DEVELOPMENT OF DC ACCELERATOR ION SOURCES USING HELICON PLASMAS

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Abstract

Compact high-density plasmas are generated with very high power efficiency by applying high-frequency, low-power radio frequency (RF) of 100 MHz and 20 watts. Taking advantage of placing antenna outside of the plasma chamber, a simple ion extraction system becomes available without placing a high voltage isolator for the RF power sources. Plasma and ion beam characteristics of a high-density helicon source are shown to be favorable for dc accelerator ion sources.

1 INTRODUCTION

Stable, high density plasma sources as ion sources are getting more important as continuous power (cw), high-current accelerators are required for various applications such as spallation neutron sources and accelerator-driven transmutation technologies[1]. Developing ion sources, which can operate continuously with high-current, low-emittance beams, is a big challenge for those high intensity accelerators. Recently, microwave ion sources using electron cyclotron resonance (ECR) have been developed for high-current accelerators by satisfying these requirements[2]. However, this source requires relatively strong magnetic field, which may increase emittance, size and cost for the development of higher current density and higher beam current sources for future applications.

Helicon modes have generated stable, high-density plasmas, which are applied mostly to plasma processing for microelectronics[3]. Noting that helicon wave can propagate in a low-frequency, low-field, high-density regime, the helicon plasma source was proposed as an ion source for cw high-current, low-emittance accelerators[4]. To confirm those favorable characteristics of helicon plasmas, a compact high-density helicon plasma source is constructed, and the characteristics of which are investigated.

In section 2, experimental setups of the helicon plasma source and the characteristics of the plasmas are described. Section 3 examines characteristics of the beam extraction from helicon plasmas. Beam characteristics are studied with a simple extraction geometry at low extraction voltage of below 5 kV via experiments and simulations. Conclusions are given in the last section. A new design of high current ion sources using helicon waves are proposed as well.

2 HIGH-DENSITY HELICON PLASMA SOURCE

2.1 Experimental Setup of Helicon Plasma Source

A helicon plasma source shown in Fig. 1 is constructed. Long glass tubes with small diameter are used as a plasma generation chamber, which may be easily attached to other chambers with a pumping system. Two tubes with different diameters of 1.5” and 1” are used. Axial magnetic fields are supplied with two solenoid coils which can provide magnetic fields of up to 2 kG. Antennas tightly fitting with glass tubes are constructed in the mode structure of m=0, providing centrally peaked plasma density, which is favorable for ion source applications.

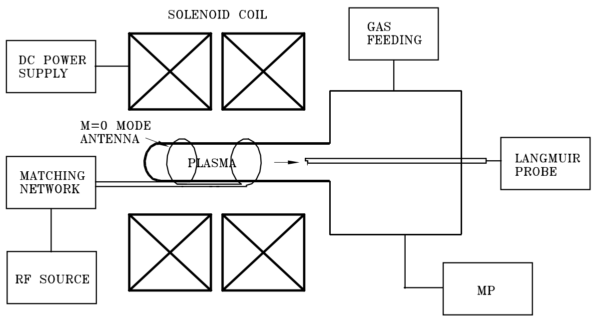

Fig. 1 Schematic of the helicon plasma source.

A low-power, high-frequency radio frequency (RF) source of 100watts, 100 MHz is applied to the antenna through the matching box of a standard type as shown in Fig. 2. Ranges of matching capacitors are determined from the plots shown in Fig. 2 for the antenna inductance and the resistance of 120nH and 0.15Ω respectively. Antennas with the inductance below 100nH are difficult to match RF power into plasma due to their small load capacitance in the matching circuit.

To measure plasma characteristics, a set of Langmuir probe is inserted axially from the opposite side of the helicon plasma source as shown in Fig. 1. The probe tip is made of Molybdenum wire with both the diameter and the length of 1 mm. Chracteristic curves of the probe are obtained by removing RF noises with a LC filtering circuit. Plasma density and temperature are estimated from the curve.

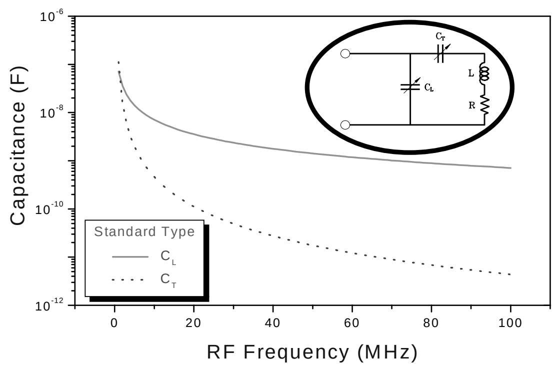

Fig. 2 A circuit diagram for the matching box and the plot of capacitors in the box for the 1” diameter antenna.

2.2 Characteristics of Helicon Plasma Source

Since an extremely efficient plasma discharge in the frequency of helicon waves, $\omega_{ci} << \omega << \omega_{ce}$, was first developed by Boswell[3], intensive studies on theory and experiments have been performed since then. Though theoretical understandings and experimental data of helicon plasmas are still insufficient, some advantageous characteristics as a plasma source were already observed experimentally by several groups[5,6,7].
The operating frequency is widely acceptable, but typically 13.56 MHz is used. In this study, high frequency of 100 MHz is chosen in favor of smaller sized-tubes as a plasma chamber. High plasma densities of up to 10^{13} cm^{-3} are obtained with very low-power of only 20 watts. Dependency of plasma density with the applied magnetic field strength is given in the Fig. 3, and showing strong linear dependency up to the magnetic field of 1 kG. Floating potential becomes so high at relatively low magnetic field, which may indicate the existence of high-energy electron streams. This electron stream may provide electrons to Duopigatron ion sources, and replace an arc filament in the source as proposed by the author previously[4].

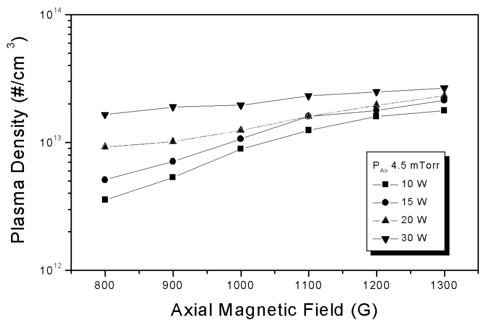

Fig. 3 Plasma density variation with respect to RF power and magnetic field strength.

To make the helicon source as compact as possible, solenoid coils are replaced by a simple permanent magnet system providing the field strength of up 1.5 kG at the center of the tube. The design and field structure of the magnet are shown in Fig. 4.

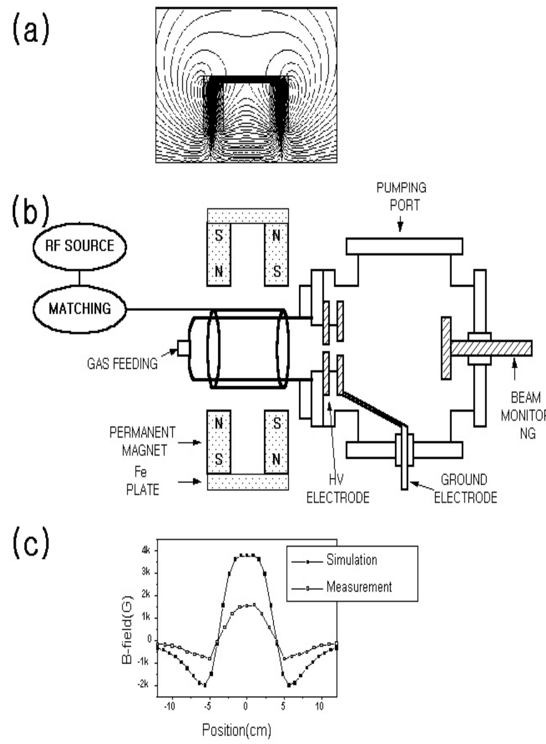

Fig. 4 Arrangement and magnetic field structure of the permanent magnet for the compact helicon source.

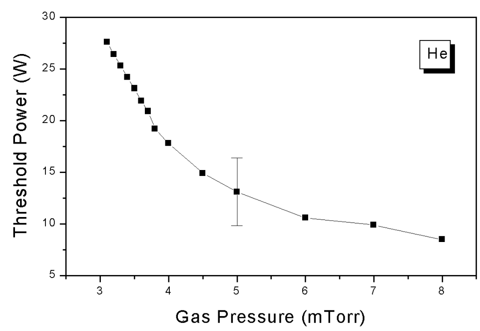

Fig. 5 Threshold powers of the helicon plasmas at various gas pressure.

With the compact helicon source, plasma characteristics are scanned with power, and transitions to helicon modes are identified as a strong jump in plasma densities above certain threshold RF power which varies with the operating gas pressure as shown in Fig. 5.

3 BEAM EXTRACTION WITH COMPACT HELICON PLASMA SOURCE

A simple, two-electrode extraction system is designed and constructed as shown in Fig. 4(b). Two electrodes are separated by 8mm, and the size of holes on the electrodes are chosen as 3 mm and 10 mm for the plasma electrode and the extraction electrode respectively.

Extraction simulations are performed using IGUN code[8] for the given electrode geometries. Simulated beam profiles shown in Fig. 6 predicts helium beam currents of 5mA at the extraction voltage and hole size of 5 kV and 3 mm respectively.

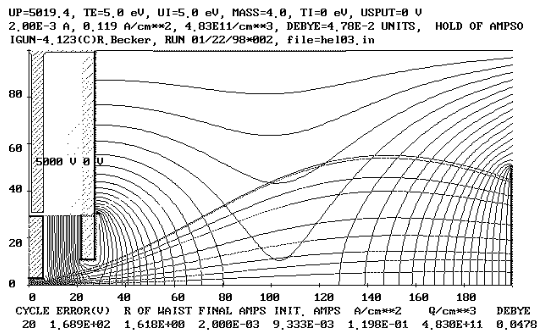

Fig. 6 Extracted beam profiles simulated by IGUN code.

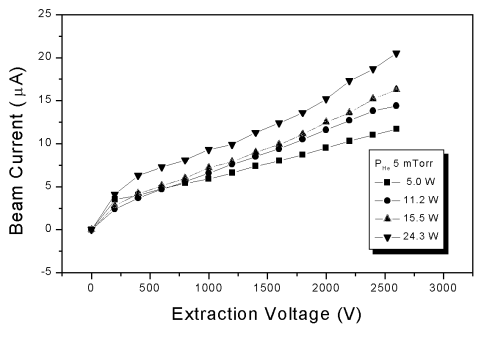

Fig. 7 Extracted beam currents as a function of RF power at various gas pressure.

Experiments of low-voltage extraction are performed with the compact helicon source. As the extraction voltage increases, the extracted ion beam current increases up to 20 μA at the extraction voltage of 3 kV. By changing the polarity of biasing supply, electron beam currents are measured to be 15 times more than that of the ions. Extracted beam currents of helium ion are measured as a function of RF power at various gas pressures and shown in Fig. 7. A low density plasma with 5 watt RF power below helicon mode transition show beam currents are limited by plasma density instead of extraction voltage.

4 CONCLUSIONS

Helicon plasmas have much higher densities in a relatively lower magnetic field than ECR plasmas do. A helicon plasma source has been constructed and generated high density plasmas with very high power efficiency. By replacing the solenoid coils with a simple permanent magnet system, a compact helicon source is built. Taking advantage of placing antenna outside of the plasma chamber, a simple ion extraction system is also composed in this source without placing a high voltage isolator for the RF power sources. Ion and electron beams are extracted from the high-density helicon source without any problem at low voltage extraction. All those above mentioned characteristics are favorable for dc high-current ion sources. Moreover, optimized extraction system with high-density helicon plasma sources at high-voltage extraction may exceed easily the present limit of extracted beam currents as long as strong focusing elements are provided after extraction. A new design of a high-current helicon ion source can be considered as shown in Fig. 8.

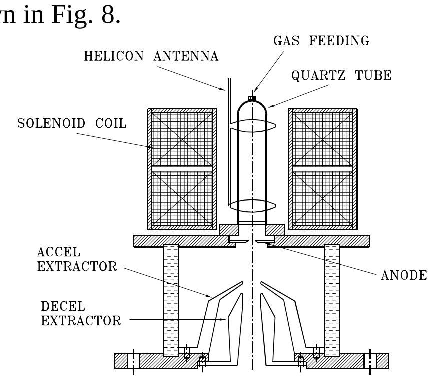

Fig. 8 A new design of helicon ion source.

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