Energy distributions of neutrals and ions in H_2/D_2 hollow cathode discharges

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Visible emission spectroscopy of the Balmer hydrogenic lines and energy resolved ion mass spectrometry have allowed to evince the production of fast atomic neutrals and ions in low pressure hollow cathode discharges, which can be attributed mainly to electron impact dissociative ionizations of the precursor molecules, H_2 and D_2, by highly energetic electrons. The results can be explained by Frank-Condon transitions to different upper levels and, in the case of atoms, reflect the Doppler broadening dependence with atomic mass. Spectral analysis of the other charged and neutral species involved in the discharge provide additional information on energy distributions.

In this work, we report an analysis of the experimental results obtained by visible emission spectroscopy and energy resolved ion mass spectrometry of H_2 and D_2 plasmas generated in low pressure hollow cathode discharges.

The spectral profiles of the main emission lines of the H and D Balmer series in the bulk of the negative glow present different components with very distinct relative amplitudes and broadenings, which can be compared with previous data on RF capacitive discharges [1,2] or dc discharges with parallel electrodes [3,4]. The narrowest (under the instrumental resolution) and most intense component of each line corresponds to the emission of thermalized atoms, whereas a broadened component shows kinetic energies of some 6 eV (Fig.1a). It proceeds from the dissociative ionization of hydrogen molecules trough Frank-Condon vertical transitions leading to fast atoms in the different excited states, and fast ions. A much broader component (with energy > 40 eV), which becomes relevant in previous works [1-4] and is attributed to excitations by collisions of fast neutrals or ions with the cathode surface, turns out to be very weak in the present case. Emission lines of molecular H_2 and D_2 are not affected by the former broadenings. From their analysis, the vibrational and rotational temperatures of these molecules can be infered [5,6].

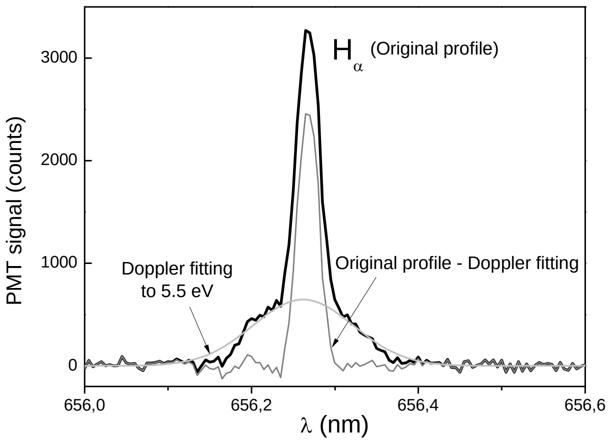

Fig. 1: Spectral profile of the H_α emission from a 150 mA, 2 Pa H_2 hollow cathode discharge obtained with a Jovin-Ybon FHR1000 spectrometer (resolution for 25 μm slits with fotomultiplier ~0.015 nm). The plasma reactor and experimental set-up is described in [5,7].

The distributions of ion energies measured by mass spectrometry are mostly determined by the acceleration of ions in the sheath region between the negative glow and the cathode, but with specific features for the distinct ions. H_2^+, D_2^+, and H_3^+ and D_3^+ (which are the major ions under these discharge conditions), show IEDFs consisting basically of a single narrow peak with energy close to the cathode sheath potential, and a much weaker continuum stretching down to 0 eV. For the atomic ions, these distributions display the narrow peak and another one exceeding some 6 eV the energy of the former one, and showing a wider distribution [7]. This peak proceeds also from the dissociative ionization of hydrogen molecules trough Frank-Condon vertical transitions leading to fast atoms and ions (Fig. 2).

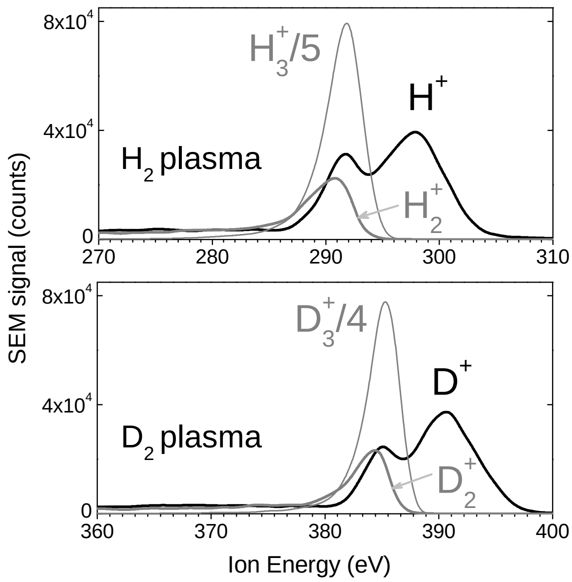

Fig. 2: Ion energy distributions for H_2 and D_2 discharges in the conditions of Fig. 1, measured with a Balzers PPM-422 Plasma Monitor.

Globally, the observation of fast atoms and ions in the plasma reveals the presence of collisions implying energetic electrons (tens of eV). We are currently working on the closer identification of the relevant excited states of the various species involved.

References

[1] I. Denysenko, J. Berndt, E. Kovacevic, I. Stefanovic, V. Selenin, J. Winter, *Phys. Plasmas*, 13 (2006) 073507.
[2] S. B. Radovanov, J. K. Olthoff, R. J. Van Brunt, S. Djurovic, *J. App. Phys.*, 78 (1995) 746-757.
[3] Z. Lj. Petrovic, B. M. Jelenkovic, A. V. Phelps, *Phys. Rev. Lett.*, 68 (1992) 325-328.
[4] C. Barbeau, J. Jolly, *J. Phys. D: Appl. Phys.*, 23 (1990) 1168-1174.
[5] I. Méndez, I. Tanarro, V. J. Herrero, *Phys. Chem. Chem. Phys.*, 12 (2010) 4239 – 4245.
[6] T. Shikama, S. Kado, Y. Kuwahara, K. Kurihara, F. Scotti, S. Tanaka, *Plasma Fus. Res.*, 2 (2007) S1045.
[7] I. Tanarro, V. J. Herrero, *Plasma Sources Sci. Technol.* 18 (2009) 034007.