AXIAL ENERGY SPREAD MEASUREMENTS OF A 27.12 MHz MULTICUSP ION SOURCE

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A 4.7 cm diameter and 8 cm long 27.12 MHz radio-frequency (RF) inductively coupled multicusp ion source has been designed for ion beam applications. Ion energy distribution functions (IED) of the extracted helium and argon ion beams were measured by use of a retarding field energy analyzer. Influence of the RF power, gas pressure and the extraction voltage on the ion energy spread of the beam is described. The ion energy spread is found to be 7 eV for helium beam at 200 W RF power and gas pressure of 5 mTorr.

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1. INTRODUCTION

Radio-frequency multicusp ion sources have been widely used for many applications in ion implantation, particle accelerators, microlithography. They have several advantages over the ion sources because of its simpler structure, longer lifetime of operation and clean plasma discharge [1]. In some of these applications, ion beams with minimal axial energy spread and nominal current are required.

A 27.12 MHz RF multicusp ion source have been constructed and tested in the Institute of Applied Physics, Ukraine. First results of the axial energy spread and beam current measurements of the RF multicusp ion source are presented in this paper.

2. EXPERIMENTAL SETUP

A schematic diagram of the RF multicusp ion source and energy analyzer assembly is shown in Fig.1. Ion source is a cylindrical metal chamber with inner diameter of 4.7 cm and length of 8 cm and surrounded by 18 columns of Nd-Fe-B magnets which are arranged with alternating polarity. Such line-cusp configuration of magnetic fields confines plasma very efficiently. The magnetic field reaches a maximum of 0.3 T at the plasma chamber wall. There is a nearly free field region with 2.5 cm diameter in the center of the source where a RF antenna is located.

Plasma is generated by inductive discharge via a three-turn antenna. RF antenna is made of a braided copper wire threaded through a Duran glass tube with a 6 mm diameter bent in a circular shape 2.5 cm in diameter. Antenna is cooled by distilled water. A 27.12 MHz 40 W oscillator and 700 W RF power amplifier are connected by a 50 Ω coaxial cable to the impedance matching system which consists of an isolation transformer, a tune capacitor and a load capacitor. A forward and reflected RF power is controlled by SWR meter [2].

The stainless steel back flange contains antenna feedthrough, gas inlet and port for glass window. The open end of the source chamber is enclosed by an extraction and focusing system. The extraction electrode has a canal with 0.6 mm in diameter and 3 mm of length. In order to eliminate the RF modulation of the DC extraction voltage with RF interference, a RF choke and capacitor were installed. They function as a L-C low pass filter. The connection between antenna and matching network was shielded to reduce RF coupling to the measurement setup. The RF power supply was operated at the ground potential.

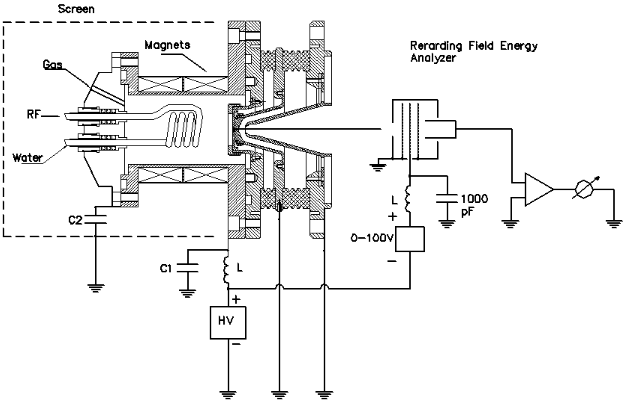

Fig.1. Schematic diagram of a multicusp RF ion source and energy analyzer assembly

The ion source is connected to the beam diagnostic chambers and the whole system is evacuated by a turbo-pump and a mechanical pump to a basic pressure of about 10^{-6} Torr. Argon and helium were used as working gases.

Ion energy distribution has been measured by using a retarding field energy analyzer. Energy analyzer is located at 20 cm from the ion source and shown schematically in Fig. 1. Energy analyzer consists of three plane parallel metal grids. The distance between the adjacent grids is 2 mm. Ion retarding positive potential is applied to the middle grid in respect to the extraction voltage. The energy analysis of the ions is accomplished by sweeping this potential from 0 to +100 V while measuring the ion current at the collector. The IED is proportional to the first derivative of the collector current. The ion energy spread ΔE is defined as the full-width at half-maximum of the IED. Analyzer energy resolution is estimated as 1 eV.

3. EXPERIMENTAL RESULTS

Total Ar ion beam current Ii of a multicusp RF source was measured by a Faraday cup. The ion current density was determined as $j_i=4I_i/\pi d^2$, where d=0.6 mm is a diameter of the extraction canal. A current of 154 μA (ion current density is 55 mA/cm^2) is achieved with input RF power of 213 W at 2.4 kV of extraction voltage.

Fig. 2 shows the evolution of measured IEDs for He at 5 mTorr, 100 W RF power for different extraction voltage in the range of 0.5…3 kV. The helium IEDs are monoenergetic at low pressure and low RF power. IED shifts towards higher energies as the extraction voltage is increased.

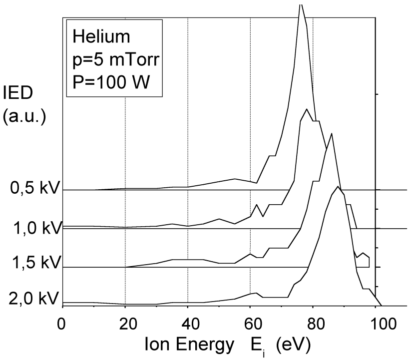

Fig.2. Measured IEDs for different extraction voltage. Helium, RF power is 100 W, pressure is 5 mTorr

The evolution of IEDs for Ar ions as function of a pressure is shown in Fig. 3. The IEDs exhibits a double peak structure at low pressure and becomes multi-peak and shifts towards lower energies as the pressure is increased.

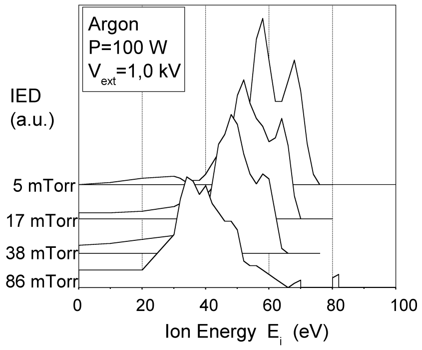

Fig.3. Measured IEDs for different pressures. Argon, RF power is 100 W, extraction voltage is 1 kV

Fig. 4 shows the calculated energy spread of helium and argon ion beams versus RF power. The energy spread increases as RF power rises. The energy spread is independent of the pressure in the range from 5 to 86 mTorr for argon and helium ions.

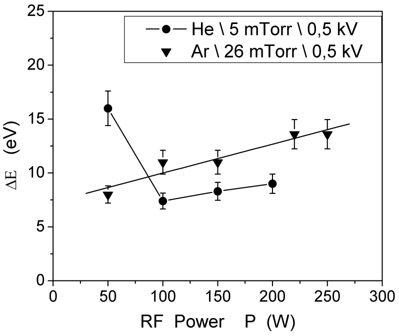

Fig.4. The ion energy spread ΔE versus RF power for He (5 mTorr) and Ar (26 mTorr) ion beams. Extraction voltage is 0.5 kV

4. DISCUSSION

Ions gain energy by acceleration in the sheath through an extraction potential drop. Due to the capacitive coupling this DC potential has an AC component superimposed. A brief review and discussion on ion energy distribution in capacitive discharges is given by Kawamura *et al* [3]. Benoit-Cattin *et al* [4] considered the theory of the ion motion through the capacitive collisionless sheath. They assumed a sinusoidal sheath voltage: $V_S(t)=V_0+V_{RF}\cdot\sin\omega t$, where V_{RF} is the RF potential across the sheath and ω is the RF driving frequency. V_0 is the mean sheath voltage and it is a DC potential across the sheath: $V_0=(kT_e/2e)\cdot\ln(M/2\pi m)+V_{ext}$, where V_p is plasma potential, k is Boltzmann constant, e is the electron charge, M and m is the ion and electron mass, V_{ext} is the extraction voltage and T_e is the electron temperature.

The crucial parameter determining the shape of the IEDs is $\beta=\tau_{ion}/\tau_{RF}$, where $\tau_{RF}=2\pi/\omega$ is the RF period and τ_{ion} is the time an ion takes to traverse the sheath when the sheath drop is at its DC value. Assuming a colllisionless Child-Langmuir space charge sheath the ratio β becomes: $\beta=(3s\omega/2\pi)\cdot(M/2eV_0)^{1/2}$, where s is the sheath thickness.

In the low-frequency regime ($\beta<<1$), the ions cross the sheath in a small fraction of an RF cycle and respond to the instantaneous sheath voltage. Their energy, therefore, depend on the phase of the RF cycle when they enter the sheath. As a result, the ion energy averaged over an RF period is strongly modulated. This leads to substantial broadening of the IED with a width ΔE of the order of the peak to peak RF voltage. The IED is bimodal with two peaks lying close together.

In the high-frequency regime ($\beta>>1$), the sheath potential oscillates many times during the time the ion crosses the sheath, and ion responds, therefore, to the average sheath voltage and the phase of the cycle in which they enter the sheath becomes unimportant, resulting in a narrower IED. In this high-frequency regime, the resulting expression for ΔE is [3]: $\Delta E=4eV_{rf}/\pi\beta$. Thus, as β increases, the IED width shrinks and the two peaks of the IED approach each other until they can no longer be resolved. In the intermediate-frequency regime, the ion trajectory depends on the number of times the oscillating plasma-sheath boundary crosses the ion's path. The resulting energy distributions are bimodal but the precise shapes of the IEDs exhibited rapid variations [5].

The processes determining the IED in the discharge are the sheath thickness s, ratio β, ion mean free path λ_I, electron temperature T_e and the RF potential across the sheath V_{RF}. These parameters were not measured in the experiment. But we can make some estimation.

The sheath thickness s can be obtained by using the Child-Langmuir law: $s=2/3\cdot(2e/M)^{1/4}\cdot(\varepsilon_0/j_i)^{1/2}\cdot V_{ext}^{3/4}$.

The ion current density j_i=33 mA/cm^2 at V_{ext}=1.6 kV for argon ion beam. We find that s=1.3 mm. Considering the two dominating collision process (Ar^+-Ar exchange and Ar^+-Ar elastic collisions), the ion mean free path λ_i can be calculated from the cross sections: λ_i=5 mm for a pressure of 5 mTorr, λ_i=1 mm for 26 mTorr and λ_i=0.3 mm for 86 mTorr. Thus for a pressure in the range from 5 to 20 mTorr, the ion mean free path is larger than the sheath thickness s and ions may traverse the sheath nearly collisionlessly. As the RF period $\tau_{RF}=0.037\mu s$ (1/27.12 MHz), the ratio $\beta=1.4$. This is a nearly intermediate-frequency regime for argon and we expect to see the bimodal energy distribution with rapid variations. This can be seen in Fig. 3. The double peak structure of the IEDs is an indication of some degree of parasitic capacitive coupling.

From plasma density measurements using an 8 mm microwave interferometer, reported elsewhere [6], we find that $n_e=10^{12}$ cm^{-3} for argon at RF power of 140 W and pressure of 2 mTorr. Plasma density is $n_e=10^{11}$ cm^{-3} for helium at the same RF power and pressure. As the sheath thickness s is a function of $n_e^{-1/2}$, we can expect for helium the ratio $\beta = 4.4$. This is a nearly high-frequency regime and the ion energy distribution is narrow and nearly monoenergetic (Fig. 2). The He ion energy spread less than argon energy spread due to the increased β.

The increasing of the ion energy spread with RF power is due to the increased RF potential across the sheath and decreased sheath thickness (Fig. 4).

For a pressure in the range from 20 to 86 mTorr, the ion mean free path is of the order or less the sheath thickness s and ions may perform collisions within the sheath. Charge exchange and elastic collisions can occur in the sheath and affect the IED. Charge exchange collisions give rise to a multi-peaked structure, due to the RF modulation of the slow ions [7]. Such multi-peaked structure of IED can be seen for argon (Fig. 3) and helium at high pressure.

CONCLUSIONS

A 27.12 MHz RF multicusp ion source has been designed for ion beam applications. A current of 154 μA of argon ions is achieved with the RF power of 213 W at 2.4 kV of the extraction voltage.

The minimal ion energy spread is found to be 7 eV for helium and 10 eV for argon beam at 200 W RF power, 5 mTorr of pressure. The ion energy spread increases as RF power and extraction voltage rises and is almost independent of the pressure. Double peak structure of the IEDs is an indication of a capacitive coupling. The multi-peaked IEDs at higher pressure indicate that the ions exhibit scattering and charge exchange collisions as they cross the extraction region.

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ИЗМЕРЕНИЯ АКСИАЛЬНОГО РАЗБРОСА ИОНОВ ПО ЭНЕРГИИ 27,12 МГц МУЛЬТИКАСПОВОГО ИОННОГО ИСТОЧНИКА

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Разработан 27,12 МГц- мультикасповый ВЧ- ионный источник диаметром 4,7 см и длиной 8 см для ионно-пучковых приложений. Измерены функции распределения ионов по энергии (ФРИЭ) извлеченного гелиевого и аргонового пучков с помощью энергоанализатора с задерживающим полем. Рассмотрено влияние ВЧ-мощности, давления газа и вытягивающего напряжения на энергетический разброс ионов пучка. Минимальный энергетический разброс ионов гелиевого пучка равен 7 эВ при 200 Вт ВЧ- мощности и 5 мТорр давления газа.

ВИМІРЮВАННЯ АКСІАЛЬНОГО РОЗКИДУ ІОНІВ З ЕНЕРГІЇ 27,12 МГЦ МУЛЬТИКАСПОВОГО ІОННОГО ДЖЕРЕЛА

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Розроблено 27,12 МГц мультикаспове ВЧ- іонне джерело діаметром 4,7 см і завдовжки 8 см для іонно-пучкових застосувань. Обмірювано функції розподілу іонів з енергії (ФРІЕ) витягнутого гелієвого та аргонового пучків за допомогою енергоаналізатора із затримуючим полем. Розглянуто вплив ВЧ- потужності, тиску газу та витягаючої напруги на енергетичний розкид іонів пучка. Мінімальний енергетичний розкид іонів гелієвого пучка дорівнює 7 еВ при 200 Вт ВЧ- потужності та 5 мТорр тиску газу.