NEUTRALIZATION OF H^- IONS ON THE PLASMA TARGET

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ABSTRACT

This work describes a plasma neutralizer for ion beams and investigation results of conversion of H^- ions into neutral atoms on the plasma target. The working medium of neutralizer is thermal plasma (potassium, cesium). The design of neutralizer allows to receive an integrated density of a plasma target ~ 10^{15} 1/cm^2 a degree of ionization of plasma may be adjusted. Dimensions of the neutralizer - diameter of 240 mm., length - 350 mm. Power consumption - 10 kW. In this work coefficient of conversion of H^- ions into neutral atoms and angular scattering of neutral atoms on a plasma target depending on ions energy, thickness of a target and degree of plasma ionization were measured.

INTRODUCTION

The reception of the accelerated beams of H^o neutral atoms is based on neutralization of hydrogen negative ions in various targets. The plasma targets, in which a coefficient of H^- ions conversion obtains 80 - 85%, are rather perspective for these purposes [1,2]. At formation of high brightness of neutral atoms beams of high energy, the important question is the influence of changing target on angular scattering of neutral atoms beams, as the emittance of H^o beam includes a component caused by particles scattering in a target.

The present work is devoted to research of neutralization of hydrogen negative ions beam with energy 30 - 200 keV on an alkaline plasma target.

EXPERIMENTAL SETUP AND PROCEDURE

The plasma target was executed as a separate block. A schematic of this target is shown in figure1.

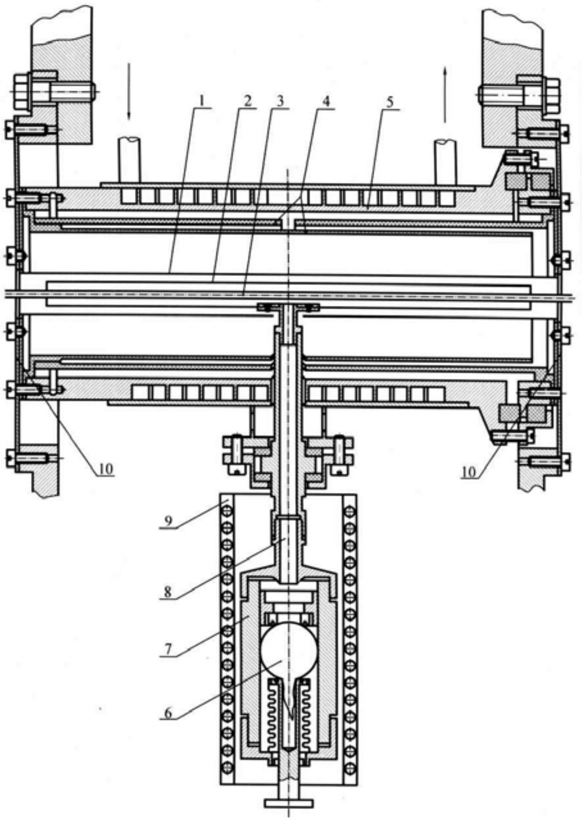

Figure 1.

The thermal alkaline plasma was formed by means of surface ionization in a heated up to high temperature tungsten ionizer 2. The ionizer was placed inside a heater 1. The heater was made from sheet tungsten. The power supply of a heater applied through the current-carrying electrods10, which contained temperature expancions. The thermal screens 4 executed from graphite were placed around the heater. The shell of a target 5 was cooled by flowing water. The working substance (potassium vapors) was supplied into the ionizer from a crucible 7. It was made of stainless steel. Its design excluded a drop emission of alkaline metal in the ionizer, and thus it provided a stable work of a target. The crucible was connected with ionizer by vapor line 8, which also represented the thermal bridge between ionizer and crucible. The temperature of crucible as well as vapor pressure in the ionizer, were adjusted with the help of the heating stove 9 and were measured by the thermocouple.

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The working substance contained in the soldered glass ampoule 6. The ampoule could be broken in vacuum after the obtaining of necessary temperature of crucible and ionizer. The electrical insulation of plasma target elements was carried out with the help of high-temperature ceramics from BeO. On the input and output of the target, water-cooled conic cups, which allowed reducing the outlet of working substance from a target into the vacuum, were placed.

A supply current of the heater 1 creates a magnetic field in the area of ion beam interaction with plasma. To exclude the influence of this field on ion beam, the heater 1 was powered by pulse current with duration 10 ms, with amplitude of a current in a pulse up to 2500 A and frequency 50 Hz. Such design of a plasma target and stabilized system of a power supply, allowed to heat the target ionizer up to temperature in an interval from 1000 K up to 2800 K, and to stabilize it for a long time with accuracy not worse 5%. The temperature of ionizer was measured by the thermocouple W-Re and also with the help of radiation pyrometer. In intervals between pulses of power supply, the measurements of parameters of ion beams were carried out.

The design of neutralizer allows to receive an integrated density of a plasma target ~ 10^{15} $1/\text{cm}^2$ a degree of ionization of plasma may be adjusted. Dimensions of the neutralizer - diameter of 240 mm., length - 350 mm. Power consumption - 10 kW.

The definition of parameters of plasma target, working in a stationary mode, causes complexities connected with high temperature of plasma formative channel, and also with a target design.

The thickness of plasma target was determined on H^- beam attenuation after the interaction with a plasma target.

$$t_{pl} = \frac{1}{\sigma_{-10}} \ln \frac{I_2^-}{I_1^-}$$

where: I_1^- - H^- ion current at the switched off target; I_2^- - H^- ion current at the switched on target.

At calculations, the cross section of electron detachment from a negative ion by electronic impact σ_{-10} was used [3,4]. We supposed that size σ_{-10} at the collisions with ions is the same, as at the collisions with electrons.

The parameters of a plasma target were also determined according to working substance consumption.

The degree of plasma ionization was determined on known experimental values of ionization efficiency of potassium on a tungsten surface [5] and also it was determined on the attenuation of H^- and H^+ beams in a plasma target.

In our experiments the maximal value of thickness of a plasma target $t_{max} = 5 \cdot 10^{14} \text{cm}^2$ was obtained. The degree of ionization ≤ 80 %, that is coordinated to results of work [6].

Schematic diagram of the experimental setup is shown in fig.2.

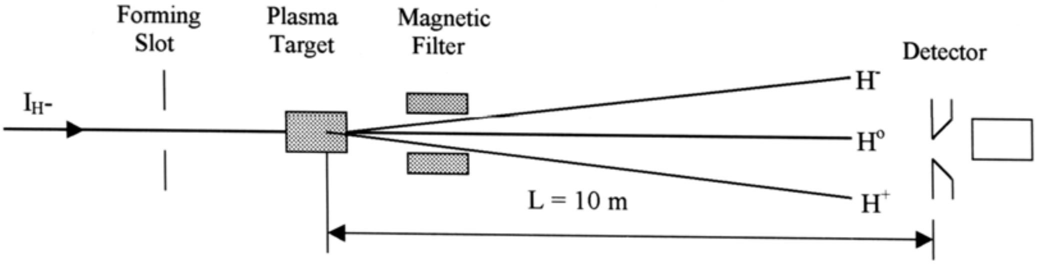

Figure 2. Schematic diagram of the experimental setup.

Tape H- ions beam, with energy 30 - 200 keV, angular divergence $2 \cdot 10^{-5}$ rad and ion current in a beam 10 μA, was directed to a plasma target. After interaction with a plasma target, the components of a beam H^-, H^o, H^+, were divided with the help of a magnet. A secondary-electron multiplier could register each of a beam component. The registration of structures of space distribution of H^- and H^o beams density was curried out by the detector, consisting of a diaphragm (size 0,01 x 5 mm), a secondary - electron multiplier and a stepper motor, which moved the detector discretely along the ion beam with a step 5μm. A distance from the interaction chamber to the detector (area of ions drift) was 10 m., thus the angular resolution of experimental setup was $1\cdot 10^{-6}$ rad. At measurement of conversion coefficient and angular characteristics of ion beams, the vacuum in the area of ion beam drift was not worse 1×10^{-8} Torr. The thickness of a gas target on the length of a drift area did not exceed $t < 4\times10^{12}$ cm^2, which is more than two orders of magnitude less than a thickness of changing target for ion beam. Therefore a drift area did not lead to large errors in the measurements.

At measurement of conversion coefficient η of H^- ions into neutral atoms, the complete currents of H^-, H^o, H^+ ions were measured. The experimental value η was determined by formula

$$\eta = \frac{I^o}{I_1^-}$$

where: I^o - neutral atoms equivalent current ; I_1^- - H^- ions current at the switched off target.

The scattering angle of neutral atoms at the fixed thickness of a target was determined by a widening of space distribution of H^o current density in comparison with the width of space distribution of primary H^- current density by formula:

$$\theta_{1/2} = \frac{1}{2L}\sqrt{(\omega_\Sigma)^2 - (\omega_-)^2}$$

where: ω_Σ - width of distribution of neutral atoms current in view of initial divergence of H^- ions beam; ω_- - width of distribution of H^- ions current density; L - distance from the center of a plasma target up to the detector.

RESULTS AND DISCUSSION

In our experiments the maximal thickness of a plasma target was $t_{max} = 5\cdot10^{14}$ cm^2. At this thickness of a plasma target and energy of ions E_{H^-} = 200 keV, we have obtained conversion coefficient η = 40%.

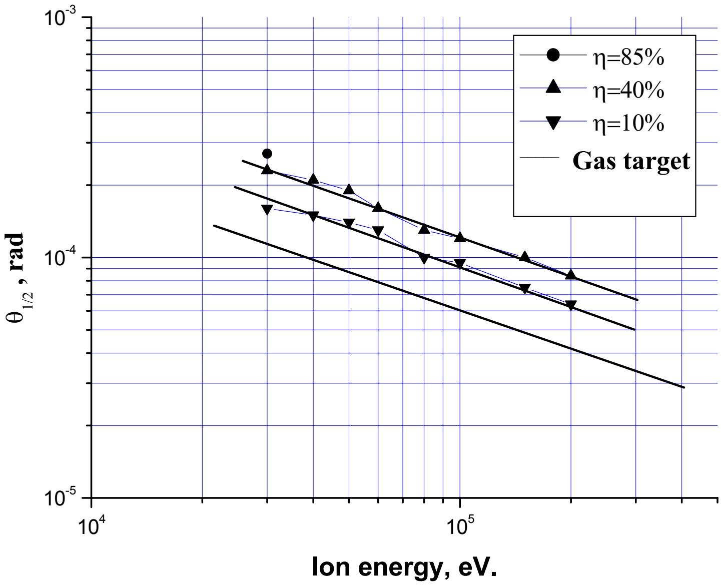

Figure 3. Scattering angle of the neutral atoms beam as a function of H^- ions energy.

Therefore measurements of a scattering angle of the neutral atoms beam $\theta_{1/2}$ as a function of H^- ions energy were carried out in two modes (figure 3):

- Conversion coefficient $\eta = 10\%$
- Conversion coefficient $\eta = 40\%$

In the same figure the scattering angle of neutral atoms $\theta_{1/2}$ is shown at value $\eta = 80\%$ ($E_{H^-} = 30$ keV). Scattering angle of neutral atoms $\theta_{1/2}$ received on a gas hydrogen target is shown by full line.

Analyzing the submitted results, it is possible to conclude, that at neutralization of H- ions on a thermal alkaline plasma target, the scattering angle of neutral atoms $\theta_{1/2}$ changes with energy as $\sim E^{-1/2}$. Moreover, the scattering angle $\theta_{1/2}$ depends on thickness of a plasma target. The increase of a plasma target thickness, at which a conversion coefficient changes from 10 up to 40 %, results in increase of a scattering angle by 30 - 40%. And at plasma target thickness when the conversion coefficient is maximal, the scattering angle $\theta_{1/2}$ of H^o ions increases in 2-3 times in relation to the appropriate value for a gas target.

For practical applications it is interesting to make a comparison of H^o accelerated beams, received on gas and plasma targets. The quality of a beam can be characterized by its brightness B. Supposing that the ion beam is Gaussian, and B_{H-} is a maximal brightness of H^- beam, then the maximal brightness of B_o neutral beam is possible to present as in the work [7].

$$B_0 = B_{H-}\left[\frac{\eta_{\max}}{1+\left(\theta^0_{1/2}\big/\theta^-_{1/2}\right)^2}\right]$$

where: $\theta^-_{1/2}$ - H^- beam divergence.

The B_O/B_{H-} ratio as a function of H^- beam divergence for gas and plasma targets is submitted in figure 4.

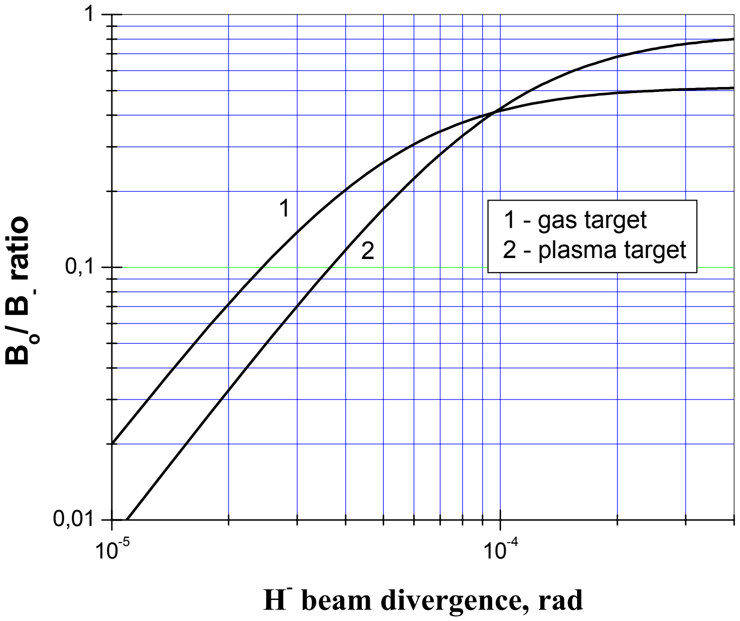

Figure 4. The B_O/B_{H-} ratio as a function of H^- beam divergence for gas and plasma targets.

At calculations the following values received experimentally were used: E_{H-}= 200 keV; $\eta_{\max}^{gas}$ = 52%; $\eta_{\max}^{pl}$ = 80%; $\theta_{1/2}^{gas}$ = 5·10^{-5}rad; $\theta_{1/2}^{pl}$ = 1·10^{-4}rad.

As it follows from the figure, the relative brightness of H^{o} beam, received on a plasma target, is higher than the relative brightness of H^{o} beam, received on a gas target, provided that the initial H^{-} beam divergence is $\theta_{1/2}^{-} \geq 10^{-4}$rad.

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