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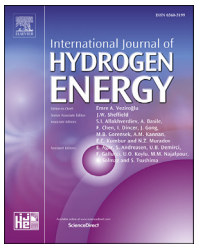

Short Communication

Effect of metal-hydride hydrogen activation on longitudinal yield of negative ions from PIG

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ABSTRACT

We present the results of the study of activated hydrogen, desorbed from a metal hydride cathode, effect on a PIG ability to emit negative hydrogen ions H^- in the longitudinal direction. It becomes possible due to a change in the discharge properties with the further output of negatively charged particles together with positive ions along the magnetic field. The separation of negative ions from an extracted flow of charged particles was carried out by an electromagnetic filter. The efficiency of the filter was investigated and the optimal external parameters for H^- ions separation were determined. The beam current of H^- ions has been obtained at the level of 5 mkA at an average discharge current 2 mA and a discharge voltage 5 kV.

Introduction

Traditionally, volume H^- sources are important ion sources for generating high-intensity neutral beams in problems of plasma heating and diagnostics [1], as well as proton beams for producing a number of medical radionuclides used in diagnosis and contact radiation therapy [2].

The production of an initial beam of negative ions is possible in two ways: by means of sources with surface and volume ionization. In the first case, significant intensity of H^- beam is achieved by cesium addition [3]. But using cesium complicates ion source operation and requires a careful stabilization of cesium injection and discharge parameters. In the second case, H^- ions are formed in the plasma volume by the mechanism of dissociative attachment of low-energy electrons to vibrationally/rotationally excited molecules of hydrogen [4]. These sources are more reliable, compact and environmentally friendly (cesium free). However, two significant drawbacks substantially limit their use. This is an extremely low intensity of H^- beam, as well as significant leakage of neutral hydrogen gas together with the extracted beam, which needs to be differentially pumped to avoid large stripping losses.

Mentioned problems, apparently, could be solved by applying a Penning Ionization Gauge (PIG) with a metal-

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hydride cathode (MH-cathode). Such a source has compact dimensions, does not require an external gas feeding, hydrogen stores in a chemically bound state in the MH-cathode and desorbs in an atomic state at the required rate under the discharge current impact. The desorption process is nonequilibrium and leads to the formation of vibrationally/rotationally excited H_2^* molecules [5]. This is what determines the main advantage of using a MH-cathode. The existing sources are two-staged. In the first stage hydrogen molecules are excited by high-energy electrons, and in the second one H^- ions are produced by the mechanism of dissociative attachment of low-energy electrons to excited hydrogen molecules [1,2,4]. In the case of a MH-cathode there is no need to waste energy on pre-exciting hydrogen molecules and the first stage could be omitted [5].

Apparently, H^- ions are formed most effectively in near-cathode region, where there is a large number of H_2^* molecules and low-energy electrons.

Commonly the extraction of H^- ions is perpendicular to an external magnetic field through an aperture in the anode. But when one of the cathodes in the PIG is changed to a metal-hydride one the properties of the discharge significantly change. It happens due to hydrogen desorption in activated state, which lead to an additional discharge regime appearing, when at high discharge voltage the negative current yields in the longitudinal direction through an aperture in the cathode [6]. If there are H^- ions in the extracted flow, the source design could be greatly simplified by the unification of the used parts. For instance, simple replacement of a cathode by a metal-hydride one and the reverse of polarity on pulling electrodes could obviously make a negative ion source from traditional positive one.

At the same time metal-hydride hydrogen activation could be the way to enhance volume source brightness due to the excluding the stage of pre-exciting hydrogen molecules in plasma. So, our work is aimed to the investigation of this phenomenon of emitting negative hydrogen ions in the longitudinal direction from the PIG with the MH-cathode.

Experiments

A schematic illustration of the experimental setup to study H^- yield from the PIG is shown in Fig. 1.

The discharge cell consists of an active water-cooled MH-cathode 1, a tubular anode 2 and a copper passive cathode 3 with a central aperture. Behind the aperture in the passive cathode an electromagnetic filter is set. It includes a grid 4 for positive ions retarding, a magnetic coil 6 to divert electrons, a collector of diverted electrons 5 and a collector of extracted axial beam of H^- ions 7. Langmuir probes 8 are set along discharge axis on the half distance between anode and cathode.

The cell is placed in an external uniform longitudinal magnetic field $H_{z0} = 0 - 1000$ G. The coil 6 creates a reverse magnetic field H_{coil} between the cathode 3 and the collector 7, so that total field H_{z0} in the gap is enough to divert electrons on the collector 5.

The MH-cathode 1 is produced from hydride-forming alloy $Zr_{50}V_{50}$ by a method including melting of the alloy, its activation and filling with hydrogen, hydride crushing and mixing it with a binder and pressing. The saturation coefficient of alloy with hydrogen is ~190 cm^3/g and the quantity of hydrogen stored in the MH-cathode is ~900 cm^3 under normal atmospheric conditions. For pressure stabilizing, the MH-cathode has water-cool and its temperature is not exceed 20 °C, that much lower than the temperature of thermal destruction of hydride phases. Therefore, H_2^* desorption is determined only by a discharge current and is provided mainly by ion-stimulated processes from the surface of metal hydride [6,7].

All investigations are carried out only on hydrogen desorbed from the MH-cathode without external gas feeding at residual pressure in a vacuum chamber $5 \cdot 10^{-6}$ Torr.

Results and discussion

Activated hydrogen desorbed from the MH-cathode impacts on the Penning discharge properties [6]. It appears that at high discharge voltages $U_d > 3.5$ kV a flow of negatively charged particles including negative ions and electrons along with positive ions starts yielding along the external magnetic field through an aperture in the cathode. The discharge voltage when it happens as well as total collector current slightly depend on the geometry of a cell and other external factors like magnetic field or pressure, for instance. However, if a MH-cathode is applied, there is always described above regime of the discharge. If it's not, the PIG works only as a source of positive ions.

Thus, MH-cathode applying in PIG is not only provide the conditions for the longitudinal yield of negative ions from the cell, but also significantly increases the efficiency of H^- ions formation due to hydrogen activation [5].

The problems that arise in this case are the optimization of the hydrogen consumption stored in the MH-cathode and the necessity of H^- ions separation from the total particle flow.

The rate of hydrogen desorption is essentially nonlinear and depends on a MH-cathode temperature [8]. Commonly it heats by ions bombardment from plasma. Therefore, to stabilize the pressure in a vacuum chamber, as well as to optimize the consumption of stored hydrogen, the temperature of the MH-cathode must be stabilized. We have realized this with additional cathode water-cool. So, the MH-cathode temperature kept unchanged and was approximately 20 °C, which, is lower than the thermal decomposition of hydride phases of $Zr_{50}V_{50}$ alloy. However, it does not lead to qualitative changes in the discharge work [6].

When a metal-hydride cathode is irradiated with an ion beam, hydrogen desorption occurs in two ways: from the sample volume due to thermal decomposition of hydride phases and from the thin surface layer due to ion-stimulated mechanism. A physical model of these processes is considered in Ref. [7]. Obviously, the forced cooling of the MH-cathode keeps only the second way – desorption due to ion-stimulated mechanism. In particular, this is shown in the fact that the measured plasma density with cooled MH-cathode ($n = 3 \cdot 10^9$ cm^{-3}) is lower than without water-cool ($n = 7 \cdot 10^9$ cm^{-3}), but higher than in the case of experiments without MH-cathode ($n = 1.5 \cdot 10^9$ cm^{-3}). Due to the stabilization rate of hydrogen desorption, the same values of plasma