INVESTIGATION OF 2.45 GHZ ECR ION SOURCE FOR PRODUCTION OF RADIOACTIVE ION BEAMS.

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Abstract

For production of radioactive ion beams of ^6He and ^8He the permanent magnet ECR ion source operating at 2.45 GHz frequency was developed [1]. The radioactive atoms are injected to the source axially through the grid. Due to potential difference and axial magnetic field gradient there is an ion flux leaving the source to the injection side. This ion current, measured at different discharge modes, equals or exceeds the current, extracted through the 5 mm hole in plasma electrode. The experiments aiming the suppression of the current to injection side were performed. This ion current was decreased by factor 10÷100 depending on the discharge mode. Also the results of measuring ion source efficiency for different gases are reported.

1 DESCRIPTION OF THE ION SOURCE

The magnetic configuration of the source is made with three permanent magnet rings with radial magnetization. This system allows create pseudo-closed resonance surface. In fact this configuration represents the well known cusp geometry.

The source consists of the cylindrical shape plasma chamber with inner diameter of 90 mm and the UHF feeding system. A 2.45 GHz microwave is injected into the plasma chamber radially through the coaxial vacuum transition ended by a rod. Matching of the microwave power to the plasma is optimized by the reactivity tuning element. The length of the plasma chamber (distance between the plasma electrode and the shorting plate) corresponds to a single TE_{111} mode cavity. The magnetron generator delivering up to 300 W of microwave power is installed at the high voltage platform.

The extraction system consists of the plasma electrode with the extraction hole of 5mm in diameter and the grounded movable puller.

The ion source is installed at the production station shown in Fig. 1. Radioactive isotopes of helium are produced in the thick beryllium target and then stopped in the hot graphite catcher. From the catcher helium atoms diffuse through the line with the length of about 1 meter and diameter of 100 mm into the ion source. After extraction the ion beams are separated by 90° double focusing magnet with the bending radius of 0.5 m. The intensity of the ion beam is measured by a Faraday cup installed in the diagnostic box.

The tuning of the separator and the beam transport line for $^6He^{1+}$ ions was performed with the beam of $^{12}C^{2+}$ ions produced from CO_2 gas.

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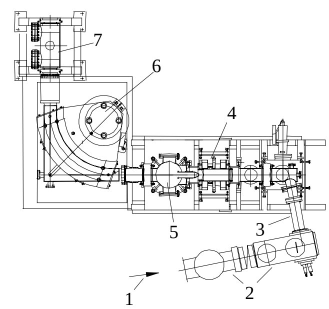

Figure 1: Layout of the DRIBs production station: 1 – primary beam; 2 – target and catcher; 3 – diffusion line; 4 – ECR source; 5 – extraction box; 6 – magnet; 7 – diagnostic box.

2 EXPERIMENTAL RESULTS

2.1. Measurements of the currents

The ion source operates with ^4He as a support gas. To allow the diffusion of ^6He into discharge chamber the shorting plate has a number of holes with the diameter of 5 mm. The total area of holes is approximately 32 cm^2. To prevent the UHF leak out of discharge chamber the thickness of the shorting plate was chosen 8 mm. In this case the ions can leave the source in both directions – through the extraction hole and through the shorting plate – that will decrease the efficiency of the source.

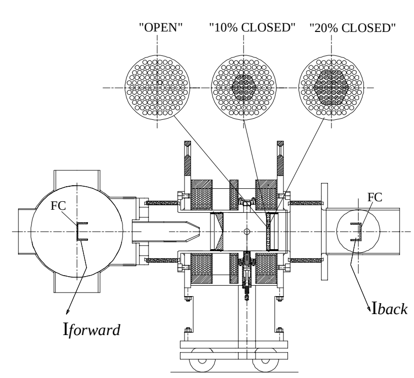

Figure 2: The scheme of experiment on measurement of ion currents from the source.

To determine the currents leaving the source in both directions two additional Faraday cups were installed as it shown in Fig.2 – one with the aperture of 30 mm in diameter in the extraction box just after the puller, which measures the current $I_{forward}$, and the second one with the aperture of 60 mm - in the diffusion line, which measures the current I_{back}. The measurements were performed with ^{4}He ion beams.

The first series of experiments was performed with original shorting plate, which is marked as “open” in Fig.2. The variable parameters were: microwave power, gas pressure in the discharge chamber and extraction voltage. The results are presented in Fig.3.

The same measurements were performed when 10% of holes in the central part of shorting plate were closed. In this case the current I_{back} was decreased approximately by factor 2 – 3. The character of currents dependences from source pressure, microwave power and extraction voltage was similar to the case of “open” shorting plate.

In the next step 20% of holes in the central part of shorting plate were closed. The results of these measurements are presented in Fig.4. It is seen from the figure that the current I_{back} is one or two order of magnitude lower than the current $I_{forward}$.

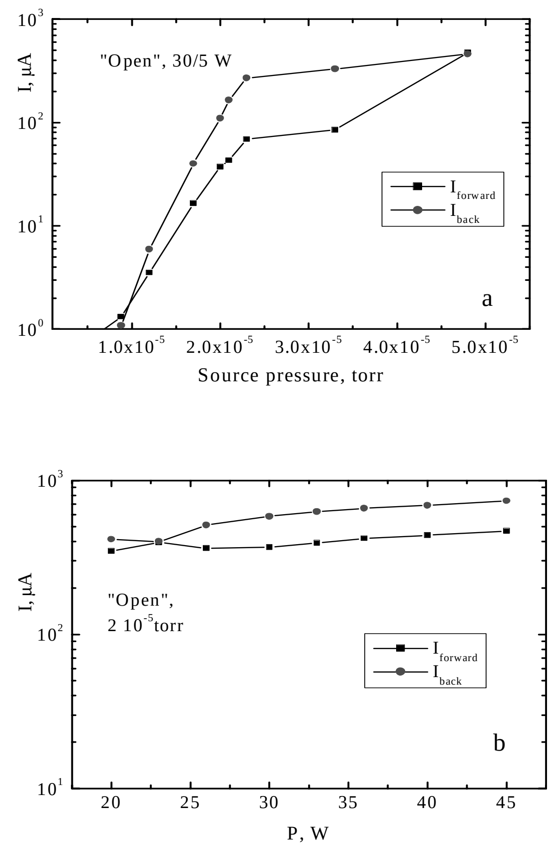

Figure 3: The variation of “forward” and “back” currents with discharge parameters: source pressure (a) and microwave power (b). 100% of holes are open.

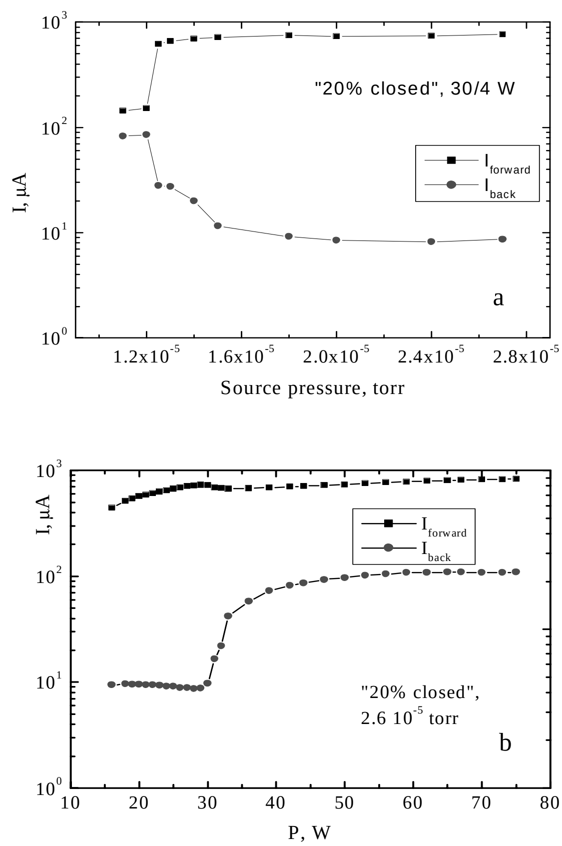

Figure 4: The variation of currents $I_{forward}$ and I_{back} with discharge parameters: source pressure (a) and microwave power (b). 20% of holes are closed.

It is seen that in all discharge modes the current I_{back} equals or exceeds the current extracted through the hole in plasma electrode. The sum of currents extracted in both directions coincides well with the drain current of high voltage power supply that means that we register the total current leaving the source.

With variation of the extraction voltage in the range of 10 – 21 kV the current $I_{forward}$ show the typical dependence with “saturation” at about 14 kV, while the current I_{back} growth continuously in this voltage range.

All measurements were performed with the extraction voltage of 16 kV.

The character of the currents variation with the discharge parameters differs from the case of “open” shorting plate.

The current I_{back} can be caused either by conventional extraction from plasma through the holes in shorting plate, either by diffusion of plasma. It should be noted that with “open” shorting plate about 60μA was registered by Faraday cup measuring I_{back} at zero extraction voltage.

Some calculations were performed using IGUN code [2] to compare the currents extracted in both directions. Fig.5a shows the simulation of extraction through the hole with the diameter of 5 mm. The parameters of plasma are set to produce the extracted current of about 1 mA. Fig.5b shows the simulation of the extraction through the shorting plate under the same conditions.

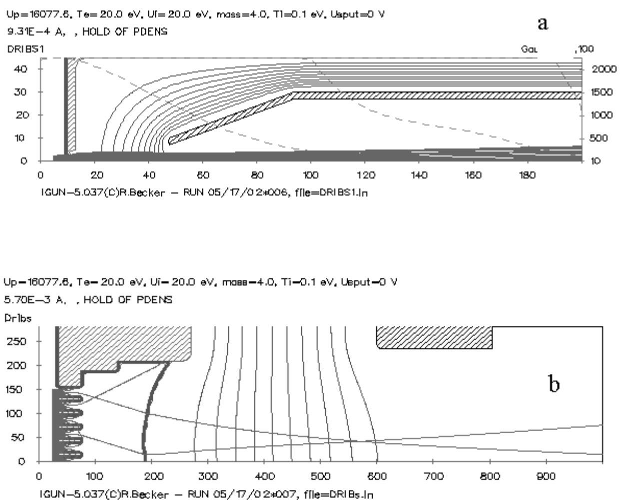

Figure 5: The IGUN simulation of the extraction through the plasma electrode (a), and through the shorting plate (b).

It is seen that current I_{back} value can not be explained by electrostatic extraction only, and this current is determined by plasma diffusion through the shorting plate.

2.2 Efficiency measurement

The measurements of the source efficiency for different gases were performed with the calibrated leaks with equivalent flux of about 30 pμA. In case of helium calibrated leak hydrogen was used as a support gas, for argon and krypton the support gas was helium.

The measurements of the source efficiency for helium were performed with different diameters of the hole in plasma electrode. The results are presented in Fig. 6.

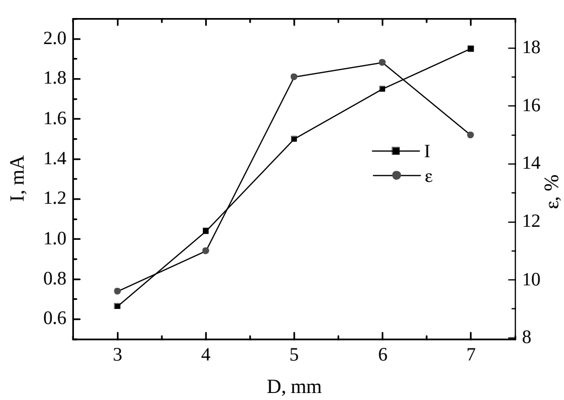

Figure 6: Maximum extracted He^{1+} current (square) and global efficiency (circle) versus the diameter of the extraction hole.

For Ar and Kr the estimated ionization efficiencies exceed 90%. Measured Ar^{1+} current versus the gas pressure in plasma chamber for different levels of directed / reflected microwave power is shown in Fig. 7.

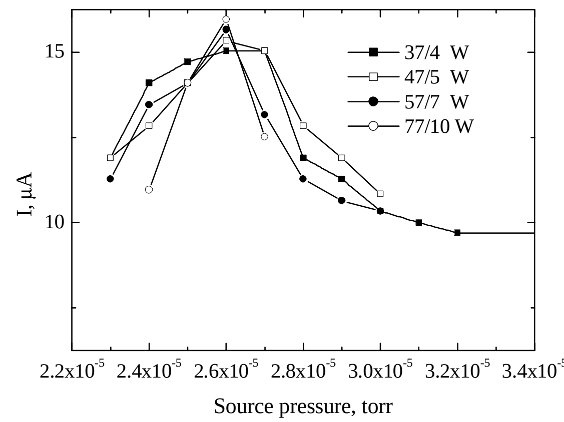

Figure 7: Measured Ar^{1+} ion current (calibrated leak 29.6 pμA) versus pressure inside the plasma chamber for different levels of direct / reflected microwave power.

The efficiency measurements were performed with completely closed shorting plate.

3 CONCLUSION

In the present work the investigations of the 2.45 GHz ECR ion source were carried out. As the results of investigations the conditions for suppression of the current extracted to gas injection side were found. The efficiency of the source for noble gases was measured.

The first experiment for the production and acceleration of $^{6}He^{1+}$ ion beam was carried out in January of 2002. The ^{6}He atoms were produced, ionized, transported to the cyclotron U-400 through the beam transport line of about 120 m length and finally accelerated. The estimated global efficiency from the production target to the accelerated ion beam was about of 1.5 %.

4 REFERENCES

[1] A.Efremov et al. “Ion sources for the first stage of the DRIBs project”. Proceedings of the 16th International Conference on Cyclotrons and their Applications. East-Lansing, Michigan, 13 to 17 May 2001, p.p.268 - 270.

[2] R.Becker “New features in the simulation of ion extraction with IGUN”. Proceedings of the 6th European Particle Accelerator Conference (EPAC98), Stockholm, 22 to 26 June 1998, p.p.1165 – 1167.