HYDROGEN INJECTOR BASED ON PENNING DISCHARGE WITH METAL HYDRIDE CATHODE

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The paper presents the results of the investigation of a neutral-hydrogen pulse injector based on Penning discharge with a metal hydride hollow cathode. The source of chemically pure hydrogen is a getter alloy $Zr_{50}V_{50}$ made in the form of a hollow cathode. The main release of hydrogen into the gas phase occurs under the influence of discharge current (about 20 *A*) in a short period of time (several hundred microseconds), during the operation in the high-current discharge regime. It is shown, that the propagation velocity of the gas front depends on the discharge current and is determined by the hydrogen temperature. The maximum velocity of gas front propagation is obtained at the level of $5\cdot10^5$ *cm/s*. The amount of hydrogen desorbed per *400-μc* pulse isabout $1.5\cdot10^{-3}$ cm^3 under normal conditions and the energy is expended on the level of 0.34 *J*.

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INTRODUCTION

An important part of the sources of ionized and neutral particles, as well as devices that perform gas supply of toroidal traps are pulsed gas injectors [1]. There are two types of injectors: piezoelectric and electromagnetic ones [1, 2]. The first are characterized by low power consumption and high response rate with a characteristic time of the gas pulse at a level of hundreds of microseconds. However, due to the small stroke of the piezoelectric element and the small flow cross section, they are not able to provide a large flow of gas [2]. Electromagnetic injectors, on the contrary, do not have a high speed, but they provide large gas flows [1, 2].

For devices operating on hydrogen or its isotopes, it is convenient to use getter injectors as a source of hydrogen, which are comparable or superior to piezoelectric injectors by fast-action, and can compete with electromagnetic ones in terms of gas flow. To their shortcomings can be attributed the need for periodic rather laborious regeneration and the possibility of working only with one type of gas – hydrogen. However, the undeniable advantages of getter injectors stimulate the development and improvement of them.

The main element of the getter injectors is a storage based on reversible metal hydride alloys, for example, zirconium and vanadium. These alloys have a sufficiently large hydrogen capacity and allow multiple recharging. Slow injection of hydrogen is due to the smooth heating of the entire accumulator, and fast – by the release of pulsed energy on its surface [3]. The magnitude of the flow of hydrogen is mainly determined by the size of the surface.

For pulse energy contribution, both electron and ion beams are suitable. In the second case, applying the Penning discharge one can form ion beams on significant surfaces without using thermal cathodes and other power-consuming elements. In addition, the yield of hydrogen here will be determined not only by the thermal effects of hydride phases decomposition, but also by ion stimulated processes [3].

Consideringthe possibility of the injector operating at high vacuum, the Penning discharge with its wide working pressure range fits best. Additional features of this injector are the ease of implementation and operation. In addition to the neutral hydrogen flow, it is also possible to form a hydrogen plasma flux. The latter is important for cathode-transformers of quasi-stationary plasma accelerators [4].

When designing pulse getter hydrogen injectors, it is important to know a number of fundamental parameters: the amount of desorbed hydrogen from a surface unit, the specific energy input, and the start time of the discharge.

The purpose of this paper is to investigate the possibility of using a Penning pulse discharge with a metal hydride cathode as a neutral hydrogen pulse injector.

1. EXPERIMENTAL SETUP

Fig. 1 shows the scheme of the metal hydride hydrogen injector based on the Penning discharge. To enhance the discharge current, the metal hydride desorption element is designed as a hollow cathode.

The Penning cell is formed by two disk cathodes C_1 and C_2 made of magnetically conductive steel and a tube-like anode *A*. A longitudinal magnetic field of 500 *Oe* is created by two annular permanent magnets *M*. The sealing is carried out by a branch pipe *W*, which ends with rubber nipples seals in cathode slots. The anode *A* and the branch pipe *W* are made of non-magnetic stainless steel.

In the central region of the cathode C_2 there are 7 apertures 4 *mm* in diameter for gas outlet. Through the same apertures, the pumping of the discharge gap is performed. In the center of the cathode C_1 in the branch pipe there is a metal hydride hollow cathode *MHC* in the form of a tube 12 *mm* long with external and internal diameters of 8 and 3 *mm*, respectively. The *MHC* cathode is made by pressing hydrogen-saturated powder of $Zr_{50}V_{50}$ alloy with copper binder. The initial hydrogen saturation degree was ~ 500 cm^3 under normal conditions.

A voltage pulse with amplitude up to + 4 *kV* was supplied to the cell anode from a capacitor C_0 of 1.5 *μF*

through a controlled switch *S* (thyratron TGI-400/16) and a ballast resistance R_b = 190 *Ω*. The discharge voltage V_d was measured by a balanced voltage divider, and the current i_d – by the Rogowski coil. In the experiments in order to eliminate the formation of an electron of the cathodes *MHC*, C_1 and C_2 was the same.

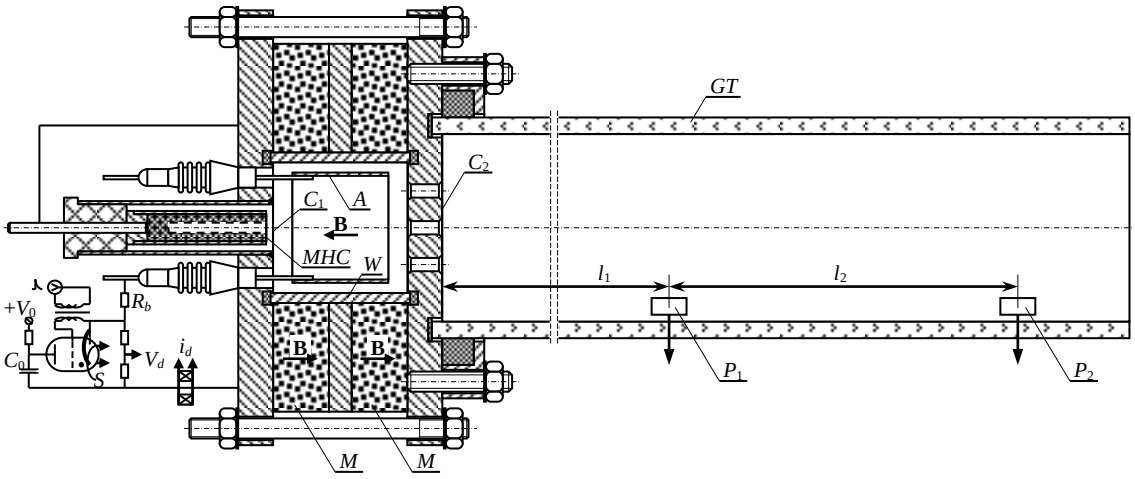

Fig. 1. Metal hydride hydrogen injector with a layout of pressure sensors

To study the dynamics of neutral gas propagation, the injector was docked to a vacuum chamber through a glass tube *GT* 40 *cm* long and 5.6 *cm* in diameter. Within the tube there were miniature ionization pressure sensors P_1 and P_2 at the distance of 15 and 25 *cm* from the injector. The sensors had a spiral filament cathode, a cylindrical anode and they operated on the principle of measuring the current in the cathode circuit. The emission current was 1 *mA*, the supplied voltage was 50 *V*. To reduce interference, the sensors used battery power.

The dynamics of the pressure in the chamber was investigated by the signal from PMI-2 sensor.

2. RESULTS AND DISCUSSION

The operation of metal hydride hydrogen injector based on Penning discharge is illustrated by the oscillogramsin Fig. 2 Voltage (*a* – general view, *b* – increased sensitivity) and current (*c* – oscillograms are clearly show two discharge stages: high-voltage ($100 \le t \le 200\ \mu s$) and high-current ($200 \le t \le 480$ μs). In the high-current stage, the discharge voltage (*b*) lies in the range 50...120 *V*, and this indicates that there is an arc discharge.

The dynamic of particle concentration along the glass tube *GT* is illustrated in (see Fig. 2,d), where oscillograms of the current of two ionization pressure sensors are shown. When the voltage is applied to the injector, the current of both sensors slightly increases (close one by 8 %, far one by 2 %) and remains practically constant for ~ 70 μs. This current, apparently, is due to ion beam, which is formed in Penning discharge. (The arrival time of hydrogen ions to the sensors is ~ 0.2 ... 0.3 μs. There is practical synchronism in the currents).

At the final stage of the high-voltage discharge stage ($170 \le t \le 200\ \mu s$), the current is increased to 20 % at close sensor, and after *20* μs delay on the far one. Here, apparently, an intensive ion-stimulated desorption of hydrogen from the metal hydride surface begins.

An even greater (up to 70 %) increase in the sensor current is observed in the high-current (arc) discharge stage. The thermal mechanisms of hydrogen desorption are included in the arc due to decomposition of hydride phases.

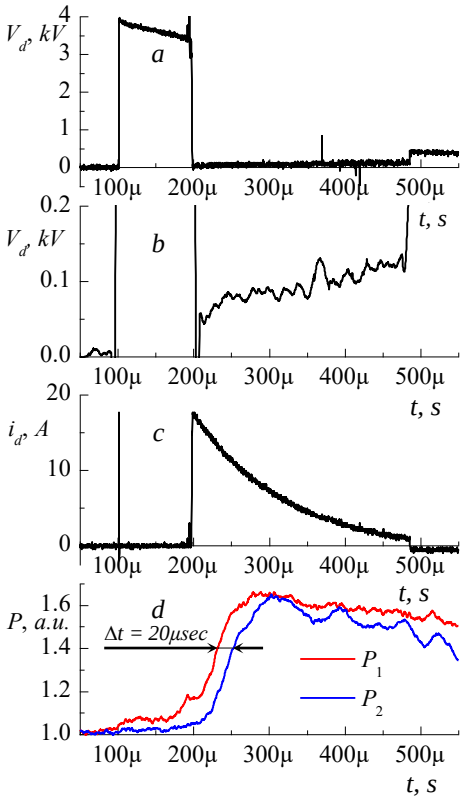

Fig. 2. The dynamics of the voltage (a, b) and discharge current (c), as well as the relative change in the current of the pressure sensors (d)

The gas temperature in the discharge can be judged from the propagation velocity of the pressure front. Calculated (see Fig. 2,d) from the current delay in the pressure sensors, the front velocity was ~ $5 \cdot 10^5$ *cm/s*, which corresponds to a hydrogen temperature of ~ 2500 *K*.

The duration of the high-voltage stage depended on the capacitor charge voltage and in our case was 100...500 *μs* at voltages of 2.5...4.0 *kV*. The energy released in the discharge at this stage was ~ 0.04 *J* at an average power of ~ 400 *W*.

The duration of the high-current stage varied in the range of 480...580 *μs*. The energy released in the discharge at this stage was ~ 0.3 *J* at an average power of ~ 1 kW.

Fig. 3 shows the velocity of gas front propagation during the discharge operation in high-current stage. It can be seen that theincrease in the power loaded to the metal hydride cathode leads to a sufficient increase in the velocity. The same figure shows the time dependence of the discharge transition into a high-current stage. One could approximate it with linear.

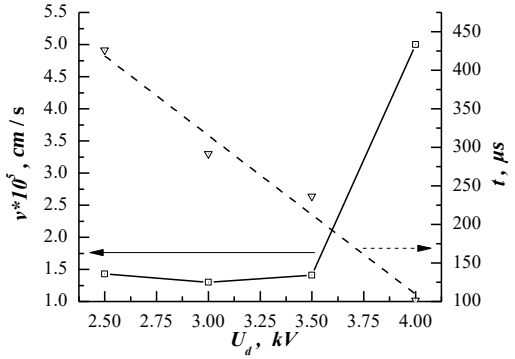

Fig. 3. Dependence of the gas front propagation velocity on the charge voltage and the transition time of the discharge to the high-current stage

To determine the amount of hydrogen released for the pulse, a PMI-2 manometer was used, which was installed at the outlet of the vacuum tube.The amount of desorbed hydrogen per pulse was calculated by measuring the relative change in pressure in the vacuum chamber with oscilloscope. Estimations have shown that approximately $1.5 \cdot 10^{-3}$ *cm³* of hydrogen under normal conditions is desorbed during the pulse.

CONCLUSIONS

Thus, it has been shown the possibility of creating a neutral hydrogen injector, where the amount and the propagation velocity of the hydrogen front can be regulated by a discharge current of a different duration. The proposed design is easy to manufacture and operate, and also has the ability to scale to produce more powerful neutral hydrogen flux. It is also possible to create several such cells located sequentially to control the front of the gas wave by programmatically starting individual cells.

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ВОДОРОДНЫЙ ИНЖЕКТОР НА ОСНОВЕ РАЗРЯДА ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ

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Представлены результаты работы импульсного инжектора нейтрального водорода на основе разряда Пеннинга с металлогидридным полым катодом. Источником химически чистого водорода служит гетерный сплав $Zr_{50}V_{50,}$ изготовленный в виде полого катода. Основное выделение водорода в газовую фазу происходит под воздействием разрядного тока (порядка 20 *А*) за короткий промежуток времени, порядка нескольких сотен микросекунд, в течение работы сильноточного режима разряда. Показано, что скорость распространения газового фронта зависит от разрядного тока и определяется температурой поверхности металлогидридного катода. Максимальное значение скорости распространения газового фронта получено на уровне $5 \cdot 10^5$ *см/с* при количестве водорода, десорбированного за импульс длительностью 400 *мкс* порядка $1{,}5 \cdot 10^{-3}$ *см³* при нормальных условиях и затраченной энергии 0.34 *Дж*.

ВОДНЕВИЙ ІНЖЕКТОР НА БАЗІ РОЗРЯДУ ПЕНІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

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Представлено результати роботи імпульсного інжектора нейтрального водню на основі розряду Пенінга з металогідридним порожнистим катодом. Джерелом хімічно чистого водню є гетерний сплав $Zr_{50}V_{50}$, який виготовлено у вигляді порожнистого катода. Основне виділення водню в газову фазу відбувається під впливом розрядного струму (близько 20 *А*) за короткий проміжок часу, близько декількох сотень мікросекунд, протягом роботи потужнострумового режиму розряду. Показано, що швидкість поширення газового фронту залежить від розрядного струму і визначається температурою водню. Максимальне значення швидкості поширення газового фронту отримано на рівні $5 \cdot 10^5$ *см/с* при кількості водню, що десорбується за імпульс тривалістю 400 *мкс* близько $1{,}5 \cdot 10^{-3}$ *см³* при нормальних умовах і витраченій енергії 0,34 *Дж*.