

Increase atom/molecular ratio of the hydrogen discharge

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Abstract. The high atomic to molecular ion ratio is important for hydrogen ion sources, but in the usual low-temperature hydrogen plasma the molecular ion component is dominating. Proton component can be increased by means of increasing plasma temperature, but in this case energy spectrum will be widened. Single electron collision with a hydrogen molecule may not only lead to the formation of the molecular ion, but also results in the formation of the proton. However, the cross section of the second process is much smaller than of the first (approximate ratio between them being 1:200). Thus, a single electron-molecule collision cannot be an efficient means of proton formation. Atomic hydrogen ions are produced by ionization of neutral hydrogen atoms. As a rule, a lifetime of neutral atoms is too short for ionization. The increase of the hydrogen atom lifetime by reducing the wall recombination coefficient allows us to get more protons. In this work we study the influence of water vapor injection on atom/molecular ratio of hydrogen plasma.

1. Introduction

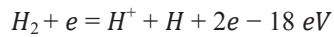
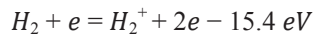
Nowadays ion sources have a large range of applications. As a rule, ion sources consist of a plasma source and an electro-optical system. Ions are drawn from plasma by accelerating potential and ion beam is formed by optic system. If plasma is made of molecular gas (like hydrogen) the ion beam will contain atom and molecular components. The cold plasma created by compact Penning source usually has a low atom/molecular ratio [1]. Atom component can be increased by means of increasing plasma temperature, but in this case energy spectrum of the ion beam will be widened. And in the compact sources it is impossible to increase discharge power.

In particular applications, for example, in Gas-filled Neutron Tube (GNT), usually only the atom component is needed. Energy spectrum of ions from Penning Plasma Source (PPS) (which is used in GNT) is a narrow peak and all particles have the same energy. So, the energy of deuteron is twice higher than the energy of individual deuteron bound in molecule ions. The increase in atom component from 5% to 35% can make GNT 3 times more effective, and 100% of atom component increases GNT efficiency sevenfold.

2. Main elementary processes of ions formation in a hydrogen plasma

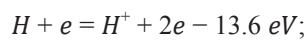
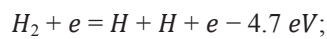
Single electron collision with hydrogen molecules can lead to the generation of molecular ions or protons [2]:



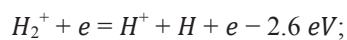
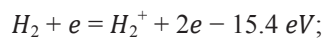


But interaction cross-section of second process is far less than that of the first (their ratio being 1:200) [3]. Thus, a single electron-molecule collision cannot be effective for generation of protons. In the low temperature plasma the main processes of atomic hydrogen ions formation are [2]:

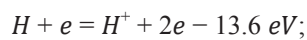
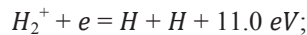
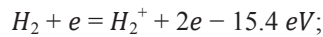
1. Dissociation of molecules with subsequent ionization of atoms:



2. Ionization of molecules with subsequent dissociation of the molecular ion:



3. Dissociative recombination:



Thus, formation of protons in plasma normally goes through ionization of hydrogen atoms. But lifetime of hydrogen atoms is very short because there is no confinement by magnetic field and they recombine on the walls. Thus, their lifetime strongly depends on recombination coefficient of plasma-facing components.

Table 1. Recombination coefficients for various materials.

Material	r_H (recombination coefficients)
Silex	7×10^{-4}
Pyrex	$7,5 \times 10^{-4}$
Aluminium (Al_2O_3)	10^{-3}
Copper	0,19
Iron	0,17
Nickel	0,18

Table 1 shows recombination coefficients for various materials. Materials with a lower coefficient are usually dielectric. Thus, if plasma-facing components are coated with a dielectric layer, then lifetime of hydrogen atoms will increase.

3. Experimental study of the influence of water vapour injection on atom/molecular ratio

The easiest way to modify plasma-facing components and decrease recombination coefficients is to form a dielectric oxide layer.

3.1. Experiment in mirror machine PR-2

The experiment on PR-2 [4] shows that small water vapor injection can significantly change ion spectrum. In this case intensity of impurities peaks is less than 5% and the partial pressure of water vapor is less than 3% of total pressure.

The increase in atom/molecular ratio takes place only after 30 minutes after the thermo-chemical water vapor source (TCWVS) [5] is turned on and remains after shutdown of TCWVS for a long time. This delay points onto the wall surface processes decreasing the recombination coefficient.

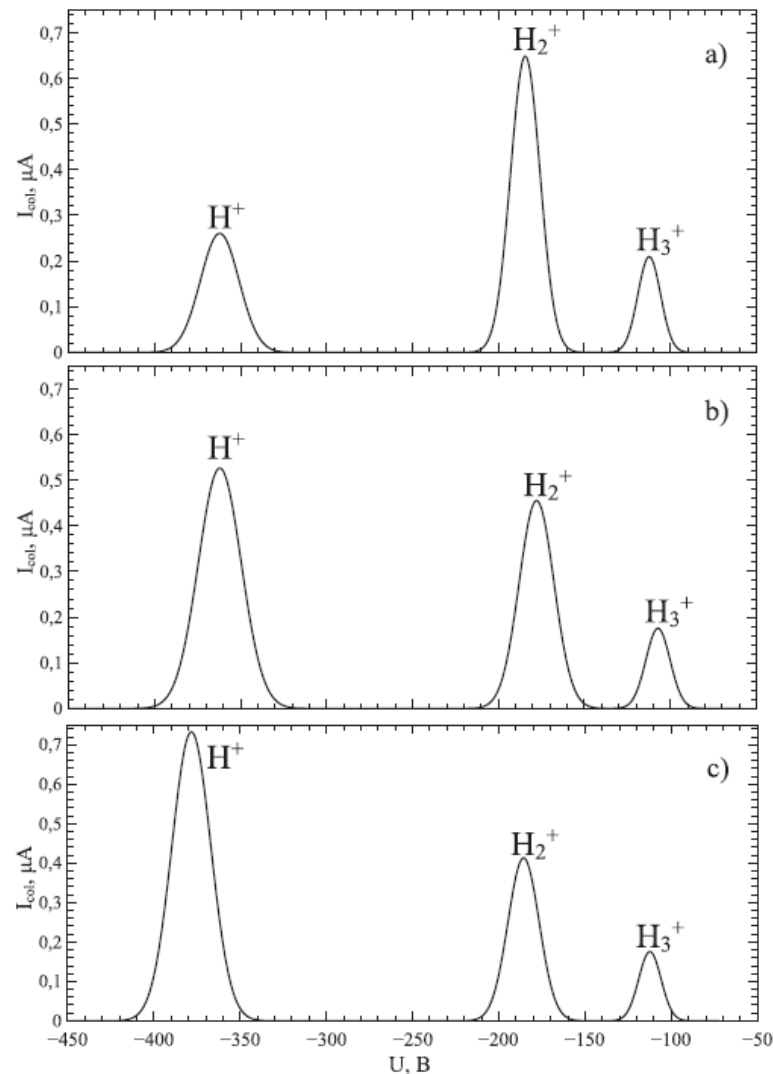


Figure 1. Ionic composition of hydrogen plasma in the PR-2:

- a) without water vapor injection;
- b) after 30 minutes, TCWVS is on;
- c) after 1 hour, TCWVS is off

3.2. Experiment in the installation for studying small-sized ion sources:

The same experiment was performed on a small-sized PPS [6]. Plasma-facing components of PPS are made from stainless steel which can form the oxide layer, but our experiments have shown that this layer is nonsufficient to achieve the expected effect.

4. Conclusion

The materials of plasma-facing components with a lower recombination coefficient (dielectrics) can lead to increase in atom/molecular ions ratio in hydrogen plasma. The simplest and the cheapest way

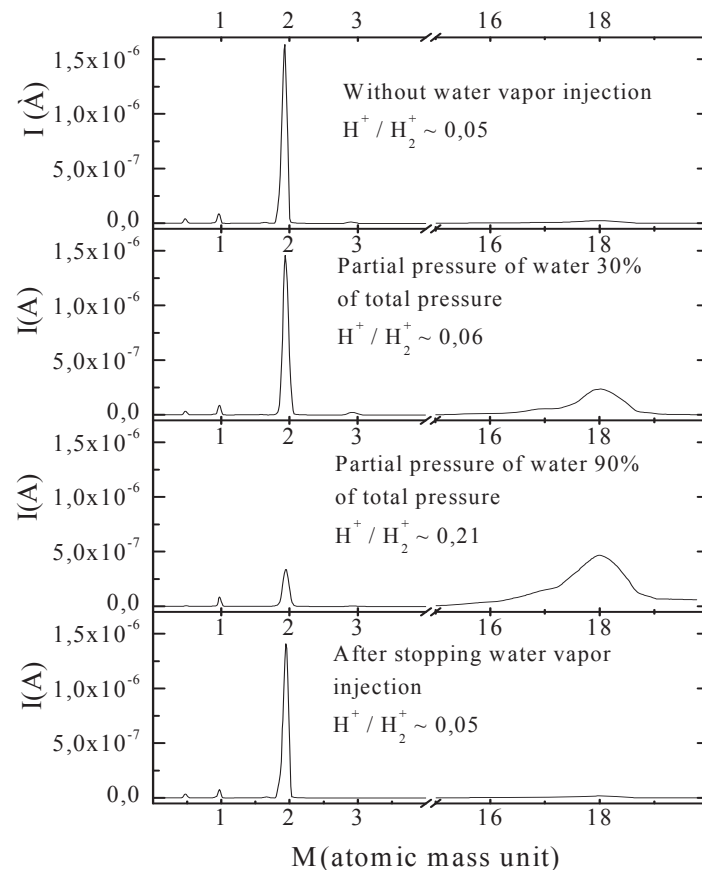


Figure 2. Relations of mass-spectrum and water vapor injecting.

to change recombination coefficient is injection of small admixtures of oxygen or water vapor into a chamber of hydrogen plasma source. For this it is necessary to use materials which form dielectric oxide layers with low recombination coefficients. Thus the lifetime of hydrogen atoms and, correspondingly, the atomic ions output from the source can be increased.

References

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