Studies on new--type full-ion source

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We have designed a new-type full-ion source at Institute of Nuclear Research of Lanzhou University. In the paper, we expound structure and physical principle of the source. By experiments we have preliminarily studied the working characteristic, the operation regularities and the optimum operation parameters of the source. In case of a single-aperture extraction and the extraction voltage of 30 Kev, 7.5 mA argon beam has been extracted. The content of metal ion in the extracted beam is not lower than 5 percent.

I. INTRODUCTION

The study of ion sources is an important aspect of accelerator physics and technology. It provides a powerful tool for multisubject fundamental research and applied research. But at present, for a given source only few ion species can be provided, so it can t satisfy needs of more extensive application. The aim of the development of the new-type full-ion source is to build an ion source, which can produce various ion , i.e., a full-ion source. The developing work is supported by the National Natural Science Foundation of China.

The features of the source are as follows: (1) In principle, ions of all elements in the periodic table can be produced and high-current ion beams may be provided for various application; (2) The hot cathode is substituted by the microwave plasma cathode (MP-cathode); therefore the cathode lifetime may be greatly prolonged, especially for the production of an oxygen ion beam; (3) The ion sputtering mechanism in the inside of the source for the production of metal ions has been adopted, thus the structure of the source is simplified and the working stability is improved ; (4) The configuration of the source and the distribution of the electric field and magnetic field in the discharge chamber contribute more to confining the plasma; (5) Multiple charge state ions may be obtained.

II. SOURCE DESCRIPTION

The structure scheme of the source is shown in Fig. 1. The source consists of the microwave plasma cathode (MP-cathode), the main discharge chamber and the extraction system of ion beam. High concentrated cathode plasma generated by the electron cyclotron resonance (ECR) microwave discharge in the cathode discharge chamber is used as an electron emitter, i.e., MP-cathode of the source and a high current electron beam can be extracted from the cathode plasma by the extraction electrode of electron beam.[1,2] The main discharge chamber of the source is a cylindrical space surrounded by the extraction electrode of the electron beam, the middle electrode and the plasma electrode of the source. A single-aperture or seven-aperture accel-decel three-electrode extraction system of ion beam, which constitute with the plasma electrode of the source, the

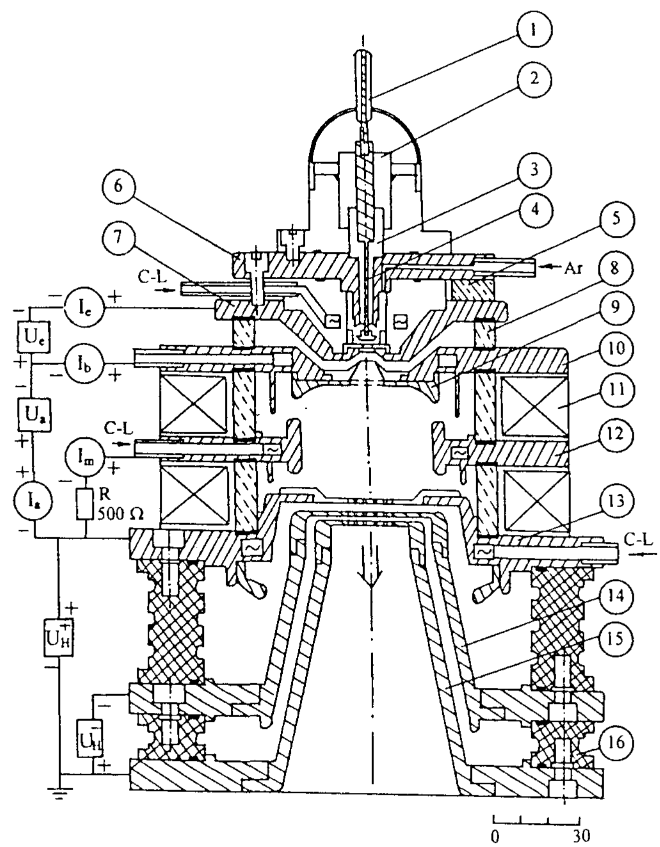

Fig 1. The structure scheme of the new-type full-ion source. (1)microwave coaxial cable, (2)sealed connector (ceramic), (3)ceramic insulator, (4)antenna, (5)permanent magnet, (6) upper magnetic pole, (7) below magnetic pole, (8)ceramic insulating ring, (9)sputtered block to be ionized, (10) extraction electrode of electron beam, (11)magnetic field coil,(12)middle electrode,(13) plasma electrode, (14)negative electrode, (15)grounded electrode, (16) polyolefin insulating ring. U_e — electron beam extraction supply, U_a — arc voltage supply, U_H^+ — positive high voltage supply, U_H^- — negative high voltage supply, C-L — cold line.

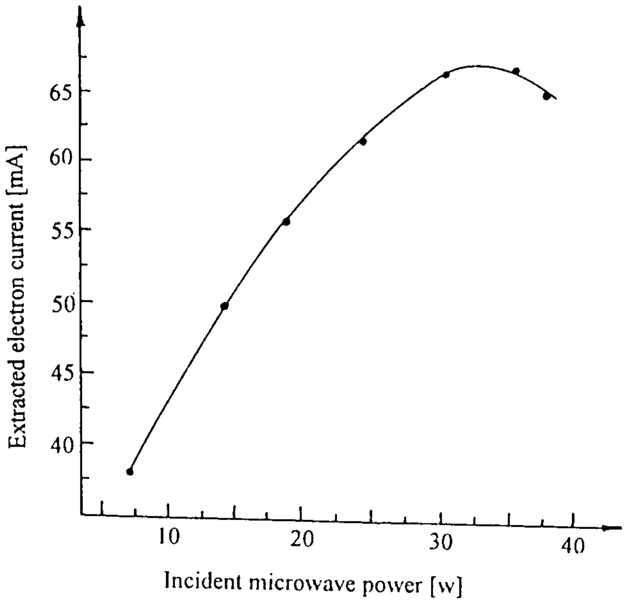

Fig 2. The extracted electron current as a function of the incident microwave power.

negative electrode and the grounded electrode , has been adopted.

In this source, the configuration of the magnetic field in the cathode discharge chamber and the main discharge chamber of the source is extremely important. The configuration and distribution of the magnetic field in the cathode discharge chamber not only must satisfy ECR condition in the microwave discharge but also can play an important part in confining cathode plasma. Therefore a valley-peak shape magnetic distribution around the symmetry axis of the discharge chamber of the cathode[1] is adopted. The magnetic field strength of the valley area is 0.0875T for the microwave frequency of 2.45GHz.In order to confine the source plasma a cusps-shape magnetic field is established in the main discharge chamber of the source by two magnetic field coils situated in the outside of the main discharge chamber.[3]

The sputtered block prepared from the material to be ionized is inlaid on the end of the extraction electrode of the electron beam and it is also used as the sputtering electrode of the source. The sputtered block may be changed according to the different kind of expected ions. Argon gas, which is used as the working gas of the cathode and is also as auxiliary working gas of the source, is introduced from the top into the discharge chamber of the cathode.

According to the connection principle shown in Fig. 1, the electron beam extracted from the MP-cathode is accelerated by the extraction voltage of the electron beam U_e and the arc voltage U_{arc} and enters the main discharge chamber of the source. The argon plasma in the main discharge chamber can be produced by the high-current energetic electron beam inelastic collision with atoms of the auxiliary gas from the MP-cathode. Under steady-state operation the plasma is situated in the potential of the plasma electrode and the sputtered block, which exposed to the dense argon plasma, is kept at a negative potential relative to the argon plasma by means of the arc voltage. Those argon ions facing the sputtered block at the ion emission surface of the plasma undergo a acceleration of the arc voltage and impinge on the surface of the sputtered block, and thus induce the block sputtering.

The ion current intensity which bombard on the surface of the sputtered block may be estimated by the formula[4]

$$I_s = 0.4en^+ \times \sqrt{2kT_e/M_i} \times A \qquad (1)$$

here, e and M_i are the charge and mass of ion, respectively, n^+ is the ion density of the plasma, k is Boltzmann's constant, T_e is electron temperature of the plasma, A is the area of the sputtered block facing the ion emission surface of the plasma. As a result of this, a vapor with a given concentration of the atoms of the block material to be ionized appears in the main discharge chamber and these atoms are then ionized by the successive electron beam.

The number of sputtered out atom from the block surface per incident ion is estimated by the formula[5]

$$N_S = \sqrt{\varepsilon E_0/E_d} \times \sum_{n=1}^{n_c} \exp\left(-\alpha\sqrt{n}\right) \times \exp\left[-(n-1)\xi/2\right] \qquad (2)$$

here, $\varepsilon = 2M_1M_2/(M_1+M_2)^2$ is the average energy transfer rate of the incident ion,

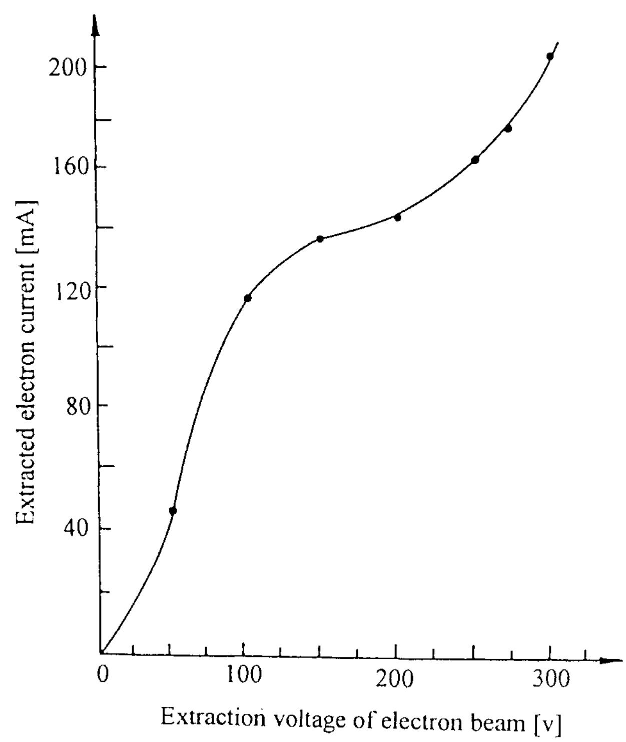

Fig 3. The extracted electron current as a function of extraction voltage.

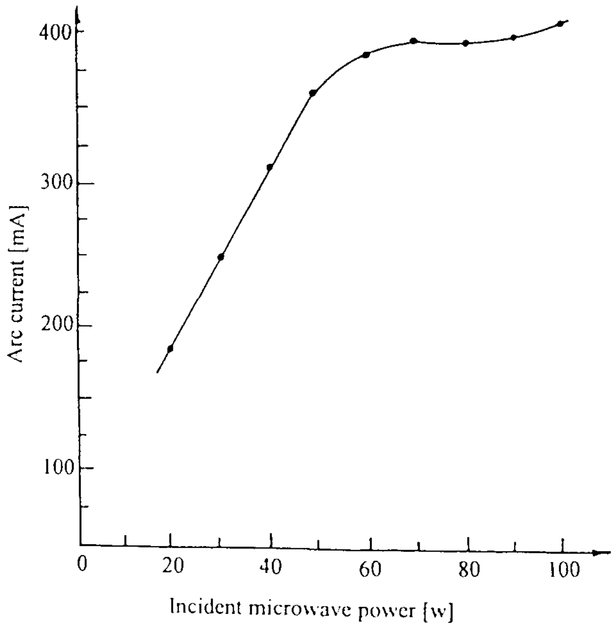

Fig 4. The arc current as a function of incident microwave power.

$n_c = \xi^{-1} \times \ln(\varepsilon E_0 / E_d)$ is the ion collision number in the block material,

$$\xi = 1 - \left[\left(M_2 - M_1 \right)^2 / 2M_1 M_2 \right] \times \ln\left[\left(M_1 + M_2 \right) / \left(M_1 - M_2 \right) \right]$$

$E_d = \varepsilon E_t$ is the movement energy of the target atom, E_0 is the incident energy of ion (here, $E_0 \approx eU_{arc}$), E_t is the sputtering threshold energy, M_1 and M_2 are the atomic weight of the incident ion and the target atom, respectively, and α is a coefficient related with ion range.

Under steady-state operation, we treat the sputtered out atom as an atom gas, thus the density of the atom in the main discharge chamber may be estimated by formula :

$$n_S = \frac{N_s I_s}{eV} \left(1 - \frac{\beta S}{V} \sqrt{kT_a / 2\pi M_a} \right) \qquad (3)$$

here, V and S are the effective gas-filled volume and the inner area of the main discharge chamber, respectively, T_a and M_a are temperature and atomic weight of the atom gas, and β is condensation probability of the atom gas impinging on the inner area. Thus we obtain the partial pressure of the sputtered out atom by formula:

$$P_s = n_S k T_a \qquad (4)$$

The relative output of ions of sputtered block material to be ionized is approximately:

$$R \approx \frac{P_s}{(P_a + P_s)} \qquad (5)$$

here, P_a is the partial pressure of Ar.

The maximum ion current intensity extracted from the single aperture is estimated by the formula[6]

$$I_{max} = \frac{6 \times 10^{-5} R^2}{\left(1 + 1.75 R^2\right) \sqrt{A/\zeta}} U^{3/2}$$

(6)

here, I is extracted beam current intensity (mA), $R = r_1 / d_1$ (aspect ratio of the extraction gap), r_1 is aperture radius on the plasma electrode, and d_1 is distance between the plasma electrode and the extraction electrode (i.e., gap width). A is atomic weight (amu) of the extracted ion, ζ is ion charge state, U is extraction voltage (V)

III. OPERATION CHARACTERISTICS

Continuous microwave power produced by a microwave generator with a frequency of 2.45GHz is transmitted by a coaxial line and supplied to the antenna placed in the discharge chamber of the cathode. In the condition of ECR, the operation characteristics of the MP-cathode depend upon incident microwave power and working pressure in the discharge chamber of the cathode. It is worth noticing that the working pressure of the discharge chamber of the cathode is used as low as possible (if only can keep a steady

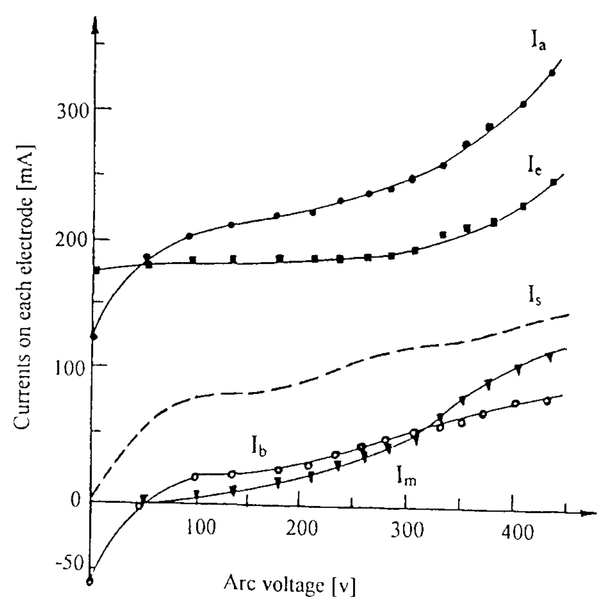

Fig 5. The currents on each electrode as a function of arc voltage. gas pressure of main discharge chamber: 5.5 $\times$ 10^{-2} Pa ,incident microwave power: 50W ,extraction voltage of electron beam: 150V.

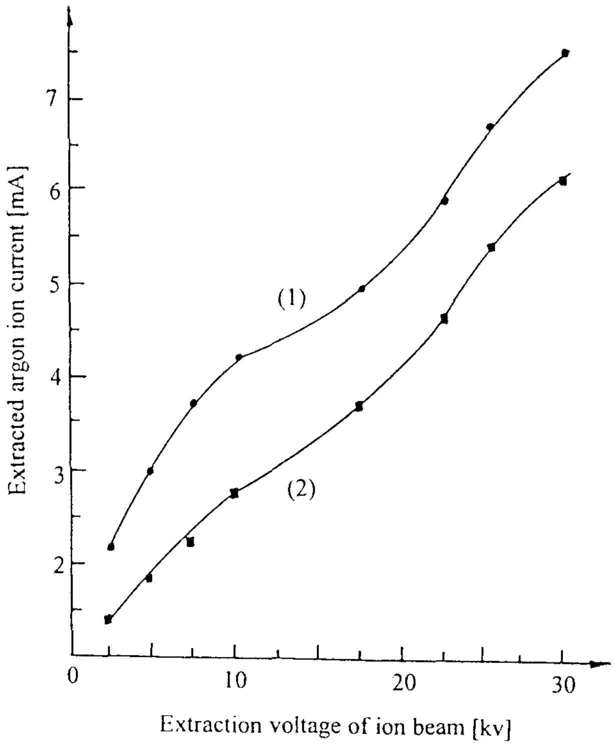

Fig 6. The extracted ion current as a function of extraction voltage.
gas pressure of main discharge chamber: 5 × 10^{-2} Pa , arc voltage: 485V, incident microwave power: 60W, extraction voltage of electron beam: 150V.

discharge of the cathode) to raising the microwave power density in the microwave discharge and the relative output of ion of solid state element [2][7].

When the gas pressure of Ar in the discharge chamber of the cathode and the extraction voltage of the electron beam are 1.3 × 10^{-2} Pa and 155V, respectively, the extracted electron current as a function of the incident microwave power is shown in Fig. 2. And when the gas pressure and the incident microwave power are 6.4 × 10^{-2} Pa and 50W, respectively, the extracted electron current as a function of the extraction voltage is shown in Fig. 3.

When the gas pressure in the main discharge chamber of the source is 7 × 10^{-2} Pa, Fig. 4 shows the variation of arc current with the incident microwave power at the arc voltage of 235V.

The variation of current on each electrode with the arc voltage is shown in Fig. 5, in which I_a, I_m and I_e express arc current, middle electrode current and load current of the extracting power supply of the electron beam, respectively, especially for I_s, which is ion current generating sputtering of the block, is calculated from the relative experimental data(see IV.discussion). The working parameters of the source are also given in the illustration of Fig. 5.

The extracted ion current from the source as a function of ion extraction voltage is shown in Fig. 6. In the case of single aperture extraction Curve (1) and (2) express two results when the bias potential of the negative electrode in the extracting system of ion beam are -5kv and zero, respectively. In the experiments, each of two magnetic field coils was used in 5500 A.T..

Ⅳ. CONLUSION AND DISCUSSION

Through the study on new-type full-ion ion source we think that the source is feasible for the production of full-ion. The MP-cathode can long-term and stable operation and delivers sufficient electron current in the pressure range of (1.3 ~ 6.4)× 10^{-2} Pa at relative low incident microwave power (30~50w). In the case of single-aperture extraction the ion current of 7.5mA can be extracted from the source at the ion extraction voltage of 30kv. More high ion current can be obtained if increasing arc voltage and adopting multi-aperture ion extraction electrode. The calculation shows that the percentages of Cu^+ and Fe^+ in the extracted ion beam are 7.5% and 5.5% for the sputtered material of Cu and Fe, respectively, at the arc voltage of 500V and the arc current of 540mA. The beams analysis (including the mass spectrum and charge state of the beam) has not made due to the limitation of magnetic analyzer. In order to increase the atom output of the sputtered material we attempt to raise the arc voltage. But the experiment discover that the source is difficult to get a stable operation at more high arc voltage, for example, 800v or more high, because the arc current is rapidly increase at high arc voltage and burn out the plasma electrode. According to the electronic connection in Fig. 1 the net ion current which cause the sputtering of the sputtered material to be ionized may approximately be calculated by $I_S \approx I_b + I_e$. Here, I_e is electron current intensity which spread on the extraction electrode of the electron beam. When the extraction voltage of the electron beam is 150V we have measured by means of an auxiliary experiment I_e=55mA. I_s as a function of arc voltage is shown in Fig. 6 as well.

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