PRODUCING OF THE HIGH CHARGED IONS BY THE MODIFICATION OF MEVVA ION SOURCE

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Abstract

A new version of MEVVA ion source with drift channel and external electron beam was developed for the injector of TIPr-1 heavy ion linac. The condition of generation of high charged heavy ions in the source are investigated. In this modification the arc plasma passes through the drift channel along the axis, which has the axial magnetic field. The external electron beam with energy of a few keV from the independent electron gun is injected to the drift channel in the direction of plasma motion. The experiments with the coper cathode showed, that for electron beam density more than 1 kA/cm^2, time-of-flight charge state spectrum for total ion beam current of 6 mA consisted of the ions with the specific charges from 1/5 to 1/3. Some results of last experiments with lead and uranium ions are presented.

1 INTRODUCTION.

The production of ions in the metal vapor vacuum arc is broadly used, but ions charge is not high enough. The maximum charge of ions in a MEVVA source depends on the electron energy in the arc discharge which is not higher than 100 eV for different cathode materials. Therefore maximum charge of ions at the source output is not higher than 3+ for copper, and 5+ for tungsten [1].

A new variation of MEVVA ion source with drift channel and external electron beam was developed for the injector of TIPr-1 heavy ion linac ITEP, Moscow. 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 to the drift channel along the axis in the direction of plasma motion. In the result ion are interacting with the high energy electron beam during the whole period of plasma drift.

Using MEVVA ion source for generation of plasma for producing high charged ions is more suitable for vacuum condition for the step-by-step ionization processes. As pressure of the metal vapor in discharge chamber exist short time during arc pulse (about 100 μs) and can not influence on the vacuum at the output of DCh substantially. So we can obtain satisfactory results with vacuum in DCh about 10^{-7}Thor.

Preliminary 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 show that 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.

2 EXPERIMENTAL SETUP.

As we note above, the new unit of the device are: drift channel and external electron gun fig.1.

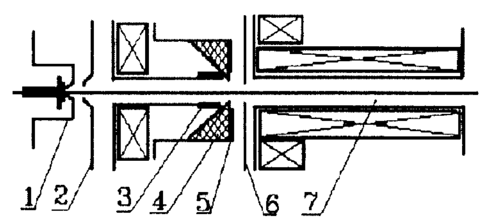

Figure 1: Schematic of the source design. 1.Electron gun; 2.Collimator; 3.Cathode of MEVVA; 4.Insulator; 5.Trigger; 6.Anode of MEVVA; 7.Drift channel.

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 give the possibility to inject the electron beam into the arc plasma plume.

The drift channel having the length of 0.7m was installed at the end of 1991. The main aim of the first experiments with the channel was 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 the electron gun with the independent control of the electron energy at the input of the MEVVA cathode in the range of 0...20kV. The accelerated electron beam is injected through the cathode axial opening to the drift plasma and provides intensification of successive ionization processes in the plasma. It is defined by the 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. This time is shorter than the time of plasma generation in the MEVVA ion source (100μs) but more longer than the plasma drift time. It creates a possibility to investigate the ion beam spectrum before the injection of electrons, as well as during and after the injection. Charge spectra were measured by time–of- flight method (TOF). The short pulses for TOF were formed in the ion optic system by the biased grid inside the extraction arrangement.

3 DRIFT CHANNEL (DCH), THE PARTICLES DISTRIBUTION AND SOME PHYSICAL PROCESSES IN DCH.

The inhomogeneous and nonequilibrium plasma comes to the DCh from the MEVVA ion source. Behavior of plasma in DCh connected with arc plasma oscillation, but here plasma has new conditions for the own oscillations both in space and in time. Probably longitudinal plasma waves are connected with energy transmission and have wide spectrum of oscillations. Each of them create its own frequency of plasma oscillation according to average electrons energy and equilibrium charge states distribution of ions with own relaxation and recombination times. As a result at the output of DCh exist a few groups of plasma electrons with different velocities. At the same time charge spectrum of ions changes also. So for copper ions except usual charge states 1+, 2+, 3+ additional charge states 4+, 5+ was obtained. For understanding of this fact further investigation is necessary. Drift movement of plasma limits ion–electron interaction time. For copper drift time is about 6μs, for lead it is about 21μs and for uranium it is about 23μs. It corresponds to the velocities from $1*10^4$ to $3*10^5$m/s. So as a result, more longer interaction time for uranium allows to get additional charge states of ions up to 8+.

The time interval for ion beam at the injector output is substantial more, than duration of the arc discharge. The beam duration is 160μs for copper, 280μs for lead, and 245μs for uranium ions, while the arc time is 120μs. Its show us, that the bunch of particles stretch during the flight. The ion spectrum dependence on Δt shows that the high charged ions fly in front and low charged ones in the tail of the bunch.

External e-beam brings into the plasma additional energy, which to converse to the energy of plasma wave and new charge states of ions at last. E-beam losses energy and part of its electrons may be captured by this wave. Another parts of the e-beam disappear at the wall DCh and by the ion recombination. As a result of the e-beam influence on the plasma at the output of DCh was obtained high charged ions such as: Cu^{17+}...Cu^{21+} , Pb^{8+}...Pb^{15+}, U^{8+}...U^{17+} Fig.2.

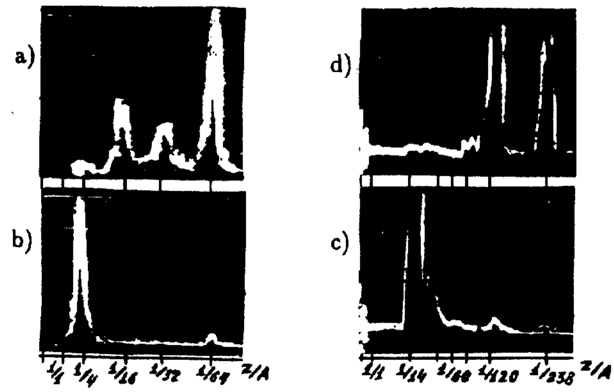

Figure 2: TOF spectra. a) Cu with e-beam, b) Cu without e-beam, c) U with e-beam, d) U without e-beam

Total current the high charged ion beam have value range 1-6 mA at the output of injector. On the oscillogram of the charge spectrum when e-beam switch on low charged ions is absent almost. It may be explained by existence of plasma wave in DCh as mention above. Peaks of ions with large specific charges can not be interpreted as ions of residual gases only. Because in this case concentration of this gases in DCh must be equal concentration of metal vapor, but it is not possible. As well as we want to note that there is the next experimental fact: the electron beam of itself (without operation of MEVVA source) don't create any ions. When the MEVVA ion source is switch off there are no ions at the injector output, even when the electron energy and the beam current have the maximum value.

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.

4 ELECTRON BEAM FROM THE INDEPENDENT GUN

Such parameters of electron beam as density of current and electrons energy are defined 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 single possibility. Electron gun with microplasma semiconductor cathode was constructed specially for this aim. 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 of high charged ions during drift time of plasma. So average energy of e-beam must be more than ionization potential of desirable ions. According to our experimental data the electron energy $< E >$ is about 5 keV (Fig.3), it was measured at the output DCh without plasma generation.

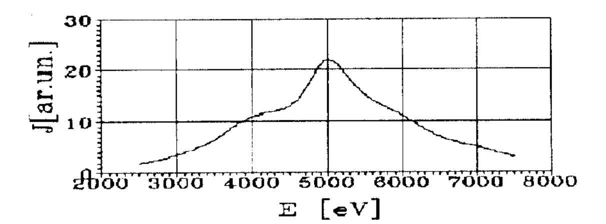

Figure 3: The energy distribution of electrons in the e-beam.

As shown in Fig.1. electron gun has accelerated gap between collimator and cathode of MEVVA, where different of their potentials defined energy of e-beam. Focusing magnetic lens provide transportation of electrons through MEVVA ion source, else 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 density of electrons current is 1...5 kA/cm^2 in the drift channel.

5 DISCUSSION OF HCI SPECTRA.

It is interesting to investigate the HCI spectra behaviour throughout the beam pulse duration.

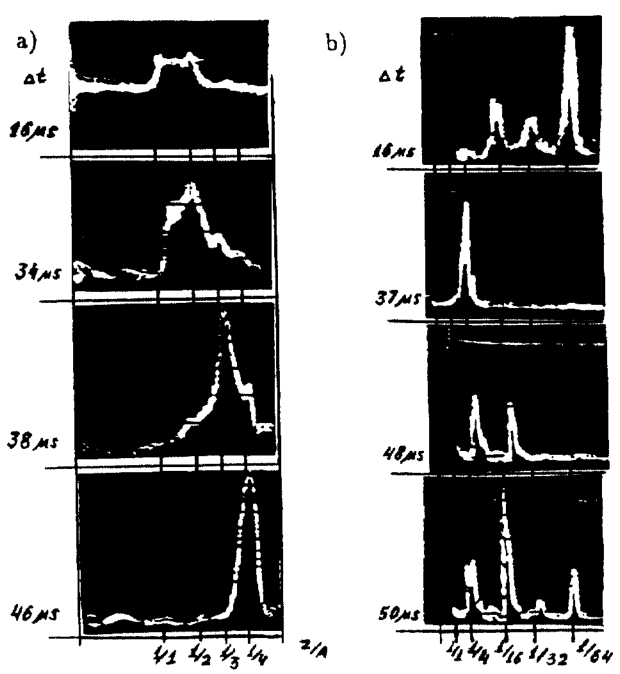

Figure 4: The time-of-flight spectra of the Cu high charged ions. a) Scanning step is 2μs, b) Scanning step is 10μs; $\Delta t = t_{ib} - t_{eb}$

Figure 4 shows us the HCI spectra dependence on the time delay between the start pulse for electron gun t_{eb} and an unblank pulse for modulator grid t_{ib}. We can see that the ions spectral state in the case when the EB switch on has the substantial difference from the spectral state for the case when EB switch off. So, if for first case the ions specific charge is from 1 to 1/3, so for the second it is from 1/3 to 1/6. The HCI generation depends on the e-energy and break off when the e-energy drop down 2keV. We don't see another explanation of the experimental facts than the HCI generation.

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 (fig.4.). The first 15—20μs after e-beam start signal there are no ions at the injector output. Then HCI appear in the spectrum and as the specific charge of the HCI (z/A) changes from 1/3 to 1/5 while the time delay changes from 25μs to 45μs. For the time delay more than 50μs HCI disappear and the normal MEVVA copper ions spectrum return. The special investigations are required to understand the feature of the charge state spread formation.

The discussion of the possibility ions acceleration by high intensity e-beam shows that such process has to give the another result, than we can see at the experiments.

6 HCI BEAM CURRENT.

The direct measurements of the HCI beam current wasn't made, but it is possible to estimate the HCI current and pulse length (fig.4.). It is the pulse with the current 6mA and the length 20μs for coper. For lead and uranium was obtain similar parameters of the high charged ion beam: the current up to 5mA length 10-15 μs. Stability of the HCI beam current depends on the sample of e-cathode and some parameters of the ion source. The best result for the pulse-to-pulse stability is 10%.

7 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 (the 6mA copper HCI now) can find an application for some HCI accelerators.

8 REFERENCES

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