Development of the High-Brightness Ion Source for Accelerator Applications

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Abstract. A helicon and a multicusp version of a radio-frequency ion source with compact permanent magnet systems for accelerator applications have been developed and tested to show the following performance data: plasma density of 10^{11} - $9{\cdot}10^{12}$ cm^{-3}, pressure of 2-10 mTorr, beam current densities of 10 - 130 mA/cm^2, brightness ~100 A/(m^{2}rad^{2}eV), energy spread 8-30 eV, and an rf power input into the plasma of 40 - 400 W. The design of a gas field ion source (GFIS) of the needle-in-capillary type operating at room temperature is proposed. A field ion emitter made on the nanostructured carbon basis is planned to be used in the source.

1. Introduction

To attain higher beam brightness the Institute of Applied Physics of the National Academy of Sciences of the Ukraine is carrying out diverse investigations: design and construction of plasma generators with high plasma density; high brightness ion source, plasma density measurements using the interferometry technique which provides a greater accuracy than the Langmuir probe does; measurements of the beam current, phase characteristics, energy spread, average energy, and mass composition; calculations of the ion source optics with the conservative matrizant method involving the experimental data; derivation of information about the channel of brightness losses from the experimental data and theoretical predictions; and simulation of the extraction system in the high brightness ion source.

This paper presents results obtained for three versions of rf ion sources developed at the Institute of Applied Physics of the National Academy of sciences of Ukraine (IAP NASU) viz., a helicon ion source, a multicusp rf ion source (MCRFIS) and Gas Field Ionization Ion Source(GFIS). The first two make use of an external magnetic field, yet the role of the magnetic field and the mechanism of RF power input into the plasma differ significantly. In the helicon source an external magnetic field is used to excite in the plasma electromagnetic helicon waves and Trivelpiece-Gould waves whose energy can penetrate deep into the plasma and be absorbed in the entire plasma volume. On the other hand, in the MCRFIS the plasma is produced by an internal rf antenna as a result of an inductive rf discharge, with the penetration depth of the rf field being limited by the skin layer thickness. The external multicusp magnetic field serves for magnetic plasma confinement and plasma isolation from the discharge chamber walls.

A gas field ion source (GFIS) has very high brightness ~10^7A/(m^{2}rad^{2}eV)[1], but the current yield is too low to be efficacious for lithography applications.

2. Experimental setup

The experimental setup for testing rf ion sources is shown schematically in Fig. 1. Measurements of the average plasma density n_e, in the rf sources were performed with an 8 mm microwave interferometer developed at the IAP NASU[2]. The interferometer design is based on a Mach-Zender scheme in which plasma is in one of two shoulders of a twin-wave interferometer. The minimum measured phase shift of 1.5^0 corresponds to the plasma density of $3{\cdot}10^{10}$cm^{-3} and the shift of 360^0 to the plasma density of $0.9{\cdot}10^{13}$cm^{-3}, with the phase shift measurement error being below 5%. The emittance was measured with a perforated plate and a mobile vertical wire probe. The perforated plate may be placed outside the measurement area, permitting measurements of the beam profile and total current with a Faraday cup. The beam mass composition was determined using a Wien filter.

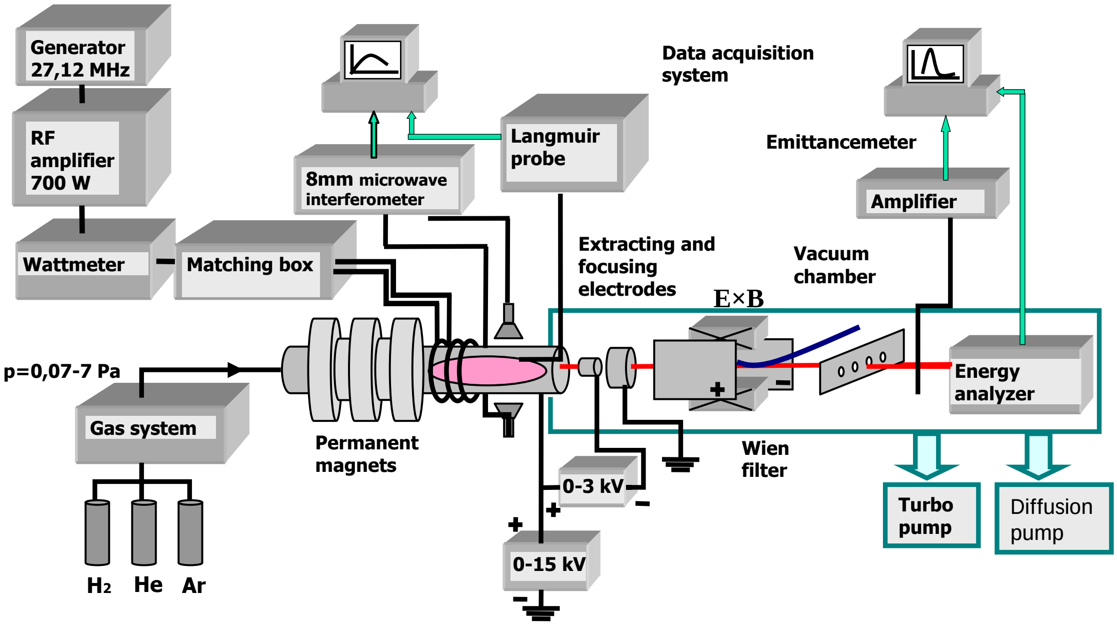

FIG.1. Ion source testing equipment.

3. Helicon ion source

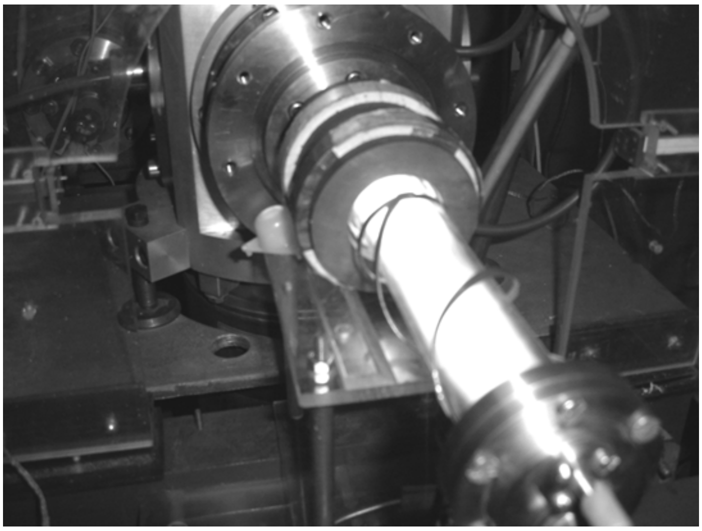

FIG.2. Photograph of the helicon ion source.

Helicon rf ion source [3] was designed for operation in the middle current (0.1 - 5 mA) mode with the ion emission current density of 1-130 mA/cm^2, the power input into the plasma not exceeding 300 W. A photograph of the helicon rf ion source are shown in Fig. 2. The discharge chamber is made from quartz, its outer diameter is 30 mm and length is 250 mm. The rf power supply comprising a driving generator (f_{rf} = 27.12 MHz), ACOM-1000 amplifier, and a matching device, provides a controlled power output of about 400 W in the continuous mode of operation. To operate the helicon RF ion source with hydrogen/helium plasma a magnetic system with circular permanent magnets **(NdFeB)** was designed and constructed, permitting a generation of a longitudinal magnetic field B_z~100 G along the length of the RF antenna and of a longitudinal magnetic field of ~1000 G with effective field length of about 10 cm to confine and transfer the plasma to the extraction system. Magnetic system in the form of parallel closely adjacent rings which are placed between the antenna and the extractor and can be moved over the gas discharge chamber surface permit a controlled magnetic field along the antenna length to be created that together with a high-frequency field generated by an inductor provide resonance conditions in the plasma for the helicon-frequency waves to be excited and efficiently absorbed. Under the resonance conditions, the greatest power input is in the center of the discharge chamber, facilitating more efficient plasma ionization and increased plasma density. In the vicinity of the permanent magnets the plasma is confined and transported to the ion-optic system. Near the emission hole of the ion-optic system the produced plasma is compressed and thus, the beam current density is increased. The measured plasma densities in the vicinity of the emission hole were $0.9 \cdot 10^{13}$cm^{-3} (for argon), $1.6 \cdot 10^{12}$cm^{-3} (for helium), and $6 \cdot 10^{11}$cm^{-3} (for hydrogen); between the antenna and the magnet they were $> 0.9 \cdot 10^{13}$cm^{-3} (for argon), $2.4 \cdot 10^{12}$cm^{-3} (for helium), and $8 \cdot 10^{11}$cm^{-3} (for hydrogen), with working gas pressure in the source < 10 mTorr and RF power input into the plasma < 350 W ($f_{rf} = 27.12$ MHz).

The helium/hydrogen beam brightness is about 100 A/(m^{2}rad^{2}eV) for the working gas pressure in the source < 10 mTorr and RF power input into the plasma < 300 W ($f_{rf} = 27.12$ MHz).

4. Multicusp RF ion source

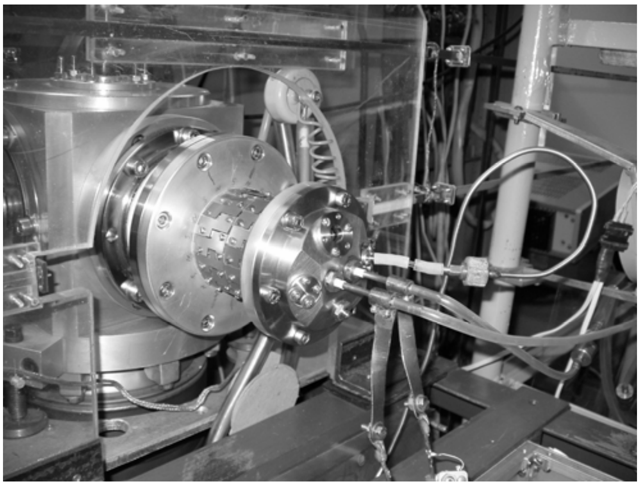

FIG.3. Photograph of the multicusp rf ion source.

A multicusp rf ion source has been developed with a view to decreasing the beam energy spread at the entrance to the electrostatic accelerator. A photograph of the multicusp rf ion source is shown in Fig. 3

The source comprises a cylindrical duralumin discharge chamber of 47 mm inner diameter and 80 mm length. The outer surface of the chamber is surrounded by permanent magnets (Nd-Fe-B) installed with alternating polarity to produce a multicusp magnetic field configuration. The number of magnets in the line is 18; magnet dimensions are 6x10x30 mm. The magnetic field reaches the maximum value of about 300 mT at the discharge chamber wall, decreasing exponentially towards the center. In the region of low magnetic field an rf antenna is located. The antenna is made of a flexible stranded copper wire pulled through a Duran glass tube. The glass tube of 6 mm outer diameter is shaped as a three-turn helix of 25 mm outer diameter. The rf antenna is cooled by a water cooling system which represents a closed loop filled with distilled water. RF power with 27.12 MHz frequency is supplied to the antenna from an rf unit. The connection of the rf antenna with a matching circuit is screened and grounded to reduce RF noise in the instrumentation. The multicusp source flange made from stainless steel accommodates a vacuum lead-in of the rf antenna and a working gas supply. A glass window in the flange is used to observe the discharge. An extracting electrode (cathode) is made from molybdenum and has an extraction channel of 0.6 mm diameter and 3 mm length.

Using a grid energy analyzer the ion energy distribution functions (IEDF) of the helium beam have been measured. The average energy, E_0, and helium ion energy spread, ΔE, were determined. The helium ion energy spread was found to be *$\Delta E=8\pm 1eV$* for rf power of 100 to 200 W, increasing with the RF power and being independent of the gas pressure in the discharge chamber of the ion source. The multicusp version realizes operating modes with the helium ion current ~ 100 μA and ion energy spread ~ 8 eV for the power input into the plasma of 200 W.

5. Gas Field Ionization Ion Source

A gas field ionization ion source is under construction now at IAP NASU. General view of the source is shown in Fig.4. The source components are placed on the standard flange CF-63. Microdisplacement sylphon (5) of the capillary is secured on the central flange axis (8) through the sectional copper gasket. Capillary displacement can be done in the longitudinal direction within the range a few millimeters and is necessary to change distances between the capillary and mesh extracting electrode. Glass electrode with outer diameter of 1-2mm approx. and inner diameter of 0.2mm is pasted into the metal changeable holder (3) of the capillary.

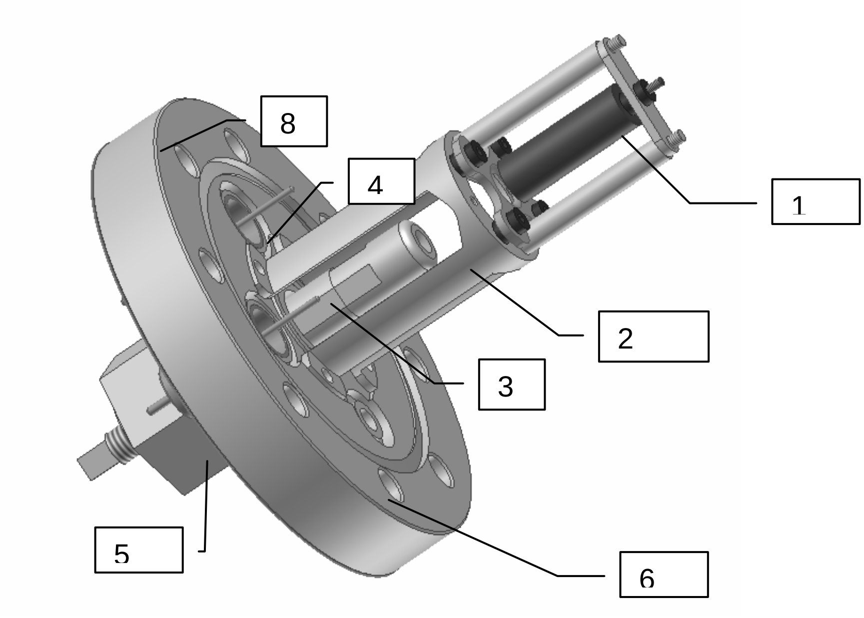

FIG.4. Gas field ionization ion source: 1-Faraday cup, 2- fastener of the extracting electrode mesh, 3-changeable capillary holder, 4-high-voltage current lead, 5-fastener of the capillary microdisplacement mechanism, 6- gas inlet, 8-ion source flange CF-63.

Working gas input to the capillary is presented by the flexible stainless steel tube with outer diameter of approx. 2mm, which connects gas inlet (6) and capillary displacement mechanism (3). Junctions of the flexible tube and metal components (6) and (3) are soldered by silver. Field emitter presented by the sharp-ended thin tungsten wire of 0.1mm diameter obtained by etching in CaOH is placed coaxially inside the capillary. Top of the emitter is in the capillary end plane where gas inlet from the capillary to the vacuum chamber takes place.
Voltage of 5-10kV is applied to the field emitter through the vacuum high-voltage input.

6. Conclusions

Compact plasma generators and plasma ion source with high plasma density ($5\cdot10^{11}$ - 10^{13} cm^{-3}) have been developed for ion-beam technology applications. Beam brightnesses achieved are about 100 A /(m^2rad^2eV). Further improvements in brightness require combined experimental and theoretical optimization studies of helicon generators and ion source extraction systems.

To obtain ion beams with low energy spread a multicusped RF ion source has been developed with frequency of 27.12 MHz. the minimum energy spread of helium ions is $\Delta E = 8 \pm 1 eV$ for the 200 w RF power.

The design of a gas field ion source (GFIS) of the needle-in-capillary type operating at room temperature is proposed and constructed.

7. References

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