THE FORMATION OF THE LOW-SIZED HIGH DENSITY PLASMA STRUCTURES IN THE SELF-MAINTAINED PLASMA-BEAM DISCHARGE

***V.N. Borisko*[1], *A.F. Tseluyko*[1], *D.V. Zinov'ev*[1], *V.T. Lazurik*[1], *I.K. Tarasov*[2]**

[1]V.N.Karazin Kharkov National University, Kurchatov av. 31, Kharkov, 61108, Ukraine, e-mail: Zinoviev@htuni.kharkov.ua;

[2]Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology", Academicheskaya str. 1, Kharkov, 61108, Ukraine

The opportunity of use self-maintained plasma-beam discharge in an extended pulsing plasma diode of low pressure for making powerful sources of the soft X-rays is investigated. Conditions of formation of the self-maintained plasma-beam discharge are determined. The mode of making of dense high-temperature plasma on the basis of stannum ions in the discharge is shown. The stannum ions are used as a working element of a radiation sources at pulsing power of electron beam $P \sim 10 \ldots 100\ MW$. Results of the examination on formation of the dense ($n_p \sim 10^{16}\ cm^3$), small sizes ($l < 1\ cm$) plasma with the electron temperature $T_e \sim 100\ eV$ in conditions of working material evaporation from the anode are given. The total contribution of energy to the discharge has made $W < 20\ J$.

PACS: 537.52

INTRODUCTION

Now progress in the area of nano-technology is bound up with development of a photolithography which is based on use of radiation with wave length $\lambda \sim 10$ *nanometers*. In this case the specific optical systems and intensive point sources of radiation are used. As a radiating element for radiation sources the dense plasma ($n_p \sim 10^{16} \ldots 10^{18}\ cm^3$) with the electron temperature $T_e \sim 50 \ldots 100\ eV$ is used frequently. High electron temperature is necessary for obtaining of multiply ionized ions which at the subsequent recombination form the radiation in a necessary range.

One of problems, which arises at the creation of soft X-radiation sources for a photolithography in nano-dimensional area, is the big impulse energy contribution ($W \sim 10^4 \ldots 10^6\ J$) in devices which are used for this purpose now (pinch [1-3] and plasma accelerators [4]). The attempt to increase of the radiated power in these devices results to very large thermal loadings on constructional elements and to quick destruction of these elements.

For decrease of energy, which is brought to a discharge cell, in this work the opportunity of formation low-sized high-temperature plasma under the action of self-maintained plasma-beam discharge (SMPBD) is investigated [5].

The presence in plasma, which transfers a current through a discharge gap, the double electric layer of a space charge with large voltage drop is the feature of such discharge. In a double layer there is a counter acceleration of powerful electron and ion beams. Between double layer and anode the discharge current is transferred by the electron beam. Thus there is an intensive heating of plasma due to collective beam-plasma interacting.

Under conditions (Fig. 1) when the dense plasma *HDHP* is formed in the near anode area of the discharge, and double layer *DL* is localized on the external boundary of this plasma, it is possible to carry out the effective heating of the dense plasma. Thus, the dense plasma can be created by the same electron beam due to vapor ionization of the anode. In this case one part of the beam energy goes on the evaporation of the anode material, and other part - on a heating of plasma up to necessary temperature.

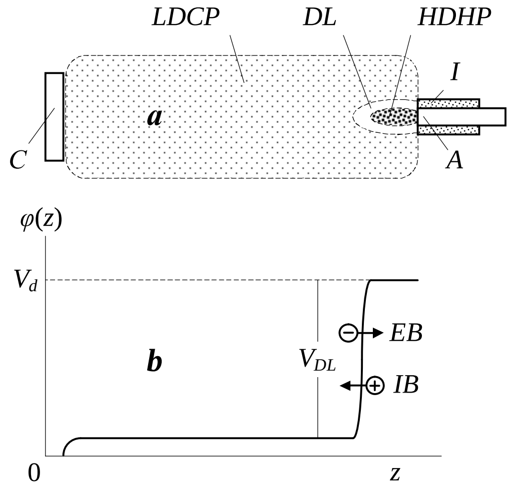

Fig. 1. The scheme of discharge area (a) and qualitative longitudinal distribution of potential φ (z) in the discharge (b): C - cathode; A - anode; I - isolator; LDCP - love temperature plasma; DL - double layer; HDHP - dense high-temperature plasma; V_d - potential of the discharge; V_{DL} - double layer potential; EB - electron beam; IB - ion beam

Because of a small amount of channels for consumption of energy in a discharge cell, the use of SMPBD can reduce the energy contribution to system essentially. It opens up the prospects for creation of effective dot source of the soft X-rays.

Important moment at the creation of a source of radiation on the basis SMPBD is search of ways of hold-in the double layer in the near anode area.

THE SHAME OF THE EXPERIMENTAL DEVICE

Experiments on formation of small size high temperature plasma in conditions of SMPBD were carried out in the extended pulse plasma diode of low pressure. The shame of the diode is shown on Fig. 2.

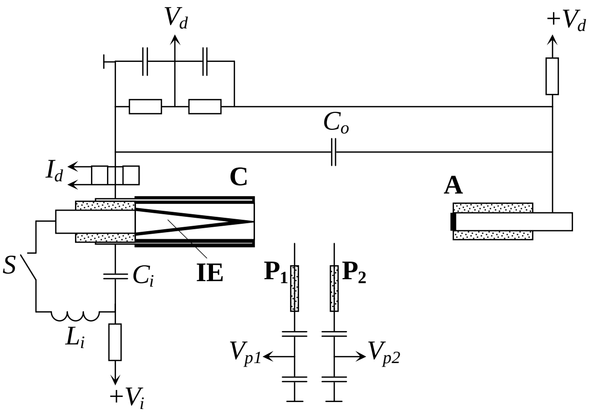

Fig. 2. The shame of the experimental device

The plasma diode consists of the cathode C and the anode A, which are located in the center of the vacuum chamber to provide the large distance to its walls (~20 *cm*). The cathode was a tubular copper electrode (length is 30 *mm*, external diameter is 10 *mm* and internal diameter is 9 *mm*). Inside of the cathode in the ceramic isolator the conical copper trigger electrode IE by length 30 *mm* and diameter at the basis 5 *mm* is located. The rod copper anode A has diameter 4 *mm*. The lateral surface of the anode is protected by glass tubular isolator. Working surfaces of all electrodes have been covered by a stannum layer with thickness of 0,5 *mm*. The distance between end-walls of cathode and anode could be changed from 3 up to 10 *cm*.

For decrease of the inductance of a discharge circuit the switching device was not used. The cathode and the anode directly connected to the battery of pulse condensers C_p with capacity of 0,5…2,0 µ*F* which was charged from the power supply $+V_d$ up to a voltage 1…15 *kV*. The anode was as a high-voltage electrode, and the cathode have the ground potential. The discharge was ignited with the help of a trigger electrode due to electric breakdown on a surface of dielectric inside the tubular cathode. The voltage to trigger electrode yielded through the switchboard *S* from the battery of condensers C_i with capacity 0,25…1,5 µ*F*. The condensers were charged from the power supply $+V_i$ up to a voltage 1…5 *kV*. With the help of inductance L_i the duration and the current of a trigger pulse changed.

For definition of localization of a double layer two movable single probes *P1* and *P2* which registered the plasma potential were used. Besides that, with the help of probes the speed of expansion of the initial plasma was defined. Signals from the probes were stored by means of capacitor dividers of a voltage with the effective capacity ~1 *pF*.

THE EXPERIMENTAL RESULTS

The investigations were carried out at the residual gas pressure $p \sim 10^{-5}$ *torr* when the basic working environment for the maintenance of the discharge is the stannum vapours. On Fig. 3 the oscillograms of a discharge current and a discharge voltage, and probe potentials ($C_o = 1$ µ*F*, $+V_d = 6$ *kV*, $C_i = 1{,}5$ µ*F*, $+V_i = 4$ *kV*, $L_i = 7$ µ*H*) are shown.

The experiments have shown that the formation of small-size high-temperature plasma in the system occurs in three stages.

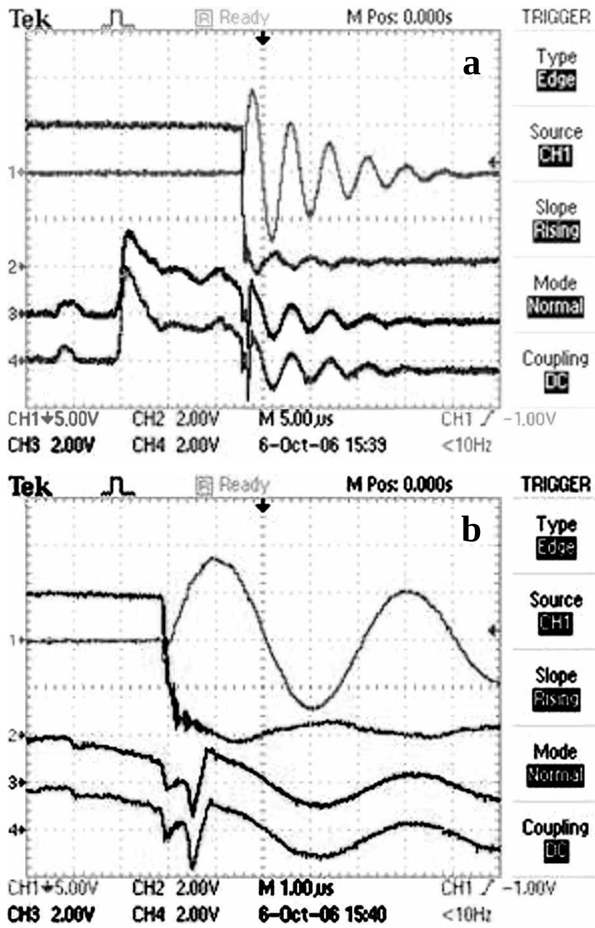

Fig. 3. Oscillograms of discharge current 1) - 5 kA/div, discharge voltage; 2) - 2 kV/div., and also probe potentials located on distance of 2 cm; 3) - 2 kV/div and 1 cm; 4) - 2 kV/div from the cathode. a) - sweep 5 µsec/div; b) - sweep 1 µsec/div

At the first stage ($0 < T_1 < 10$ µ*s*, Fig. 3a) the dense cathode plasma is formed due to surface breakdown and extended to the anode direction. At that the mode of the vacuum diode with the plasma emitter of electrons takes place. The electron beam, which is formed in an interval between the front of cathode plasma and the anode, bombards of the anode surface and causes occurrence of stannum vapours in the anode area. The beam intensity and intensity of evaporation of the anode material grow with the approach of cathode plasma front to the anode. The first stage Duration is defined by speed of extension of cathode plasma v_f, which was ~10^6 *cm/s* according to probe measurements.

The second stage of the discharge evolution comes after shorting of the discharge gap by cathode plasma ($10 < T_2 < 23$ µ*s*). At that in the discharge gap filled by plasma a double layer forms. At first ($10 < t_{21} < 12$ µ*s*) one double layer *CDL* formed near the cathode area. Total voltage drop of the discharge concentrated on this layer ($V_{CDL} \approx V_d$). Then ($12 < t_{22} < 14$ µ*s*) one more double layer *ADL* is formed near the anode area. Voltage between the layers is progressively redistributed. During time $14 < t_{23} < 23$ μ*s* in the discharge there are two consistent double layers with voltage drop $V_{CDL} \approx 1{,}5$ *kV* and $V_{ADL} \approx 4{,}5$ *kV*.

At the second stage the electron beam which is ignited in a layer near the anode, prolongs to evaporate and ionize the anode material intensively. It results to formation of dense plasma. The layer in the cathode area heats up other plasma of the discharge gap.

After creation of the dense hot plasma on the basis of stannum vapors in the discharge gap the third stage there comes. At this stage the inductive discharge occurs ($23 < T_3 < 25$ μ*s*), and the discharge voltage is redistributed on inductance of a discharge circuit. However, during the period ($23{,}4 < t_{31} < 23{,}8$ μ*s*) in the discharge there is a layer in the anode area again. The electron beam with a current 6 *kA* heats up the anode plasma to a level when it is capable to provide the current density to the anode $j_A \approx 70$ kA/cm^2. The characteristic sizes of dense plasma in anode area are commensurable with the sizes of the anode working surface.

CONCLUSIONS

As a result of experiments the opportunity to use SMPBD for formation of the small-sizes high-temperature dense plasma on the basis of stannum ions in anode area of the extended plasma diode is shown. For effective evaporation of the anode material, vapour ionization and collective hitting of plasma the opportunity of generation of the electron beam in the double layer of a space charge near to a anode working surface is present. For confinement of a double layer in the anode area the several conditions is necessary to carry out. First, the power supply should provide current I_o greater, than a thermal current of plasma in the field of a minimum of conductivity:

$$I_o > \oint_{S(t)} j(\mathring{r},t)\cdot d\mathring{s} \approx \oint_{S(t)} \frac{e\cdot n_p^{\min}(\breve{r},t)}{4}\sqrt{\frac{8T_e(\mathring{r},t)}{\pi\, m_e}}\cdot d\mathring{s},$$

where *S (t)* - external border of dense anode plasma. Second, the minimum of density of the basic plasma $n_p^{\min}(\breve{r},t)$ of the discharge gap should be near external border of the dense plasma *S (t)*.

For decrease of sizes of dense plasma it is necessary to reduce of the anode working surface.

This work has been supported STCU Project # 3368.

REFERENCES

1. Borisov V.M. et al.// *Plasma Physics*. 2002, v.28, №10, p. 952-956 (in Russian).
2. Usenko P.L. et al.// *Priboru i tehnika experimenta*. 2002, №3, p.93-100 (in Russian).
3. G. Niimi et al.// *J. Phys. D. Appl. Phys.* 2001, v. 34, p. 1-4.
4. S. Hussain, S. Ahmad et al.// *Physics Letters*. 2006, v.349, Iss. 1-4, p. 236-244.
5. E.I. Lutsenko, N.D. Sereda , A.F. Tselujko// *Journal of Technical Physics*. 1988, v.58, № 7, p. 1299-1309.

ФОРМИРОВАНИЕ МАЛОРАЗМЕРНЫХ ПЛАЗМЕННЫХ ОБРАЗОВАНИЙ ВЫСОКОЙ ПЛОТНОСТИ В САМОСТОЯТЕЛЬНОМ ПЛАЗМЕННО-ПУЧКОВОМ РАЗРЯДЕ

***В.Н. Бориско**, А.Ф. Целуйко, Д.В. Зиновьев, В.Т. Лазурик, И.К. Тарасов*

Изучена возможность использования самостоятельного плазменно-пучкового разряда в протяженном импульсном плазменном диоде низкого давления для создания мощных источников мягкого рентгеновского излучения. Определены условия и показан способ формирования в таком разряде плотной высокотемпературной плазмы на основе ионов олова как рабочего элемента источника излучения при импульсной мощности электронного пучка *P~10…100 МВт*. Приведены результаты исследования по формированию малоразмерных (*l<1 см*) плотных ($n_p \sim 10^{16}$ $см^{-3}$) плазменных сгустков с температурой электронов $T_e \sim 100$ *эВ* в условиях испарения рабочего вещества с анода при энерговкладе в разряд *W<20 Дж.*

ФОРМУВАННЯ МАЛОРОЗМІРНИХ ПЛАЗМОВИХ УТВОРЕНЬ ВИСОКОЇ ЩІЛЬНОСТІ В САМОСТІЙНОМУ ПЛАЗМОВО-ПУЧКОВОМУ РОЗРЯДІ

***В.М. Бориско**, О.Ф. Целуйко, Д.В. Зінов'єв, В.Т. Лазурик, І.К. Тарасов*

Досліджено можливість використання самостійного плазмово-пучкового розряду в протяжному імпульсному плазмовому діоді низького тиску для створення потужних джерел м'якого рентгенівського випромінювання. Визначено умови та показаний спосіб формування в такому розряді густої високотемпературної плазми на основі іонів олова в якості робочого елемента джерела випромінювання при імпульсній потужності електронного пучка *P~10…100 МВт*. Наведено результати досліджень з формування малорозмірних (*l<1 см*) щільних ($n_p \sim 10^{16}$ $см^{-3}$) плазмових згустків з температурою електронів $T_e \sim 100$ *еВ* в умовах випару робочої речовини з анода при вкладі енергії в розряд *W<20 Дж.*