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H atom generation and loss kinetics in VHF plasmas

S. Nunomura[1], H. Katayama[2], I. Yoshida[3]

[1] *National institute of advanced industrial science and technology (AIST), Tsukuba, Ibarak, 305-8568, Japan*
[2] *Panasonic corporation, Kaizuka, Osaka 597-0094, Japan*
[3] *Photovoltaic Power Generation Technology Research Association Minato-ku, Tokyo 105-0011, Japan*

We study hydrogen (H) atom generation and loss kinetics in capacitively coupled low pressure H_2 plasma. The H atom density has been measured by using vacuum ultra violet absorption spectroscopy (VUVAS), under two different electrode setups: conventional diode (direct) and triode with an intermediate mesh (remote). In the triode setup, the H atom density is strongly reduced across the mesh electrode; it varies from 10^{12} cm^{-3} to 10^{10} cm^{-3} across the mesh. The fluid model simulations for VHF discharges have been performed to study the details of the H atom generation, diffusion and recombination kinetics.

A H atom is widely known to be reactive species, which reacts easily with other gas-phase species and various material surfaces. So, its reaction kinetics often plays key roles in plasma processing. So far, the H atom kinetics has been studied in “direct” plasma configuration. However, it is not studied for the “remote” plasma configuration that has advantages of less-ion bombardment and reduced surface charging.

Here, we study the H atom kinetics in capacitively-coupled very high frequency (VHF) discharges not only in direct (diode) configuration but also in remote (triode) configuration. The H atom density is experimentally determined from VUVAS [1]. The fluid model simulations of VHF discharges are performed to study the H atom kinetics.

Figure 1 show the meausrement results of the H atom density, n_H, in VHF H_2 discharges [2]. It is found that n_H is of the order of 10^{12} cm^{-3} in the discharge region, whereas it is of the order of 10^{10} cm^{-3} in the processing region under the remote configuration. For our mesh geometry, i.e., a mesh with 0.2 mm in thickness and 36% in aperture ratio, n_H varies two orders of magnitude across the mesh.

Figure 2 shows the simulation results. As shown Fig. 2(a), n_H is broadly peaked at the middle of the discharge region. The peak value is recognized to be ~1.0 x 10^{12} cm^{-3}, which is in good agreement with that measured by VUVAS in this study. The H atoms are generated mainly in the discharge region, via two processes: the electron impact dissociation (e + H_2 => e + 2H), as shown in Fig. 2(b), and the ion-molecule reaction (H_2^+ + H_2 => H_3^+ + H), as shown in Fig. 2(c). We also notice that in the processing region, the generation rate of the H atoms, g_H, is negligibly small. This is because the electron temperature is rather low compared with the threshold energy of the electron impact dissociation. As for the loss of H atoms, the electron attachment (e + H => H^-), shown in Fig. 2(d), is negligibly small, compared with the generation. The loss of H atoms is thus dominated by the surface recombination on the electrode. In the presentation, more details of experimental and simulation results are presented.

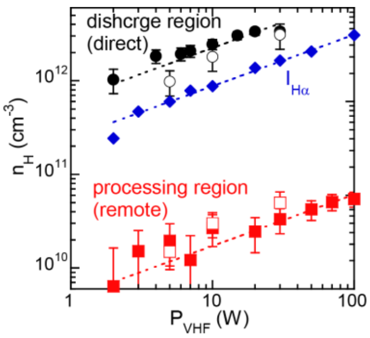

Fig. 1. H atom density, n_H, & Balmer emission intensity, $I_{H\alpha}$, vs. the discharge power, P_{VHF} at H_2 gas pressure of p = 0.3 Torr.

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[2] S. Nunomura, H. Katayama and I. Yoshida, *Plasma Sources Sci. Technol.* **26** (2017) 055018.

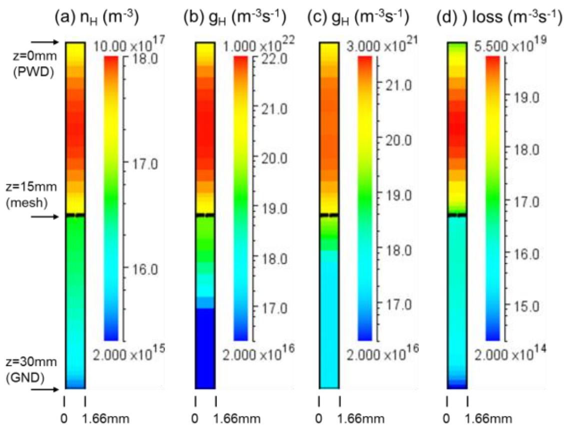

Fig. 2. Contour plots of hydrogen (H) atom related parameters [2]. (a) H atom density, n_H, (b) H atom generation rate, g_H, associated with the electron impact dissociation (e + H_2 => e + 2H) (c) H atom generation rate, associated with the ion-molecule reaction (H_2^+ + H_2 => H_3^+ + H) and (d) H atom loss rate due to the electron attachment, e + H => H^-. The simulation space includes two unit cells of the mesh structure in the horizontal axis of 0 – 1.66 mm.