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Main magnetic focus ion source with the radial extraction of ions

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ABSTRACT

In the main magnetic focus ion source, atomic ions are produced in the local ion trap created by the rippled electron beam in focusing magnetic field. Here we present the novel modification of the room-temperature hand-size device, which allows the extraction of ions in the radial direction perpendicular to the electron beam across the magnetic field. The detected X-ray emission evidences the production of Ir^{44+} and Ar^{16+} ions. The ion source can operate as the ion trap for X-ray spectroscopy, as the ion source for the production of highly charged ions and also as the ion source of high brightness.

1. Introduction

In this work, we present the miniature main magnetic focus ion source (MaMFIS) with the radial extraction of highly charged ions. The design of this device is based on fundamental dependence of the potential distribution of axially symmetric electron beam, which is determined by logarithmic ratio of the radius R of the drift tube to the radius r_e of the electron beam. The sag of the potential ΔU in space between the metal wall of the drift tube and the z axis of the electron beam reads

$$\Delta U(r_e) = V_e\left(1 + 2\ln\frac{R}{r_e}\right), \quad (1)$$

where the potential difference inside the electron beam V_e is given by

$$V_e = \frac{UP}{4\pi\varepsilon_0\sqrt{2\eta}}. \quad (2)$$

Here ε_0 is the permittivity of free space, $\eta = e/m$ is the magnitude of the electron charge-to-mass ratio, U is the potential of the drift tube with respect to the potential of the cathode, $P = I_e/U^{3/2}$ is the perveance of the electron beam and I_e is the electron current.

The local ion traps, which are formed in crossovers of the rippled electron beam with the variable radius $r_e(z)$, are used for the efficient production and axial extraction of highly charged ions in the MaMFIS [1–3]. The local ion traps are characterized by extremely high electron current density and relatively short length of the trap (typically of about 1 mm). It implies that ions stored in the trap are concentrated in a very small volume and can be extracted in the radial direction perpendicular to the electron beam through the extractor electrode with small entrance diameter. This concept allows one to develop the very compact ion source of high brightness, especially for elements of the first half of the periodic table.

2. Principle of design

The principle of design of the MaMFIS with the radial extraction of ions is shown in Fig. 1(a). The ion source includes the electron gun, the anode integrated with the drift tube, the electron collector and the extractor with ion optics. The anode has few holes in the middle plane. The extractor is located in one of these holes and is installed in the direction perpendicular to the electron beam.

The beam of electrons emitted from cathode is focused by magnetic field B and Wehnelt electrode into the sharp focus in the median plane of anode. The potential distribution on the length of anode is shown in Fig. 1(b). In three-dimensional space, the potential surface along the z axis looks like a curved gutter with the greatest depth at the point corresponding to the position of crossover of the electron beam characterized by the smallest radius $r_{\min}$. The potential well, which serves as a trap for storage of atomic ions, occurs due to variability of the radius r_e of the electron beam along the z axis within the range $r_{\min} \leqslant r_e \leqslant r_{\max}$. Ions can fill the ion trap up to the potential level corresponding to the electron

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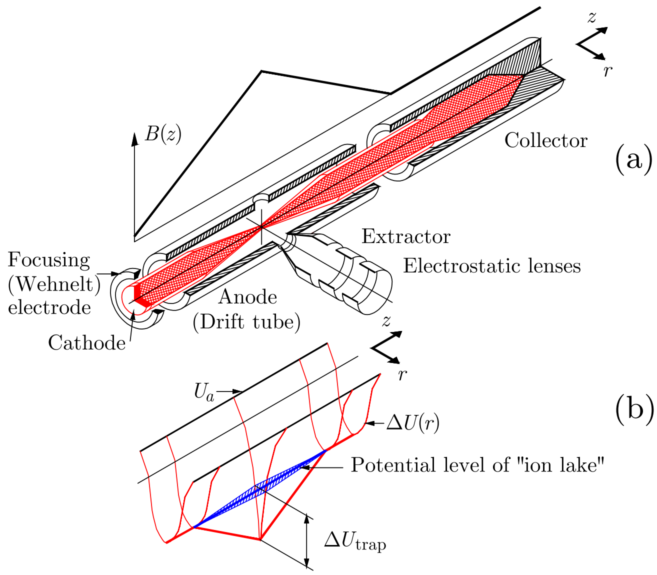

Fig. 1. The principal scheme of the ion source. The z axis indicates the direction of electron beam, $B(z)$ is the distribution of focusing magnetic field, U_a is the potential of anode (drift tube), $\Delta U(r)$ is the sag of potential in the space of drift tube and $\Delta U_{\rm trap}$ is the depth of local ion trap.

beam with the constant maximal radius $r_{\rm max}$. This potential level restricts the depth of the "ion lake", which is estimated by [2]

$$\Delta U_{\rm trap} = 2V_e \ln \frac{r_{\rm max}}{r_{\rm min}}. \qquad (3)$$

The ions with energies above this crucial level leave the trap in the axial direction.

The installation can operate in three different running modes. The mode of ion trap is realized, if the potential $U_{\rm ext}$ of the extractor is equal to the potential U_a of the drift tube (see Fig. 2(a)). This running mode can be used for X-ray spectroscopy and micro-plasma research. The running mode of ion source is switched on, when the potential of the extractor is lower than the potential of the drift tube (see Fig. 2(b) and (c)). In this case, ions escape the trap in the radial direction across the magnetic field. The ion extraction of this type has been thoroughly studied in ion sources for cyclotrons. The extraction potential can be either constant or

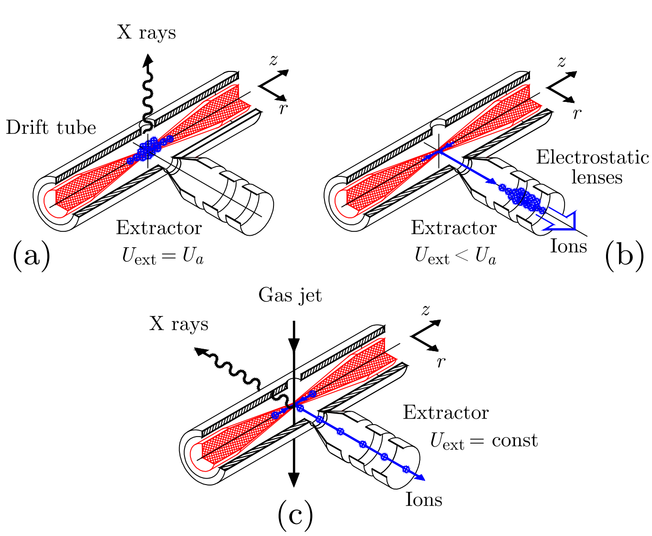

Fig. 2. Running modes: ion trap (a); ion source (b); ion source of high brightness (c).

pulsating. The pulsating potential corresponds to the running mode of ion traps with a certain confinement time. The repetition rate, i.e. the time between pulses of the extraction voltage, determines the confinement time, while duration of the voltage pulse determines the duration of the ion pulse. The running mode with the constant extraction potential allows the production of the direct ion current from extremely small ionization volume. The relatively intense ion current is gained under poor vacuum in the ionization region. Gas jet can be applied for this purpose. Some deviation of ions from the extraction axis due to influence of the magnetic field is compensated by the electrostatic lenses (see Fig. 3).

3. Design of pilot example

The pilot example of the miniature ion source was developed in two modifications: for relatively high voltage (up to 10 kV) with the water cooling collector and for low voltage (up to 2 kV) with the air cooling (see photos in Fig. 4). The ion source consists of the vacuum body, the electron gun, the focusing magnet system, the electron collector and the extraction system. The vacuum vessel is the double cross of the minimum standard 16-mm-ConFlat flanges.

The principle sketch of the ion source is shown in Fig. 5. The cross sections of the construction are made in the Cartesian coordinate system. The electron gun and the electron collector are installed in the y–z plane. The high-voltage anode integrated with the drift tube is located between the cathode and the collector. The drift tube has three holes in the central part. The extractor electrode for the ion optics is mounted in the direction perpendicular to the drift tube. The Be window for X-ray spectroscopy is placed opposite to the radial extractor.

The focusing magnet system can be considered as a key part of the device, since the magnitude of the magnetic field and its distribution along the z axis define properties of the electron beam. Here it is used the principle of focusing systems with the radial permanent magnets (see, for example, Ref. [4]). The magnetic field system consists of two iron parts of complicated shape, in which the rectangular permanent magnets are held (see photo in Fig. 6). These parts are fastened to each other with screws on the vacuum body of the ion source. The radial magnetization vectors of the permanent magnets in each part have opposite directions. The number of permanent magnets and their positioning in the system can be changed in various combinations. Therefore, both the amplitude value and distribution of the magnetic field can be discretely changed (see graphs in Fig. 6).

4. Electron beam

The electron beam is formed in the electron gun with the metal alloy Ir–Ce cathode of 0.5 mm in diameter. Then it is refracted by focusing magnet system into a long flow, which can have different properties. According to the basic requirements the electron beam with one focus in the drift tube is suitable for the ion source. However, for typical sizes of the installation with the vacuum standard CF16 in the electron energy range of about 1 keV the focusing magnetic field should be either very short or very weak. Therefore, here we shall consider the electron beam with a few successive focuses in a thick magnetic lens. The trajectories of the electron beam calculated for different parameters are shown in Fig. 7 [5]. In order to run the MaMFIS in the first focus of the electron beam with the energy of 4 keV, the magnetic field distribution should correspond to the curves in Fig. 6. According to theoretical estimates, the electron current density lies within the range of 5–10 kA/cm^2 for high