THE HYDROGEN PLASMA INJECTOR WITH THE METAL-HYDRIDE HOLLOW CATHODE

A.F. Tseluyko, V.N. Borisko, D.V. Zinov'ev
V.N. Karazin Kharkov National University, Kharkov, Ukraine

The intensive pulse source for synthesized electron-ion beams on the basis of the Penning discharge with the metal hydride hollow cathode was investigated. The main feature of this device is the application of metal hydride $Zr_{50}V_{50}H_x$ as an electrode material for the hollow cathode. The using of metal hydride hollow cathode allows to provide the pulse working gas feed at low starting pressure $p = 10^{-3}$ Pa. The density of ion current in the source achieved 50…100 mA/cm^2 at the energy of ion and electron beams 0,5…1 keV. The comparison of parameters of the charged particles sources in different modes of hollow cathode operations is carried out.
PACS: 52.30.-q

INTRODUCTION

The self-maintained plasma-beam discharge (SMPBD) [1,2] is of the wide use for generation of the intensive electron and ion beams with currents 1-10^5 A and energy 10^2-10^6 eV.

Two specific types of the SMPBD discharge are distinguished: K and M–discharges, which differ in both spatial localization of a double layer and the conditions of its ignition and the dynamic of its maintenance [3,4]. In the case of M–discharge the localization of a double layer on the length of the diode gap is determined by the area with the minimum of plasma concentration. Thus the electron beam transfers the basic current of the discharge only on the length of the double layer-anode zone. Changing of the area of the minimum of plasma concentration makes possible to control the layer location and the location of generation zone of the intensive beams of charged particles consequently.

Use of the SMPBD generates interest at creating of intensive X-ray generators [5]. The localization of the double layer immediately at the anode-target surface is more preferable in this case as eliminates the energy losses of the electron beam at the interaction with plasma [6]. The creation of the plasma concentration gradient with the minimum at the anode of the high-current pulse plasma diodes is possible both at the expense of the concentration gradient of the primary plasma, which diode gap is filled previously and at the expense of pressure gradient of the neutral gas along the discharge tube.

In this work for creation of necessary gradient of primary plasma and hydrogen pressure in the discharge tube of the plasma diode was used original plasma sources based on the Penning cell with metal hydride hollow cathode.

EXPERIMENTAL RESULTS

The detail description of the device construction and its operation of are given in [6].

The additional source of the primary plasma consists of Penning cell and the metal hydride hollow cathode. The longitudinal magnetic field is created by ring permanent magnets. Galvanically isolated metal hydride hollow cathode is located in the center of the cathode.

The metal hydride hollow cathode by length of 20 mm represents a set of four tablets. In the center of each tablet the hole by diameter of 4 mm is made. Hydride forming getter alloy $Zr_{50}V_{50}$ composition prepared by a method of electron-beam smelt was used as an initial material of the tablets.

The criterion of the alloy choice for the hollow cathode was the opportunity of its work in desorbtion mode of hydrogen in vacuum conditions [7]. The decomposition of the hydrogen phases of these material allows to ensure the hydrogen isotopes fill-in at the working temperatures 400…900 K.

The additional source of the primary plasma could work in conditions of internal and external filling of hydrogen. Internal hydrogen filling was carried out at the expense of hydrogen desorption from the metal hydride hollow cathode. External hydrogen filling was made through the usual hollow cathode similar by the form and the sizes to the metal hydride hollow cathode.

High-current discharge was excited by the pulse voltage up to 20 kV between the interior cathode and anode in glass discharge tube. The work of the additional primary plasma source was supported by the voltage feed +4 kV to the anode of the Penning cell and –1 kV to the metal hydride hollow cathode relatively to the potentials of the exterior cathode.

Localization of the double layer on the length of the plasma diode was controlled during the discharge by 4 external capacitor probes, which traced the plasma potential value in the probe location. The plasma concentration was estimated by the SHF-signal cut-off method on the wavelengths of 3 cm and 8 mm that corresponds to plasma density of 10^{12} cm^{-3} and 10^{13} cm^{-3} accordingly. The studying of the distribution functions by energies for electron and ion beams was made with the help of Use-Rozhansky cylindrical energy analyzer.

Research of the parameters of the additional primary plasma source was carried out in the stationary and pulse operating modes of the Penning cell without voltage supply to the electrodes of the plasma diode. The high-voltage mode was investigated at the replacement of the metal hydride hollow cathode by its copper analogue in conditions of the external feeding of hydrogen. The high-current operating mode of the source was studied at the internal and external feeding of hydrogen. In the case of internal feeding the metal hydride hollow cathode was used. In the high-current mode in both cases of the gas feeding at the identical pressure the concurrence of the discharge characteristics of the source was marked.

In Fig. 1 the discharge characteristics of the additional source of the primary plasma in high-voltage and high-current operating modes at the stationary anode voltage are shown.

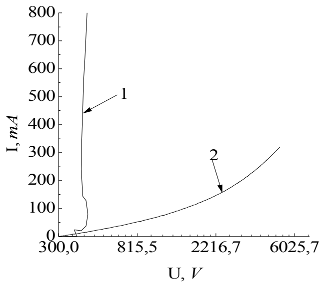

Fig. 1. The volt-ampere characteristic of the Penning cell with the hollow cathode under high-current (1) and high-voltage (2) modes

From the figure it is seen, that in the high-current mode the discharge current 2…3 order exceeded the discharge current in the high-voltage mode, reaching the values of 0,8 A. It is caused by the excitation of the hollow cathode mode. Anode voltage at which the additional source of the primary plasma passed to the high-current mode, was within the range of 0,7…1,0 kV and practically did not depend from the bias voltage on the hollow cathode U_{hc}. Anode voltage of the primary plasma source in high-current discharge mode changed a little by changes of the discharge current and had values 0,4…0,6 kV.

Results of research of the beam parameters generated by additional source are resulted on Fig. 2. Fig. 2a illustrates the schematic image of the Penning cell with the longitudinal potential distribution in the high-current operating mode of the source at the bias voltage on hollow cathode U_{HC} = –1 kV. Fig. 2b gives the representation of energy distribution functions of ion and electron beams in the near axial area. On Fig. 2c the beam current density distributions along the section at the distance of 10 cm from the discharge outlets of the source is shown. The energy of the electron beam can be changed independently from the ion beam energy by change of the bias voltage U_{hc}.

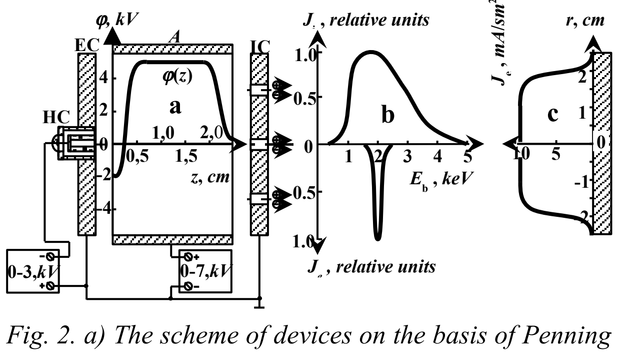

Fig. 2. a) The scheme of devices on the basis of Penning discharge with the hollow cathode:

b) The energy distribution function for ion j_i and electron j_e beams;

c) The current density distribution of the electron beam along cross-sectional

At transition to the pulse feed of anode of the Penning cell in conditions of the internal feeding of hydrogen it was determined that the formation of the high-current mode of the source and excitation of the hollow cathode mode take place during 20…100 μs after applied voltage and need higher anode voltage in comparison with the external gas feeding. At the internal feeding the pulse anode voltage was U_A = 4…5 kV, whereas at the external it was U_A = 1,0…1,2 kV. However the starting pressure of transition to the high-current mode of the discharge excitation at the internal gas feeding has decreased more than one order from $P_o = 10^{-1}$ Pa up to $P_o = 3\cdot10^{-3}$ Pa.

The basic difference external and internal feeding of hydrogen was that in the first case the pressure gradient of the working gas existed constantly and in the second case it was formed only in the period of the pulse action. The threshold pressure $P_o = 10^{-1}$ Pa in the additional source at the external feeding corresponded to the pressure $P = 2\cdot10^{-2}$ Pa in the discharge gap of the plasma diode (due to the constant pumping-out of hydrogen and vacuum resistance of discharge outlets). At the internal feeding the starting pressure $P_o = 3\cdot10^{-3}$ Pa was identical both for additional source and for discharge gap of the plasma diode.

The typical oscillograms of the discharge current $I_d(t)$, discharge voltage $V_p(t)$ and signals from capacitor probes $V_{pr1}(t)$ and $V_{pr2}(t)$, located at the distance of 3 cm and 6 cm from the anode-target respectively are shown on Fig. 3. These dependences are obtained in the case of the internal feeding of hydrogen.

From oscillograms it is seen that all active voltage is

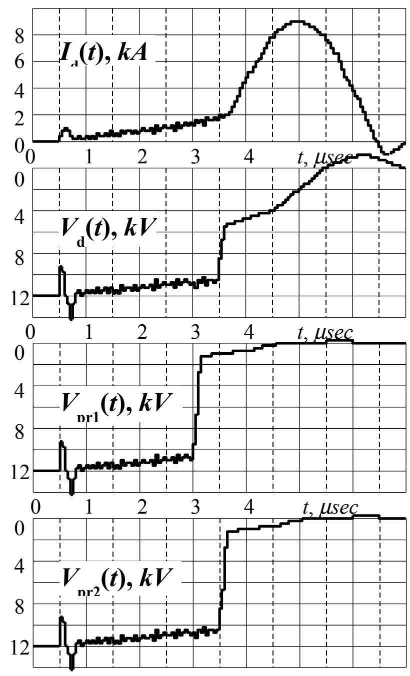

Fig. 3. The oscillograms of the discharge current $I_d(t)$, discharge voltage $V_d(t)$ and the signals from the capacitive probes $V_{pr1}(t)$ and $V_{pr2}(t)$, which located on the distance of 3 cm and 6 cm from the anode correspondingly

focused in the anode area on the space charge layer after the high-current discharge excitation at the time t = 0,5 μs (both capacitor probes register high negative potential).

The electron beam generation occurs in conditions of practically linear increase of the current to the time t = 3,5 µs. Thus, at the time t = 2,5 µs the removal of the double layer from the anode is observed, that is confirmed by sharp voltage reduction on the probe V_{pr1} which is located near the anode. The voltage on more removed probe V_{pr2} during this moment remains high, that testifies about the localization of a double layer in the near anode zone. The beam current during this moment is $1{,}5\cdot10^3$ A and beam energy $\sim10^4$ eV, that corresponds to power density $2{,}6\cdot10^6$ W/cm^2. The using of the internal feeding of hydrogen essentially influenced the operation both of the additional source primary plasma and the plasma diode. At the external feeding of hydrogen excitation of the high-current discharge in plasma diode occurred in 40…50 µs after the voltage supply to the anode cell additional source. In the case of the internal feeding the time of the excitation of the high-current discharge was increased up to 150…500 µs. The time excitation depend from filling velocity of the discharge gap by plasma. However the basic positive moment of application of the internal feeding was reduction the starting working pressure of the plasma diode up to $P_o = 10^{-3}$ Pa in comparison with $P_o = 2\cdot10^{-2}$ Pa for the external feeding.

CONCLUSION

The additional source of the primary plasma on the basis of the Penning discharge with the metal hydride hollow cathode allows to create the pressure distribution with necessary spatial-temporal parameters along the discharge tube and to control the location zone of beam generation. In contrast to known hydrogen injector based on on-surface breakdown of the hydride-containing materials, in the given system the erosion of constructional elements is minimized that favorably affects the device service life. The using of described source of primary plasma make is possible to control intensity and duration of the charged particle beam formation in the plasma diode by changing the external parameters of the source.

For obtaining of the high gradients of hydrogen pressure and decreasing the dead time of excitation of the high-current discharge in the plasma diode it is necessary to use the increased anode voltage in the Penning cell. In this case there is some minimal anode voltage at which the excitation of the high-current discharge is possible. The given limited voltage is determined by many factors: the size of working surface of the metal hydride hollow cathode; the hydrogen saturation value; working volume of the discharge tube and the vacuum resistance of discharge outlets of the source.

REFERENCES

1. Yu.I. Lutsenko et all. // *Letters in JTP*. 1987, v.13, N5, p. 294-298. (in Russian)
2. Yu.I. Lutsenko et all. // *JTH*. 1988, v.58, Is.7, p.1299-1309. (in Russian)
3. Lutsenko Yu.I. et all. // *Ukrainian Journal of Physics.* 1988, v.33, Is.5, p.730-736. (in Russian)
4. Yu.I. Lutsenko et all. // *Letters in JTP*. 1984, v.10, N22, p.1349-1353. (in Russian)
5. V.N. Borisko et all. // *Proc. of 29 EPS Conference on Plasma Physics and Controlled Fusion. Montreux, Switzerland*. 2002. P-4.029.
6. V.N. Borisko et all. // *Proc. of the 30th European Physical Society Conference on Controlled Fusion and Plasma Physics. St Petersburg, Russia*. 2003. P-4.102.
7. A. Stern et all. // *J. Less-Common Met*. 1982, v.88, p.431-440.

ВОДОРОДНЫЙ ИНЖЕКТОР ПЛАЗМЫ С МЕТАЛЛОГИДРИДНЫМ ПОЛЫМ КАТОДОМ

А.Ф. Целуйко, В.Н. Бориско, Д.В. Зиновьев

Рассматривается интенсивный импульсный источник для синтеза электронно-ионных пучков на основе разряда Пеннинга с металлогидридным полым катодом. Особенностью устройства является применение металлогидрида $Zr_{50}V_{50}H_x$ в качестве материала электрода полого катода. Использование металлогидридного полого катода позволяет обеспечить импульсную подачу рабочего газа при пониженном начальном давлении $p = 10^{-5}$ Па. Плотность тока ионов в источнике достигает 50…100 мА/см^2 при энергии пучка 0,5…1 кэВ. Проведено сравнение параметров источников заряженных частиц в различных режимах работы полого катода.

ВОДНЕВИЙ ІНЖЕКТОР ПЛАЗМИ З МЕТАЛОГІДРИДНИМ ПОРОЖНИСТИМ КАТОДОМ

О.Ф. Целуйко, В.М. Бориско, Д.В. Зінов'єв

Розглядається інтенсивне імпульсне джерело для синтезу електронно-іонних пучків на основі розряду Пенінга з металогідридним порожнистим катодом. Особливістю пристрою є застосування металогідриду $Zr_{50}V_{50}H_x$ в якості матеріалу електрода порожнистого катода. Використання металогідридного порожнистого катода дозволяє забезпечити імпульсну подачу робочого газу при зниженому початковому тиску $p = 10^{-5}$ Па. Щільність струму іонів у джерелі досягає 50…100мА/см^2 при енергії пучка 0,5...1 кеВ. Проведено порівняння параметрів джерел заряджених часток у різних режимах роботи порожнистого катода.