E-MEVVA ION SOURCE FOR HIGH CHARGED URANIUM IONS GENERATION

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Abstract

The test results of the E-MEVVA operation with an uranium cathode are discussed. The E-MEVVA was installed on the ITEP RFQ heavy ions linac injector for the investigation of high charged ions generation.

Introduction.

A new variation of MEVVA ion source, E-MEVVA, with drift channel and external electron beam was developed for the injector of TIPr-1, ITEP heavy ion linac [1]. The generation conditions of high charged heavy ions in this ion source were investigated. In this modification the arc plasma passes through the drift channel, which has the axial magnetic field. The external electron beam with the energy of a few keV from the independent electron gun is injected into the drift channel along the axis in the direction of plasma motion. As a result ion are interacting with the high energy electron beam during the whole period of plasma drift. Estimates which take into account successive ionization processes in the drift channel [2] show that at the injector output it is possible to obtain the intense beam of high charged ions. The experimental results for the copper cathode [1] show that for using an electron beam and the drift channel the specific charge spectrum of ions at the output changes so that maximum of the spectrum substantially shift to the region of highly charged ions. Some results of the E-MEVVA ion source operations with an uranium cathode are discussed here.

Experimental setup.

As we have noted above, the new units of the device are: drift channel and external electron gun.

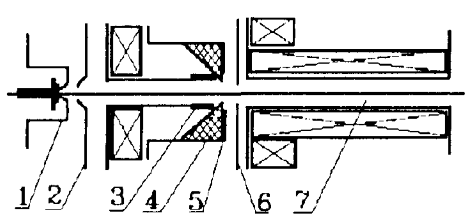

Fig. 1: Schematic of the source design. 1.Electron gun; 2.Collimator; 3.Cathode of MEVVA; 4.Insulator; 5.Trigger; 6.Anode of MEVVA; 7.Drift channel.

In fig.1 their position in the device is shown. The plasma generator is the ITEP version [3] of the MEVVA ion source with the axial cathode opening which permits to inject the electron beam into the arc plasma plume.

The drift channel having the length of 0.7m and the diameter of 5cm was installed at the end of 1991. The main purpose of the channel operation without e–beam is to provide plasma plume transmission through the channel and to obtain the good enough beam current at the output of injector. The plasma losses were reduced by choosing the optimal conditions of plasma transmission through the channel. As the result the beam current reached 20mA at the injector voltage of 50kV. Charge state measurements showed the presence of new ion charge states.

The second component of the modification is electron gun with the independent control of the electron energy at the input of MEVVA cathode in the range of 0...10kV. The accelerated electron beam is injected through the cathode axial opening into the drift plasma and provides intensification of successive ionization processes in the plasma. It is defined by an ionization factor [2] in the drift channel, which has to be maximum for successful results.

In the experiments the electron beam pulse with the duration 20...30μs was used.

Drift channel (DCh), the particles distribution and some physical processes in DCh.

The inhomogeneous (in the space and in the time) and nonequilibrium plasma comes to the DCh from the MEVVA ion source. The electron component of the plasma consists on two (at least) groups of electrons, with the different velocities, quick and slow. During the drift the slow part goes with the ions, while the quick one overtakes the plasma (ions and electrons), and goes through them. The ions component is also inhomogeneous for the longitudinal speeds, the high charged ions flies quickly. This picture of the particles movement in DCh was drawn on the base of the experimental data [1].

The dependence of the uranium ions charge state distribution (CSD) from the time interval $\Delta t = t_{ib} - t_{tr}$ is shown in fig.2. The dependence plotted on the base of TOF (time-of-flight) spectra which was measured for different time delay an unblank pulse for the modulator grid (t_{ib}) from the arc trigger pulse (t_{tr}).

It is necessary to note the following characters of these spectra and dependances:

a) The time of the first appearance each of the z/A – separated components on the Faraday cup depends on the z/A magnitude.

b) The life times of the some z/A components substantial more than the arc discharge pulse duration.

c) There is complex composition of the z/A components.

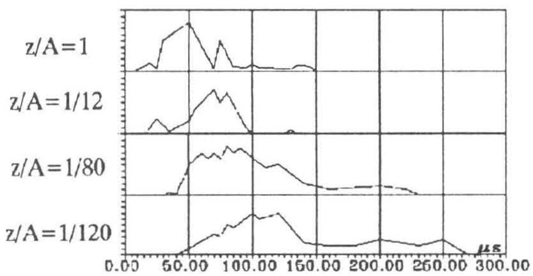

Fig. 2: Dependence of CSD from $\Delta t = t_{ib} - t_{tr}$

Let us discuss the characters more detail:

a) The time delay between trigger time, t_{tr} , and a time of the first appearance of the component, determines the time of flight through the total length of the DCh for the ions which are in the front of plasma plume. The measured times from the data of the fig.2 give the possibility to calculate the drift velocities of ions.

Table 1
Ion velocities: $v = \sqrt{2zeU_{eff}/Am_p}$

ion	z/A	Velocity m/s	U_{eff} V
H^+	1	$>1\times10^5$	>75
C^+	1/12	$\sim 4.2\times10^4$	~ 130
U^{4+}	1/60	$\sim 2.25\times10^4$	~ 140
U^{2+}	1/120	$\sim 1.50\times10^4$	~ 140

b) In the same time there are a prolongation of pulses of an ion U^{2+} and U^{3+} current (out of the duration of a arc pulse) up to 150 microseconds. It means that there are a groups of U^{2+} and U^{3+} ions with the velocities no more than 5×10^3 m/s.

c) It is necessary to attract the attention to the complex composition of the each of a z/A component in TOF spectra. They consist from a few peaks (two or three) separated by 1 or 2 microsecond interval , fig.3 .

Appearance such structure of a z/A component can be explain by the history of its generation. So, if suppose that last peak in each of component generated directly by electron impact, the another may be created as a result of highly charged ions recombination, because the high charged ions have a more high velocities. But the data of Table 1 give not verification of such supposition because for realization of such of processes, the velocities difference had be more than in the table. The estimation shows that the necessary difference can be provides by acting of a dynamic friction force in the middle and the tail parts of the plasma. Analysis of experimental data for DCh permits to suppose that a few independent groups of ions with their own charge distributions and relaxation times are created into the DCh, and that the main passive processes in the plasma during a drift in the DCh are the recombination of highly charged ions: (5+)→ (4+) → . . .(1+) → (0).

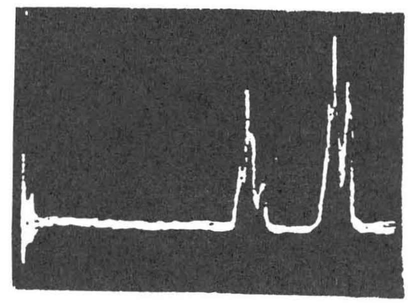

Fig. 3: Complex composition of z/A components

Electron beam from the independent gun

Such parameters of electron beam as density of current and electrons energy define regime of generation high charged ions. It is connected with receiving large ionization factor $j\tau$. Drift velocity of plasma limits τ parameter so increasing of density electrons current j is only possibility. The electron gun with microplasma semiconductor cathode was constructed specially for this purpose. This gun allows to obtain electron beam with low temperature, so that large value of current density become achieved.

Electrons with high energy from the gun create conditions for producing and existence high charged ions during drift time of plasma. So average energy of e-beam must be more than ionization potential of desirable ions.

Focusing magnetic lens provide transportation of electrons through MEVVA ion source, but unfortunately we could not achieve transportation of electrons without losses. Initial diameter of the e-beam (it is limited by the collimator) equals 1.5 mm, and diameter of the MEVVA cathode opening is 4. . .6 mm for different samples of cathode. In our experiments electrons current density was 1. . .5 kA/cm^2 in the drift channel.

The ions with the big specific charge.

The our installation — the injector of the linac — has no magnetic spectrometer with the good resolution (there are no any free area in the ion transport line between the injector and linac), therefore we used three independent methods for high charged ions (HCI) spectra measurements. The time-of-flight (TOF) method, magnetic analysis (MA) and resonance acceleration in RFQ linac.

First of all it is necessary to check the verification of our conclusions that these measured spectra are truly HCI spectra. Let us consider processes which would give the results detected as the HCI generation, but are not the HCI generation in real.

a) The generation of light ions from residual gas with the time of flight identical to observed times of flight.

b) The acceleration of ions from the MEVVA ion source by the high density electron beam.

c) Some distortion in the electronic devices operations, which can initiate a light ions generation from the residual gas.

At first we want to note that there is the next experimental fact: the electron beam of itself (without MEVVA) don't create any ions. When the MEVVA ion source is switched off there are no ions at the injector output, even when the electron energy and the beam current are maximum high.

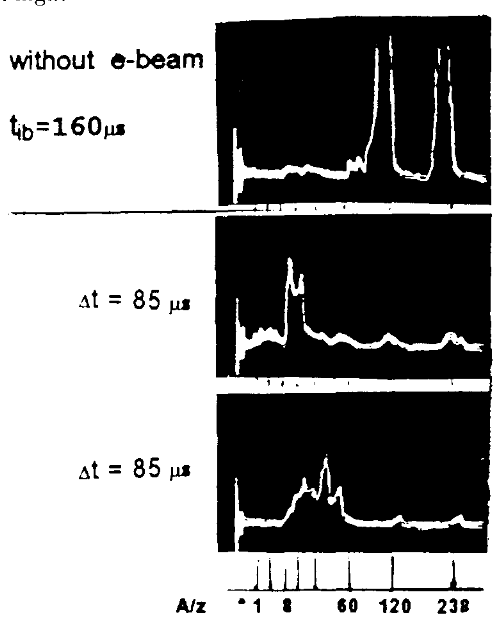

Fig. 4: The time-of-flight spectra of the U high charged ions. Scanning step is 10μs; $\Delta t = t_{ib} - t_{eb}$

Let us have a look at fig.4. It shows us the HCI spectra dependence on the time delay between the start pulse for electron gun,t_{eb} and a unblank pulse for modulator grid t_{ib} (scanning step is 10 microseconds). We can see that the ions spectral state in the case when the e-beam is switched on has the substantial difference from the spectral state for the case when EB is switched off. So, if for first case, the quick part of ions have the specific charge from 1 to 1/5, so for the second case it is from 1/3 to 1/8 (fig.4). For E-MEVVA function with an e-beam it is possible to pick out once more z/A component interval: from 1/16 to 1/40 (fig.4). The measurements with the scanning step 2 and 5 microseconds and MA spectra verify these results. We don't see another explanation of the experimental facts then the HCI generation.

It is possible to assume that the change of the z/A value with Δt is determined by the time dependence on e-energy . The direct measurements of this dependence give a verification of the assumption . The HCI generation depends on the e-energy and breaks off when the e-energy drops down 2 keV [1].

The dependence of the HCI spectra on the time delay between the start signal for e-gun and the unblank pulse for the biased grid is remarkable. The first 45 — 50 μs after e-beam start signal there are no ions at the injector output. Than we can see as HCI appear in the spectrum and as the specific charge of HCI (z/A) changes from 1/3 to 1/8 and from 1/12 to (1/16...1/40) while the time delay changes from 65 μs to 90 μs. For the time delay more than 100 μs HCI disappear and the original MEVVA ions spectrum return. We suppose that the effect of the ion beam disappearing for the first 45 — 50 μs after e-beam start signal is a result of a high intensity e-bunch stopping and scattering in the extraction field, so the electron cloud neutralized an ions beam. The special investigations are required for understanding the feature of the charge state spread formation.

The direct measurements of the HCI beam current wasn't made, but it is possible to estimate the HCI current from a total ion beam current pulse at input of injector. It is the pulse with the current 4mA and the length 20μs for uranium. The set of z/A components, the stability of the HCI beam current and its duration depends on the sample of e-cathode, e-beam current density, e-energy and some parameters of the ion source. The best result for the pulse-to-pulse spread was 10% for copper cathode [1].

Conclusion.

The HCI sources such as ECR and EBIS are used for injectors of many accelerators all over the world. The special modification of MEVVA ion source, or the e-MEVVA, which can provide the high current HCI beam (4mA) can find an application for some HCI accelerators.

References

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