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INVESTIGATION OF EMISSION CHARACTERISTICS OF H^- ION SOURCE ON THE BASIS OF REFLECTIVE DISCHARGE WITH METAL HYDRIDE CATHODE

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Abstract. In this paper the theoretical and experimental investigations of emission characteristics of the plasma source of negative hydrogen ions have been carried out on the basis of the Penning discharge with the metal-hydride cathode. It is shown, that the use of the metal-hydride as a material of the cathode allows to increase gas and current efficiency of this device. This effect is determined by an ion-induced desorption of vibrationally excited hydrogen molecules from the metal-hydride surface.

Introduction

The high efficiency of D^- and H^- ions neutralization in energy range from 150 keV up to 1 MeV determines prospects of their use for a plasma heating. Recently without cesium plasma sources with volume generation of the negative ions H^- are intensively developed [1]. In such sources the negative ions are formed in the volume of the gas discharge as the result of the dissociative attachment of low-energy electrons to vibrationally excited hydrogen molecules $H_2(\nu\geq1)$. With increase of the oscillatory quantum number ν of the hydrogen molecule from 0 up to 5 the cross-section of dissociative attachment increases on five orders of magnitude and reaches value 10^{-16} cm^2. The energy threshold of this process is reduced from 3.73 eV (for ν=0) to 1.45 eV (for ν=5) [2]. Possible methods of the output increase of negative ions in sources with volume generation are the increase of density of low energy electrons in the discharge region, where process of dissociative attachment takes place intensively, as well as the injection in this region the highly excited molecules of the working gas [3]. One of the effective mechanisms of realization of this approach is the use of the plasma source on the basis of the Penning discharge with metal-hydride cathodes. It was shown in [4], that the application of such materials for electrodes in plasma-forming part of the source allows to increase the current of the extracted H^- beam, gas efficiency, and also to create compact and secure constructions.

The aim of this paper is searching of the effective mechanisms of the emission of vibrationally excited hydrogen molecules, which are necessary for increase of H^- ions output in the plasma source on the basis of the reflective discharge with the metal-hydride cathode.

Experimental

The scheme of experimental installation is shown in fig. 1. The flat reflective electrode represented the tablet of diameter 2 cm and thickness 0.7 cm, pressed from a powder of an alloy $Zr_{55}V_{40}Fe_5$+3%B_2O_3, saturated by hydrogen, and binding copper powder in the amount of 40 % from hydride mass. This composition ensures uniform filling of

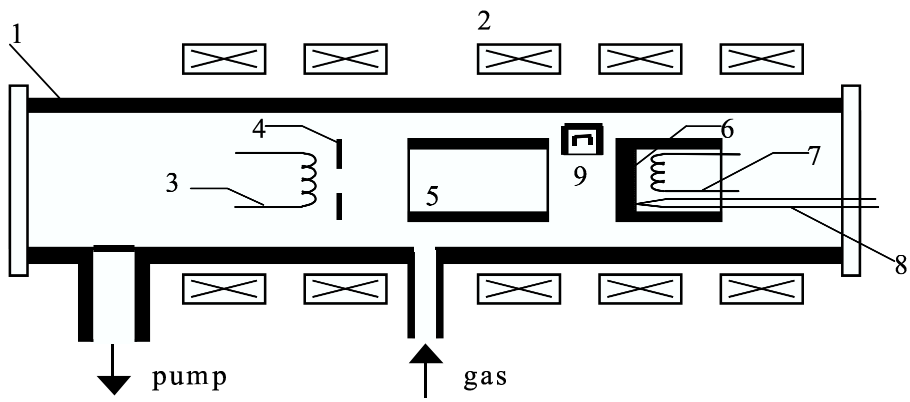

Fig. 1 The schematic diagram of experimental setup.
1 – vacuum chamber; 2 – electromagnet coils; 3 – filamentary cathode; 4 – washer; 5 – anode; 6 – metal hydride cathode; 7 – electric heater; 8 – thermocouple; 9 – greed analyzer.

hydrogen in a range of operating temperatures [5]. The wolframic heating cathode separated from the discharge gap by the earthed molybdenic diaphragm, with the hole at centre 0.6 cm. The diaphragm simultaneously fulfilled functions of the second reflective electrode in the Penning cell and anode of the electron gun. The heating cathode was under negative potential concerning ground potential. The residual pressure in the discharge chamber did not exceed $3 \cdot 10^{-4}$ Pa. As working gas the hydrogen was utillized, which depending on the problem of the experiment could move from a tank, metal-hydride block of the external filling on the basis of hydride $LaNi_5H_x$ or from a metal-hydride electrode. The amount of hydrogen, accumulated in the metal-hydride electrode, was 1.5 ndm^3. The temperature of the metal-hydride electrode was checked by chromel-alumel thermocouple. The range of the working pressures was from 0.1 up to 10 Pa. During experiments the efficiency of ions H^- formation in the regime of the induced hydrogen desorption in the case of the bombardment of the metal-hydride surface by electron or ion beams was investigated. In these cases the emission of excited hydrogen molecules and secondary low energy electrons happens. As a result the favourable conditions for the negative ion formation on the mechanism of dissociative attachment are formed. The electron beam current was 10 mA, and energy – 300 eV. The bombardment of the metal-hydride surface by positive hydrogen ions was carried out in the reflective discharge with cold cathodes. The dependences of the output of negative ions on the magnetic field have been investigated at various filling methods and hydrogen pressures.

Results and discussion

In fig. 2 the dependences of negative ion current on hydrogen pressure at the magnetic field H_0=0.06 T are presented for different methods of hydrogen filling. From this

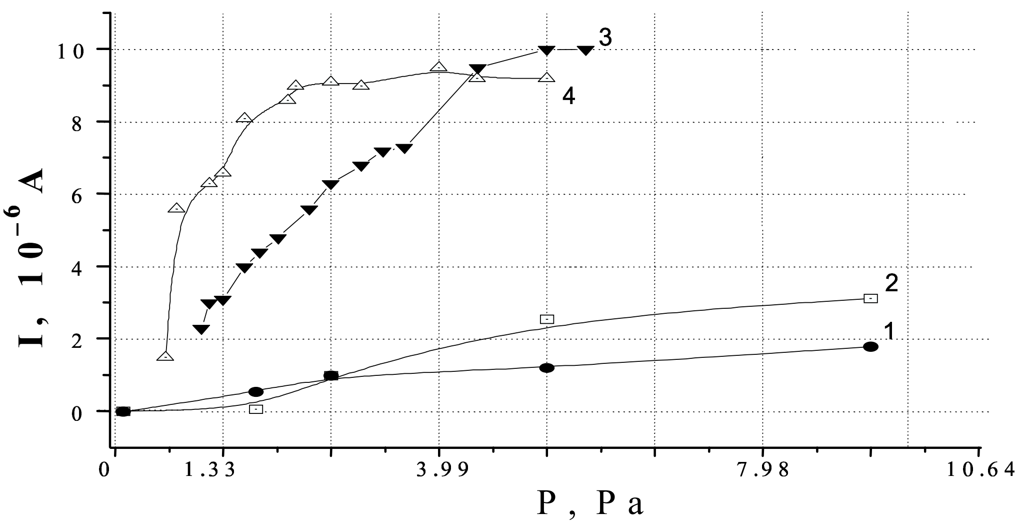

Fig. 2 The dependences of extracted current of negative hydrogen ions on hydrogen pressure.

1. Hydrogen from cylinder.
2. External metal hydride supply unit.
3. Metal hydride cathode irradiated by electron beam.
4. Metal hydride cathode irradiated by ion beam.

figure one can see that the saturation of the H- current occurs at hydrogen pressures 2.5-4 Pa for all methods of its filling. In all cases the power, transmitted to the metal-hydride cathode, was supported identical. The output of negative ions at the irradiation of the metal-hydride by the electron beam is characterized by the curve 3. In check experiments the same hydride-forming alloy, unsaturated by hydrogen, was utillized as the material of the target. In this case the hydrogen filling was carried out from a tank (curve 1) or from external metal-hydride source (curve 2). The target was irradiated by the electron beam with the same parameters. In this case the low-energy electrons were formed also as a result of secondary emissive processes. However output of negative ions was much less. It is determined by smaller concentration of vibrationally excited molecules. In the case of the ion bombardment (curve 4) the H^- output remains the same, as well as at the electron irradiation (curve 3). The ion beam current on the metal-hydride cathode was 4.3-5 mA. However the saturation of dependence is observed at smaller pressure of the working gas in the source. Hence the gas efficiency of the H^- source is greatest at the ion bombardment.

The theory of the ion-induced emission of the vibrationally excited hydrogen molecules was developed by us. The detailed presentation of this theory will be published later. Here only basic ideas and results of anticipatory calculations of the output of negative ions in the reflective discharge with metal-hydride cathodes have been presented. The image about a direct momentum transfer at the collision of flying high energy ions and atoms with the hydrogen atoms, dissolved in the metal, are put in the basis of the theory. As the particles of identical mass collide, and the volume density of hydrogen atoms, typical for the saturated metal-hydrides, about the density of solid hydrogen, then the efficiency of such process is high enough to ensure the intensive emission of hydrogen from the metal-hydride. The calculations, based on this mechanism, provide a linear dependence of the negative ions I^- current on the current I of positive hydrogen ions, bombarding the metal-hydride.

$$I^- = \sum_{k=1}^{\infty}\left[\left(1-\frac{\Delta_0 S}{S}\right)\cdot\left(1+\frac{\delta S_H}{S_H}\theta\right)\right]^{2k-2}\frac{\Delta S}{S}I$$

where ΔS is the cross-section of scattering back on a knot of the crystal lattice; $\Delta_0 S$ is the complete cross-section of scattering on a knot of the crystal lattice; δS_H is the cross-section of scattering on the hydrogen atom, dissolved in the metal-hydride; S_H is the sectional area of an internode, occupied by hydrogen atom; S is the sectional area of an unit cell of the crystal lattice of the metal-hydride; θ is the filling degree of free vacancies in the metal-hydride by hydrogen atoms.

For our experimental conditions this dependence looks like $I^- = 0.37 \cdot I$. This result is consistent with experimental data [4].

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References

[1] K.N.Leung, C.A.Hauck, W.B.Kunkel, S.R.Walhter. Sci. Instrum., **60** (4), 531 (1989).

[2] M.Allan and S.F.Wong, Phys. Rev. Lett., **41** (26), 1791 (1978).

[3] O.J.Orient, A.Chutjian, S.H.Alajazian. Sci. Instrum., **56** (1), 69 (1985).

[4] V.N.Borisko, Ye.V.Klochko, M.V.Lototsky and Yu.F.Shmal'ko, VANT (Probl. in Nuclear Science and Engineering), Ser. Physics of Radiation Damages and Radiation Material Science, **3(69)**, **4(70)**, 179 (1998).

[5] V.A.Yartys', I.Yu.Zavaliy, M.V.Lototsky, I.I.Bulyk, P.B.Novosad and Yu.F.Shmal'ko, F.Kh.M.M. (Physical-Chemical Mechanics of Materials), **27**, 26 (1991).