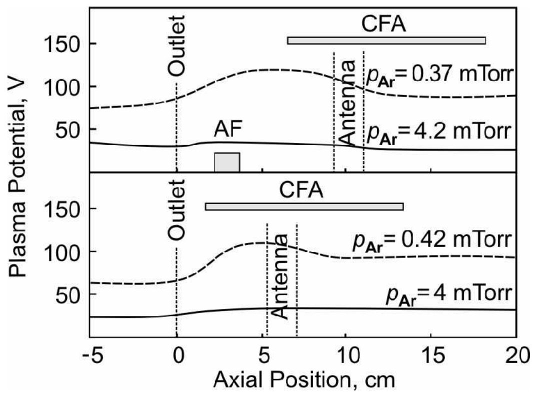

Fig. 6. Axial distribution of the plasma potential, for the AF+CFA (top) and the single CFA (bottom)

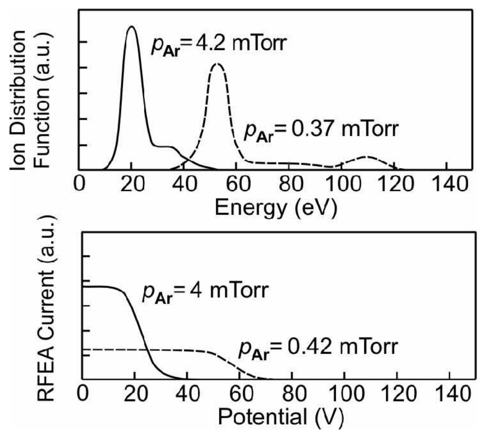

Fig. 7. Ion distribution functions for AF+CFA (top) and the RFEA characteristics for the single CFA (bottom)

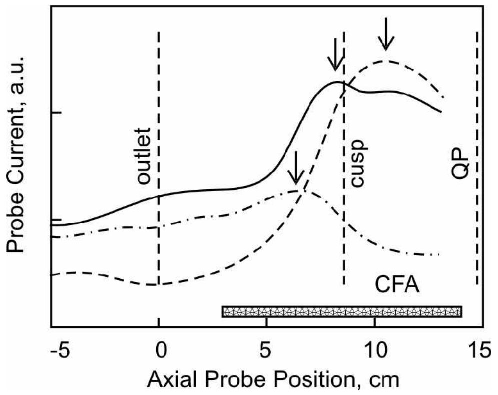

Fig. 8. Axial profiles of the ion saturation current onto the probe, at various antenna positions marked by the arrows

4. DISCUSSION AND CONCLUSIONS

The magnetic configuration governs both the plasma generation and the ion ejection. In optimal configurations, the plasma density is considerably enhanced and the emergent beam of accelerated ions arises. Configuration with the single CFA enables to produce quite intense but not accelerated ion flux; it is promising for materials processing applications. In configurations with the AF, elimination of magnetic field cusps is critical for enhancement of plasma ejection. Removing the cusp between the antenna and the AF, by adding the CFA field, localizes the discharge in the region of strong field adjoining to the source outlet, and the maximum plasma density grows up to 5×10^{12} cm^{-3}, at Ar pressures 3-5 mTorr and rf input power of 600 W. Directional discharge burning along converging magnetic lines, i.e., towards the source outlet, which occurs with use of the CFA or the CFA+AF, enables to shorten twice the discharge chamber length without change in the discharge modes: plasma density and ion flux characteristics remain the same.

In conclusion, the magnetic configuration is a critical factor for plasma production and ion acceleration, the latter being driven not only by the electrostatic potential but also by some other, not yet ascertained mechanisms.

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ХАРАКТЕРИСТИКИ ПЛАЗМЫ И ВЫХОДЯЩЕГО ИОННОГО ПУЧКА В КОМПАКТНОМ ГЕЛИКОННОМ ИСТОЧНИКЕ С ПОСТОЯННЫМИ МАГНИТАМИ

Ю.В. Вирко, В.Ф. Вирко, К.П. Шамрай, А.И. Якименко

Исследован компактный геликонный источник с многокомпонентной изменяемой магнитной ситемой с целью получения улучшенных параметров плазмы и выходящего ионного пучка. Изменение магнитной конфигурации оказалось основным средством для повышения плотности плазмы и тока ионного пучка. Эффективность источника также критически зависела от положения ВЧ- антенны и давления аргона. Путем оптимизации этих параметров был существенно повышен выход плазмы и получен выходящий пучок ионов с энергиями свыше 100 эВ.

ХАРАКТЕРИСТИКИ ПЛАЗМИ ТА ВИХІДНОГО ІОННОГО ПУЧКА В КОМПАКТНОМУ ГЕЛІКОННОМУ ДЖЕРЕЛІ З ПОСТІЙНИМИ МАГНІТАМИ

Ю.В. Вірко, В.Ф. Вірко, К.П. Шамрай, О.І. Якименко

Досліджено компактне геліконне джерело з багатокомпонентною змінюваною магнітною системою з метою одержання поліпшених параметрів плазми та вихідного іонного пучка. Зміна магнітної конфігурації виявилась основним засобом для підвищення густини плазми та струму іонного пучка. Ефективність джерела також критично залежала від розташування ВЧ- антени та тиску аргона. Шляхом оптимізації цих параметрів був істотно підвищено вихід плазми та одержано вихідний пучок іонів з енергіями понад 100 еВ.