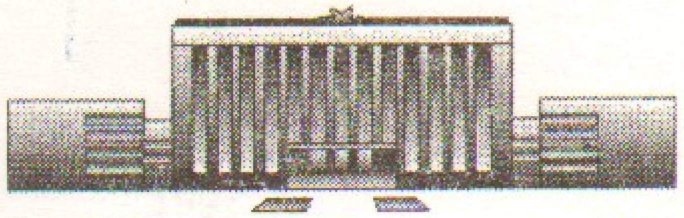
Budker Institute of Nuclear Physics
SB RAS

I. Churkin, A. Steshov, V. Volosov

UNIVERSAL METAL ION SOURCE

Budker INP 97-76



Novosibirsk

Universal metal ion source.

I.N.Churkin, V.I.Volosov, A.G.Steshov

Budker Institute of Nuclear Physics,
Novosibirsk, 630090, Russia

Abstract

The metal ion source based on the magnetic trap with crossed fields (radial electrical and axial magnetic) is considered. This source forms plasma flow with magnetized heavy (metal) ions flowing along the longitudinal magnetic field. The self-supporting heavy ion discharge is existed in the source. The working substance is a cathode material which can be any conducting material. The operating principles and the features of the source are discussed. The plasma flows consisted of various metal ions (Cu, Ni, Ti) were experimentally obtained. The main parameters and the dependencies of the titanium ion source are presented in detail. The typical parameters of this plasma flow are following: longitudinal velocity of $2\text{-}3\cdot 10^5$ cm/s; ion transversal energy of 20-80 ev, average plasma density of 10^{12} cm^{-3}; electron temperature of 40-60 ev; total ion current of plasma flow reach up to 3,6 A in pulse mode (discharge duration of 4-10 msec) of the source. The application of the source for plasma separation process is discussed.

PACS number(s):

e-mail: churkin@inp.nsk.su
e-mail: volosov@inp.nsk.su
e-mail: steshov@inp.nsk.su

I. INTRODUCTION

Metal ion sources are wide used for modification of constructional materials. In recent years the interest in the field of plasma sources of metal ions is increased in connection with the active researches of plasma separation process by ion cyclotron resonance heating [1,2,3]. Powerful and universal ion sources having following specific parameters: plasma density of 10^{12}-10^{13} cm^{-3}, ion transversal energy of 10-30 ev, longitudinal velocity of plasma flow of $(6\text{-}10)\cdot 10^5$ cm/s [3] are required for development of this separation method.

In the most cases metal plasma are created by ionization of metal atoms obtained by various methods. The sputtering of a metal surface is universal method to obtain metal atoms. The average energy of sputtered atoms of the majority elements (several ev) is optimum energy for ICR separation method.

Self-sputtering of a cathode is used in the universal metal ion source considered below. This source differs from conventional metal ion sources due to its operating principles. Experimental results presented below show the perspectives of this source.

II. DESCRIPTION OF UNIVERSAL METAL ION SOURCE

The schematic view of the universal metal ion source is shown in fig.1. It's design is based on the magnetic trap with crossed fields (radial electrical and axial magnetic). The radial electrical field is introduced into the plasma by the end electrodes. The mirror magnetic field is formed by the solenoidal coils. The main constructive dimensions of the source for considered below experiments were following: anode diameter of 280 mm, cathode diameter of 10 mm, diameter of the outlet channel of 50 mm. The high voltage pulse system for the electrical field was used. The range of the magnetic field is 0.2-0.8 T, the mirror ratio is 1.1. The working vacuum is (1-5)$\cdot 10^{-6}$ torr.

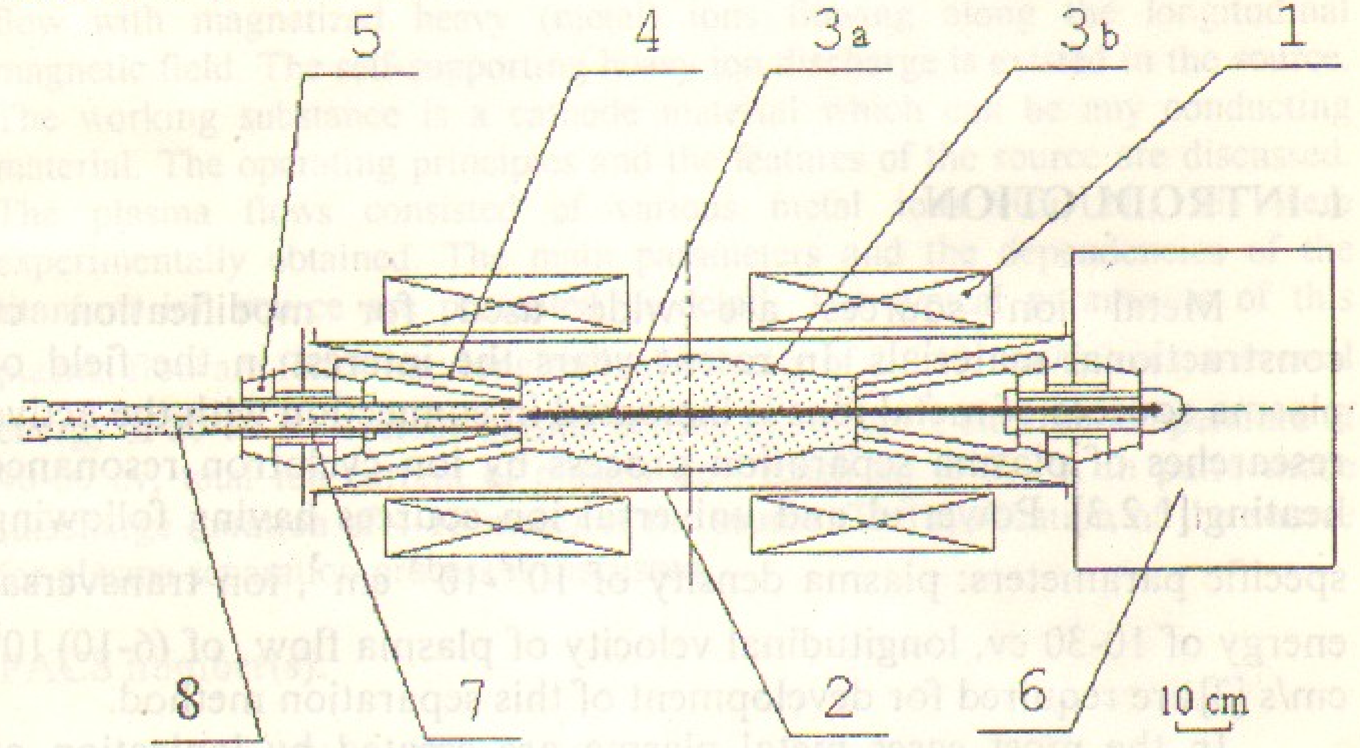


FIG. 1. Universal metal ion source. (1 - electromagnet coils; 2 - vacuum chamber; 3a - cathode, 3b - anode, 4 - end electrodes; 5 - isolator; 6 - high voltage system; 7 - outlet channel; 8 - plasma flow).

The source plasma is produced by the self-supporting heavy ion discharge [4,5]. The heavy (metal) ions are formed due to the ionization of atoms sputtered from a cathode surface by metal accelerated ions (self-sputtering). The working substance is a cathode material. It permits to obtain the discharge with ions of various elements including refractory materials. The additional gas (hydrogen, nitrogen and etc.) is injected into the source to initiate the discharge [5].

III. PLASMA FLOW FORMATION

The main processes inside the source are illustrated in fig.2.

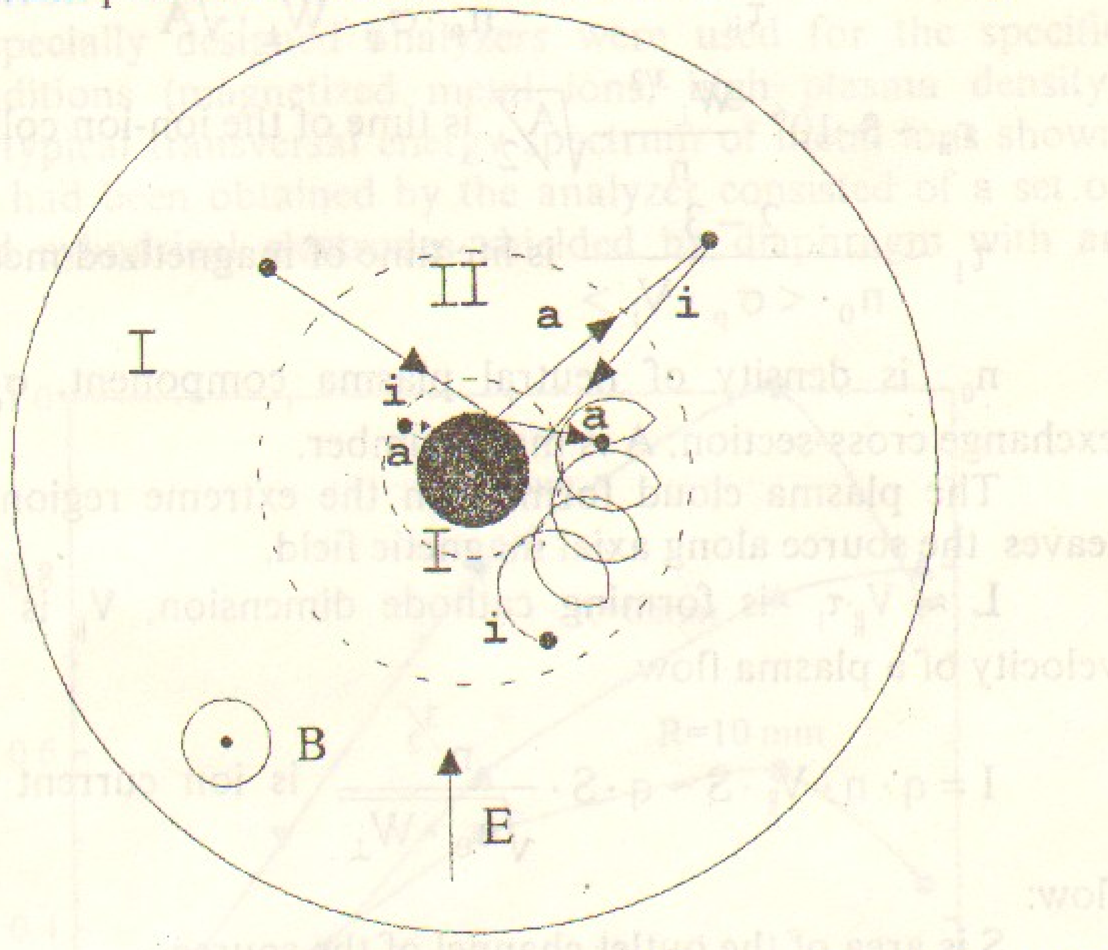


FIG. 2. Main processes inside the source (E - radial electrical field, B- axial magnetic field, a - sputtered atom, i - ion).

The radial electrical field is reduced due to the compulsory distribution of electric potentials by the end electrodes near the cathode area. The interelectrode region can be conditionally divided in three regions. The cathode region I is the region of low energy unmagnetized metal ions which directly fall to a cathode. The region II is the region of magnetized metal ions. The Larmor radius of these ions is less than radial size of the cathode area. Accelerated metal ions from the anode region I directly fall to a cathode and sputter its surface and support the discharge. The magnetized metal ions formed in the cathode area are lost due to the departure on the cathode by means of its charge-exchange on a neutral plasma component. The transversal energy ($W_\perp$) transforms to the longitudinal energy ($W_\parallel$) due to the ion-ion collisions during the life time of magnetized metal ions inside the source plasma:

$$W_\parallel = W_\perp \cdot \frac{\tau_1}{\tau_{ii}} \approx 8\cdot 10^{-7} \cdot \frac{n}{n_0 \cdot \sigma_p \cdot W_\perp \cdot \sqrt{A}}$$

$\tau_{ii} \sim 3\cdot 10^6 \cdot \frac{W_\perp^{3/2}}{n} \cdot \sqrt{A/2}$ is time of the ion-ion collisions,

$\tau_1 \sim \frac{2-3}{n_0 \cdot <\sigma_p \cdot V_i>}$ is life time of magnetized metal ions,

n_0 is density of neutral plasma component, σ_e is charge-exchange cross-section, A is mass number.

The plasma cloud formed on the extreme region of cathode leaves the source along axial magnetic field.

$L \approx V_\parallel \tau_1$ is forming cathode dimension, $V_\parallel$ is longitudinal velocity of a plasma flow.

$I = q\cdot n\cdot V_\parallel \cdot S \sim q\cdot S\cdot \frac{n^{3/2}}{\sqrt{n_0 \cdot W_\perp}}$ is ion current of plasma flow:

S is area of the outlet channel of the source.

The ambipolar potential $\varphi = T_e \cdot \ln(n/n_0) + \text{const}$ reduces an ion potential pit in the source and improves an ion maintenance from the trap $W_\parallel \geq (R-1)\cdot W_\perp - e\cdot\varphi$ [6].

IV. EXPERIMENTAL RESULTS

The plasma flows consisted of various metal ions (Cu, Ni, Ti) were experimentally obtained. The main parameters and the dependencies of the titanium ion source are presented in detail. The majority of measurements were made at typical parameters of the source: average discharge current of 50 A, anode-cathode voltage of 5 kv, discharge duration of 4 msec, magnetic field of 0.8 T. The measurement of main parameters of plasma flow: longitudinal velocity of plasma ($V_\parallel$), ion transversal energy ($W_\perp$), radial distribution of heavy ion density (n_i), total ion current, electron temperature (T_e) were made inside the outlet channel behind the magnetic mirror.

The specially designed analyzers were used for the specific plasma conditions (magnetized metal ions, high plasma density) [7,8,9]. The typical transversal energy spectrum of metal ions shown in fig.3 and had been obtained by the analyzer consisted of a set of the enclosed cylindrical electrodes shielded by diaphragm with an aperture.

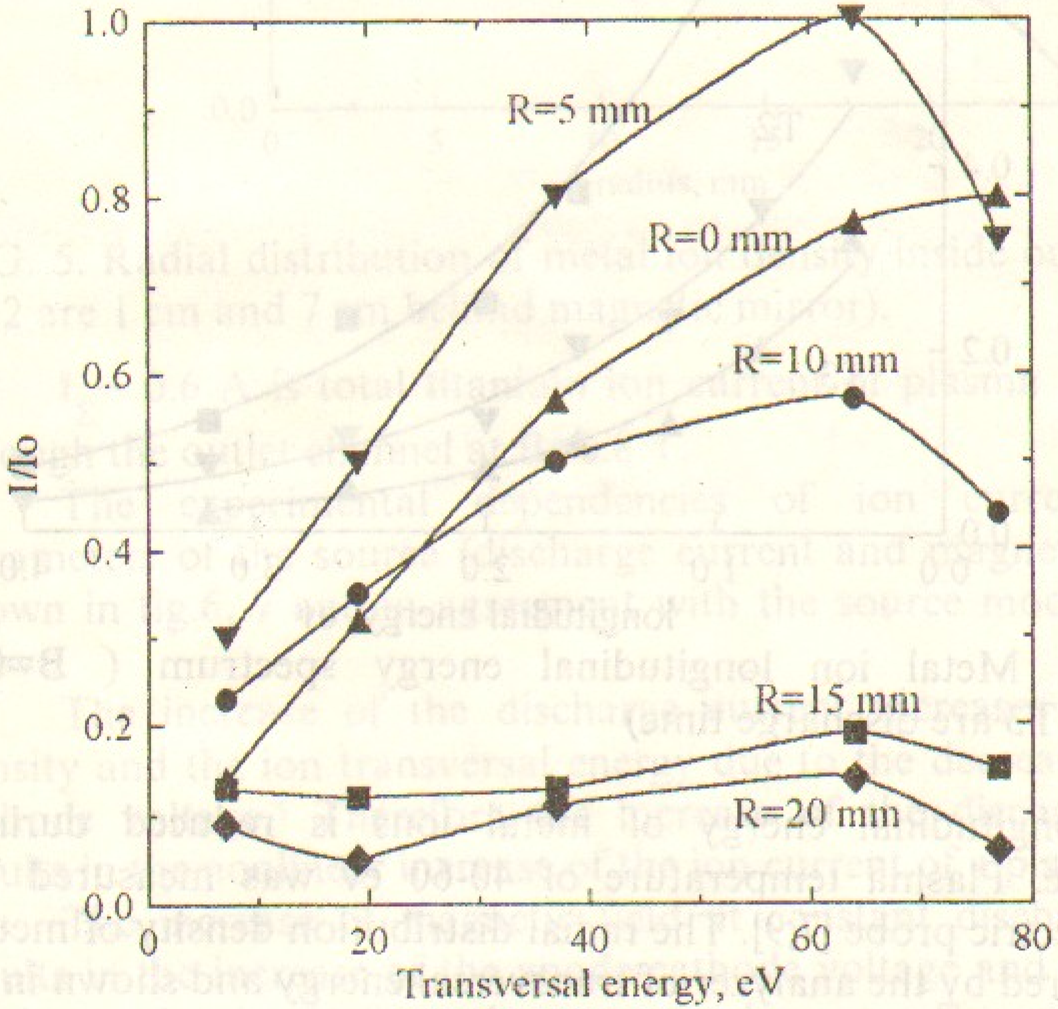


FIG. 3. Metal ion transversal energy spectrum for 10 mm from magnetic mirror (R - measurement radius inside the outlet channel)

The dependence of Larmor ion radius on its transversal energy for constant magnetic field is used in the analyzer [7,8,9]. The longitudinal energy spectrum is obtained by the analyzer-spectrometer in which the independence of the ion rotation frequency on magnetic field is used [7,8,9]. The longitudinal energy spectrum for various times of the discharge is shown in fig.4.

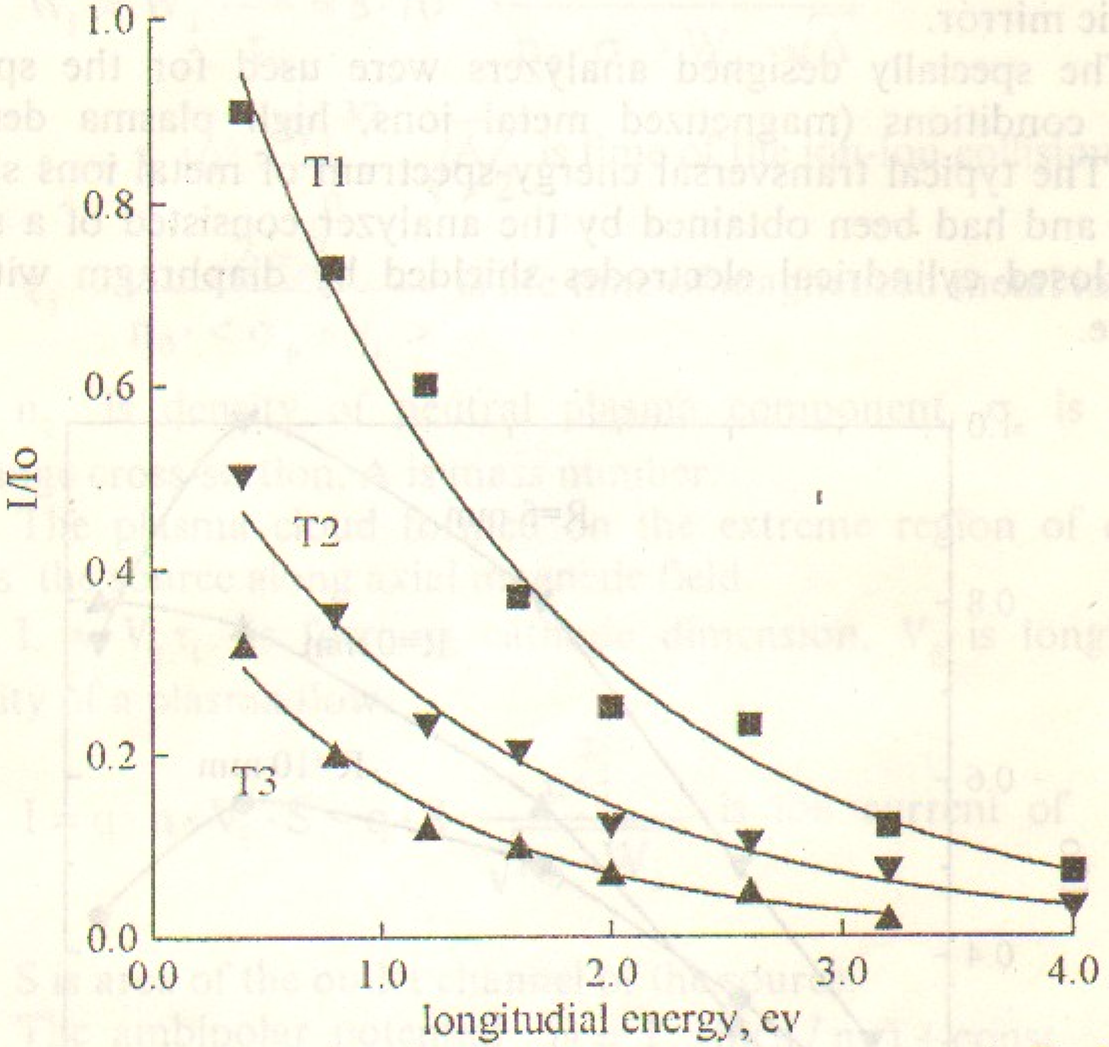


FIG. 4. Metal ion longitudinal energy spectrum (B=0.8 T, T3>T2>T3 are discharge time)

Longitudinal energy of metal ions is reduced during the discharge. Plasma temperature of 40-60 ev was measured by the single electric probe [7,9]. The radial distribution density of metal ions is measured by the analyzer of transversal energy and shown in fig.5.

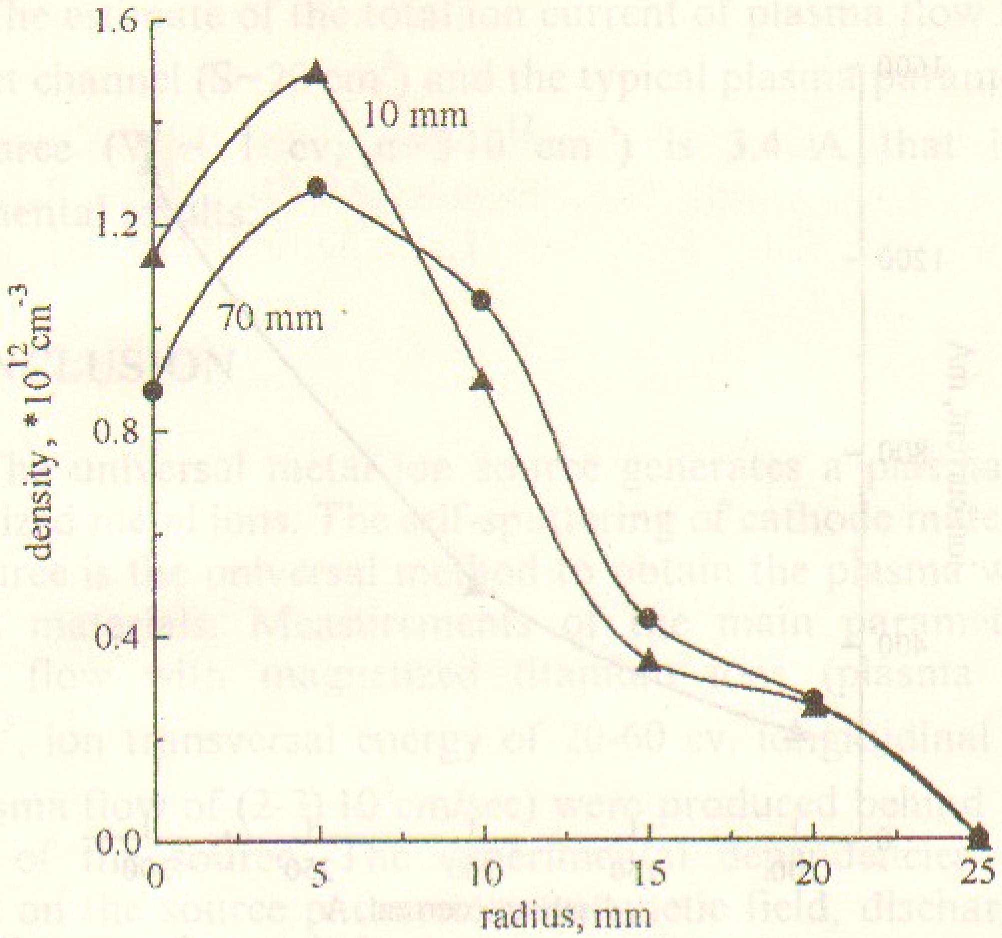


FIG. 5. Radial distribution of metal ion density inside outlet channel (1, 2 are 1 cm and 7 cm behind magnetic mirror).

I_Σ ~ 0.6 A is total titanium ion current of plasma flow leaving through the outlet channel at B=0.8 T.

The experimental dependencies of ion current on the parameters of the source (discharge current and magnetic field) are shown in fig.6, 7 and in agreement with the source model described above.

The increase of the discharge current increases the plasma density and the ion transversal energy due to the decrease of anode-cathode voltage.[5] Therefore the increase of the discharge current results in the nonlinear increase of the ion current of a plasma flow.

The increase of magnetic field at constant discharge current results in the increase of the anode-cathode voltage and the decrease of plasma density, because the transversal energy of magnetized metal ions is increased and total ion current is reduced.

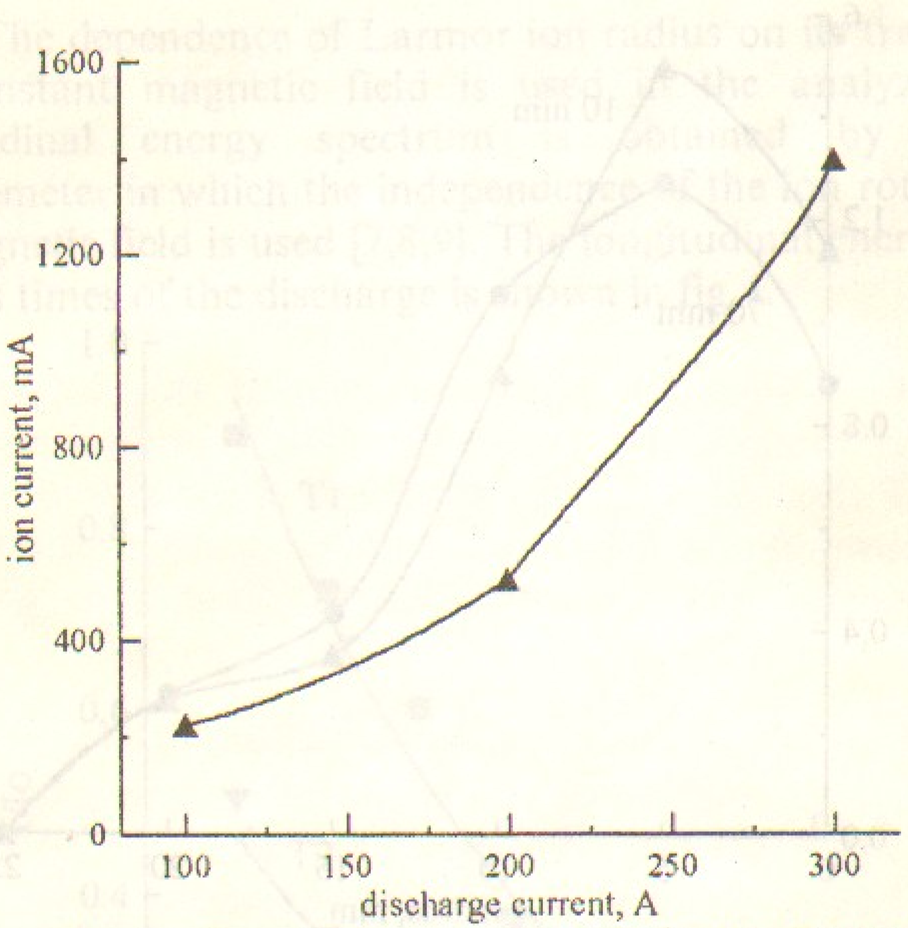


FIG. 6. Dependence of metal ion current of plasma flow on discharge current (B=0.6 T)

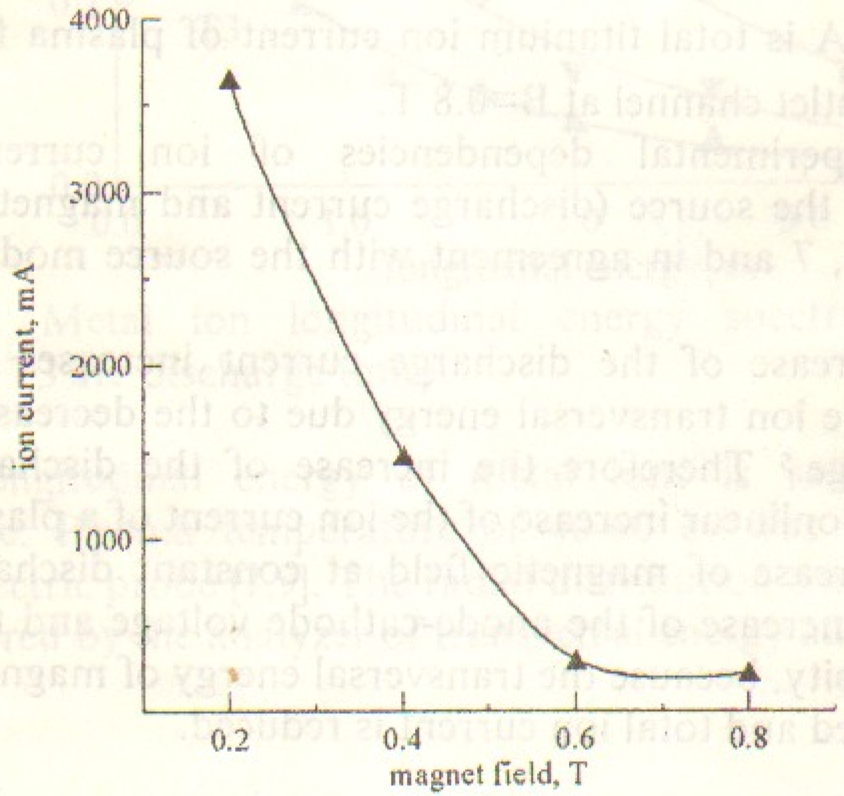


FIG. 7. Dependence of metal ion current of plasma flow on magnetic field (discharge current of 100 A).

The estimate of the total ion current of plasma flow for the size of outlet channel (S~20 cm^2) and the typical plasma parameters inside the source ($W_\parallel$~ 1 ev, n~5·10^{12}cm^{-3}) is 3.4 A that is close to experimental results.

V. CONCLUSION

The universal metal ion source generates a plasma flow with magnetized metal ions. The self-sputtering of cathode material used in this source is the universal method to obtain the plasma with ions of various materials. Measurements of the main parameters of the plasma flow with magnetized titanium ions (plasma density of 10^{12}cm^{-3}, ion transversal energy of 20-60 ev, longitudinal velocity of the plasma flow of (2-3)·10^{5}cm/sec) were produced behind the magnet mirror of the source. The experimental dependencies of the ion current on the source parameters (magnetic field, discharge current) are in agreement with the theoretical estimates. The parameters of presented source are close to required parameters for plasma separation process. It is possible to increase the ion current by the change of the main sizes of the source (outlet channel, cathode, anode) and the mirror ratio and the decrease of the transversal energy of magnetized metal ions and the increase of the ambipolar potential.

REFERENCES

[1] Dawson J.M., Kim H.P., Arnush D., Fried B.D., Gould R.W., Heflinger L.O., Kennel C.F., Romesser T.E., Stenzel R.L., Wong A.Y., Wuerker R.F., Phys. Rev. Lett., 37, 1537 (1976).

[2] Tracy J.C., Nucl. Instr. & Meth., A282, 261-266 (1989).

[3] Muromkin Yu.A., Itogi nauki i techniki, Fisika plasmi, 12, 83-111 (Moscow, VINITI, 1991).

[4] Volosov V.I., Abdrashitov G.F., Bekhtenev A.A., Kubarev V.V., Pal'chikov V.E., Yudin Yu.N., Journal of Nuclear Materials, 128, 129, 445-451 (1984).

[5] Churkin I.N., Thesis of PhD (Novosibirsk, BINP, 1997).

[6] Erofeev V.I., Ryutov D.D., Fisika plasmi, 12, is.10, 164-1169 (1986).

[7] Volosov V.I., Churkin I.N., Steshov A.G., Abstacts of XXIV Russian Conference on Plasma Physics, 179 (Zvenigorod, 1997).

[8] Volosov V.I., Churkin I.N., Steshov A.G., Pribori i Technika Eksperimenta (to be published)

[9] Volosov V.I., Churkin I.N., Steshov A.G., Preprint BINP 96-59 (in Russian), (Novosibirsk, 1996).

I. Churkin, A. Steshov, V. Volosov

Universal metal ion source

Budker INP 97-76

Ответственный за выпуск А.М. Кудрявцев
Работа поступила 29.09. 1997 г.

Сдано в набор 30.09.1997 г.
Подписано в печать 30.09.1997 г.
Формат бумаги 60×90 1/16 Объем 0.9 печ.л., 0.8 уч.-изд.л.
Тираж 100 экз. Бесплатно. Заказ N° 76

Обработано на IBM PC и отпечатано на
ротапринте ГНЦ РФ "ИЯФ им. Г.И. Будкера СО РАН",
Новосибирск, 630090, пр. академика Лаврентьева, 11.