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Measurements of Probability for Heterogeneous Recombination of Hydrogen Atoms on Surfaces of Fusion Relevant Materials

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Abstract We have performed experiments in plasma afterglow in order to determine the recombination coefficients of various fusion relevant materials such as graphite and tungsten. Plasma was created by means of a radio frequency generator in a mixture of argon and hydrogen at the pressure around 100 Pa. The degree of dissociation of hydrogen molecules was found to be between 0.1 and 1. The H-atom density was measured by Fiber Optic Catalytic Probe. The recombination coefficient was determined in two ways: (1) by measuring the atom densities in the presence of different materials in the plasma reactor and comparing them to the densities measured in the presence of a material with a known recombination coefficient and (2) by measuring the axial profile of the H-atom density and using Smith's side arm diffusion model. The recombination coefficients were found to vary with the material and surface structure.

1. Introduction

Weakly ionized plasma is the foundation of important modern industrial and research technologies as a source of free atoms with a low kinetic energy, suitable for surface engineering. The most popular industrial uses of weakly ionized oxygen plasma are: surface activation, selective etching, surface cleaning, etc.[1,2] However, weakly ionized hydrogen plasma can be used for removing of oxide layers and it is useful also in other applications that require reduction reactions.

Movement of free atoms is of importance in the fusion reactors. Unlike charged particles, free atoms are electrically neutral and as such are not affected by the magnetic field which enables them to move freely throughout the area. One of the quantities that describe the interaction of free atoms with the solid state surfaces is recombination coefficient. It is defined as the probability that an atom recombines on a solid state surface.

So far various techniques for determination of the recombination coefficient have been described [3-10]. While emission [7,8] and absorption [9,10] spectroscopy techniques offer fast measuring, the Smith side arm diffusion method [3,4] is distinguished by simplicity of operation and to some extent independence of absolute atom density.

2. Experimental

The experiments were performed in the plasma reactor made of 85250 borosilicate glass tube with the length of 1 m and the inner diameter of 3.6 cm. The afterglow chamber of the tube branched out to two additional side tubes of a 3 cm inner diameter and 8.5 cm length in which two probes were respectively placed. The system was pumped with a two stage rotary pump with the maximum flow of 28 m^3/h. Hydrogen and argon were conducted through precise vacuum valve. The plasma was generated by an inductively coupled radiofrequency generator with a nominal power of 700 W and frequency of 27.12 MHz. The pressure was measured with a Baratron gauge.

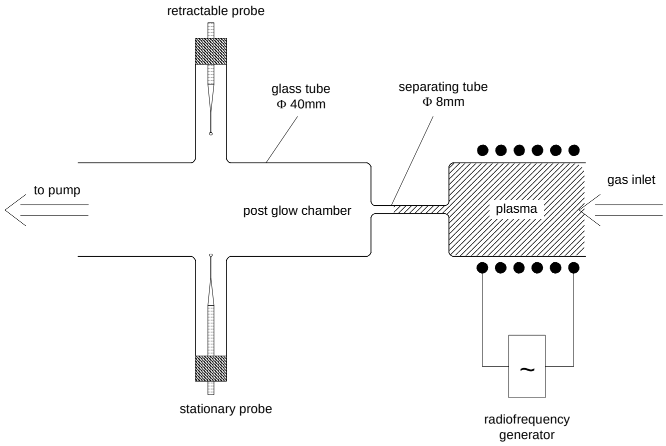

Figure 1. The sketch shows the post-glow chamber with its two side tubes. A retractable probe is placed in the upper tube, a stationary probe in the lower tube.

A nickel and copper fiber optic catalytic probes [11,12] were used to measure the H-atom density. The copper probe was kept in the main part of the post glow chamber as a reference while the nickel probe was retracted along its side vessel. The side vessel itself was closed with a metallic part which ensured that the H-atom density at the end of the tube was practically zero due to the recombination. The axial H-atom density profile was measured inside the side vessel. The inner walls of the side vessels were covered by different materials with different recombination coefficients. For covering the inner walls we used two aluminium foil cylinders with a layer of tungsten and carbon with the thickness of 10 nm, which was deposited by means of plasma deposition. We have also measured the axial density profile inside a Teflon cylinder and inside uncovered wall. The profiles were measured at different pressures ranging from 60 Pa to 280 Pa.

In the second part of the experiment we have placed a piece of investigated material in the afterglow chamber and measured the H-atom density in its proximity. Unlike the side vessel axial profile measurements, these measurements hold more of a qualitative value rather than quantitative.

3. Results and discussion

Rather than the density itself we state the ratio of the density in the side vessel to the density in the main vessel. The H-atom density is a function of many parameters, of which not all can be under control. By using the ratio of the densities, we eliminate all but two effects that define the axial profile – the recombination coefficient of the wall and the mean free path of the H-atoms.

While we could very well observe the decline of the atom density along the side vessel, we couldn't measure the actual zero density because at densities lower than a tenth of the density in the main vessel, the signal was drowned in noise. Recombination coefficients were calculated by fitting the numerical model to experimentally obtained data, as shown on Figure 2. All recombination coefficients were found to be lower than we had initially expected, either because of our own experience or because values reported by other authors [5]. This could be attributed to the peculiar nature of the measured surface in the case of tungsten and carbon. Whereas we, as well as other authors, had previously used bulk material, this time measurements were performed with a thin deposited layer. Our results are listed in Table 1. The recombination coefficient was found sufficiently low that the density profile was a linear one. Therefore the exact value of the recombination coefficient could not be determined by the model.

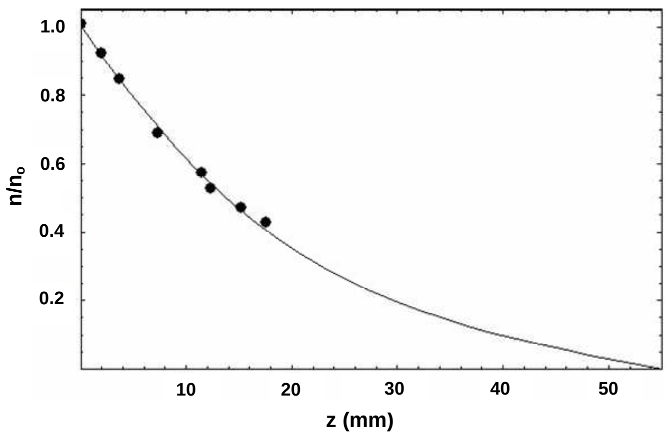

Figure 2. Fitting the experimental data to the numerical model for tungsten

The results of the second part of the experiment were found to be less conclusive. At the presence of a gold foil with a recombination coefficient 0.18 [14], the H-atom density dropped to approximately 20% of the original value. In the presence of a tungsten foil the density was found to be somewhat higher. However, at the presence of a small carbon cylinder the density dropped below the measurement threshold, which indicates that in the bulk form carbon has a considerably higher recombination coefficient. This is most probably because while the surface of the deposited carbon film is smooth, the bulk carbon is porous.

Table 1. Values of recombination coefficients for different materials determined by analyzing the axial hydrogen atom density profiles.

Material	Recombination coefficient	Standard deviation
85250 borosilicate glass	0.0032	0.0011
Tungsten	0.0025	0.0011
Carbon	0.0043	0.0018
Teflon	$< 10^{-3}$	

4. Conclusion

Recombination coefficients of 85250 borosilicate glass, tungsten, carbon and Teflon were calculated by analysis of axial H-atom density profile in a side vessel of a plasma reactor by Smith's side arm diffusion method. The recombination probability was found to be 0.0025 for tungsten, 0.0043 for graphite and 0.0032 for borosilicate glass.

5. References

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