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DETERMINATION OF THE DEGREE OF DISSOCIATION OF HYDROGEN DISCHARGES IN A TANDEM TYPE PLASMA SOURCE

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Introduction

Diagnostics and optimization of sources of negative hydrogen ions [1] are topics of active research motivated by the current development in fusion. Results from recent modelling [2] of plasma maintenance in tandem type of plasma sources – the design of sources of negative hydrogen ions – show that the plasma in the expansion region (the region of generation and extraction of the negative ions) is sustained manly by charged particle fluxes from the driver (the region which is optimized regarding creation of vibrationally excited hydrogen molecules). With regards to this, knowledge for the plasma parameters (gas temperature, concentration of hydrogen atoms and degree of dissociation) in this region of the source is important. The atom concentration in the discharge is a crucial plasma parameter because one of the main loss mechanisms of the negative ions is via collisions with atoms. Besides, the gas temperature and the concentration of the atomic hydrogen are very often external parameters in the discharge simulations.

In this study the actinometry diagnostics method is employed for determination of the concentration of hydrogen atoms and, respectively, of the degree of dissociation of the hydrogen molecules in the driver region of an inductively-driven tandem plasma source. Results for the gas temperature are also presented.

Experimental set up

The plasma device is a two-chamber source, inductively-driven. Figure 1 schematically presents the experimental set-up which includes: vacuum vessel, rf generator and a matching device. The two parts of the vacuum vessel are a quartz tube where the plasma is produced (driver region) and a metal chamber providing space for plasma expansion from the driver (expansion region). The rf power is applied via nine-turn copper coil positioned over the quartz tube. The internal and external diameters of the discharge tube are, respectively 4.5 cm and 4.9 cm; its length is 30 cm. Electromagnetic shield covers the driver of the source. The discharge maintenance is at frequency of f = 27 MHz. All the results given below are at gas pressure p = 10 mTorr. The applied power has been varied in the range P = (300-600) W.

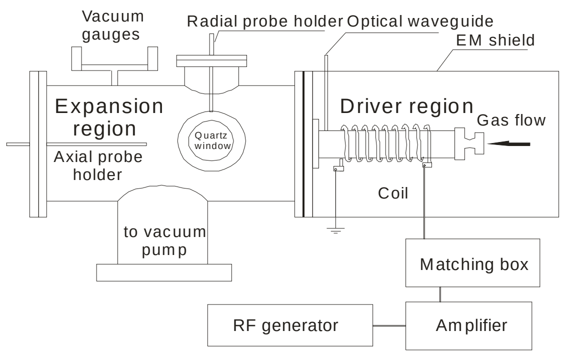

Fig 1. Scheme of the experimental set-up.

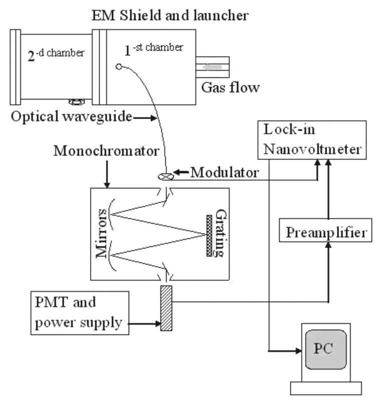

Fig 2. Arrangement for the optical emission spectroscopy diagnostics.

High resolution registration of the atomic spectral lines as well as of the Fulcher-α molecular band is achieved by using the spectrometer system shown in Fig. 2. The system consists an 0.6 m focal length Fasti MDR-2 (Lomo-Russia) monochromator, equipped with PMT-79 photomultiplier and a grating with 1200 grooves/mm for detection in the region λ = (400 – 900) nm. Both, the entrance and exit slits of the monochromator are fixed at 50 μm assuring wavelength resolution of about 0.1 nm. A PC provides the wavelength tuning and calibration, spectra observation in real time and data acquisitions. Lock-in amplifier detection is applied for measuring the light signal. The optical detection efficiency as a function of wavelength is calibrated with a standard tungsten-ribbon lamp.

Determination of the degree of dissociation

The actinometry [3] is a widely used optical emission spectroscopy method for determination of atomic fraction in molecular plasmas. In hydrogen plasmas, the method involves monitoring of line intensities of tracer gas (Ar in our case), introduced in a given – small – quantity, and of intensities of the Balmer lines (H_m, m = α,β,γ). Under the conditions of corona equilibrium and Maxwellian electron energy distribution function the relation between the hydrogen atoms density N_H and the spectral line intensity ratio I_H/I_{Ar} of given hydrogen and argon spectral lines is:

$$N_H = K \frac{I_H}{I_{Ar}} N_{Ar} \quad \text{with} \quad K = \frac{\alpha_{Ar} A_{Ar} \tau_{Ar} \lambda_{nn'}}{\alpha_H A_{nn'} \tau_{nn'} \lambda_{Ar}}. \qquad (1)$$

Here $\alpha_{Ar,H}$ are the rate coefficients for direct excitation of the corresponding Ar and H atom levels, with value of the electron temperature taken from probe measurements in our case, $A_{Ar,nn'}$ and $\tau_{Ar,nn'}$ are, respectively the radiation transition probabilities and the life times of the corresponding exited states and λ is the wavelength. In the presentation of the results below, the selected combinations of line intensity ratios (I_H/I_{Ar}) are $I(\mathrm{H}_\alpha)/I(\mathrm{Ar811})$, $I(\mathrm{H}_\beta)/I(\mathrm{Ar750})$ and $I(\mathrm{H}_\gamma)/I(\mathrm{Ar750})$, where by $I(\mathrm{Ar811})$ and $I(\mathrm{Ar750})$ the line intensities of the argon 811.5 nm and 750.4 nm lines are denoted. The concentration of N_{Ar} is determined by using the equation of state and the value of the gas temperature T_g. The latter is obtained, according to Ref. [4], from analysis of the intensity distribution of the spectral lines in the Q branch of the Fulcher-α system. The degree of dissociation is defined according to $D = N_H/(N_H + N_{H_2})$.

Results

Choosing the quantity of the tracer gas so that the perturbations of the discharge to be negligible is a well known requirement in the actinometry [3]. Our measurements (Fig. 3) show that the saturation – with increasing Ar percentage – of the maximum intensity of the H_γ and H_β lines is at about 4-5%. The results presented further on are at 3% of Ar (0.909 sccm), at hydrogen flux of 30.3 sccm.

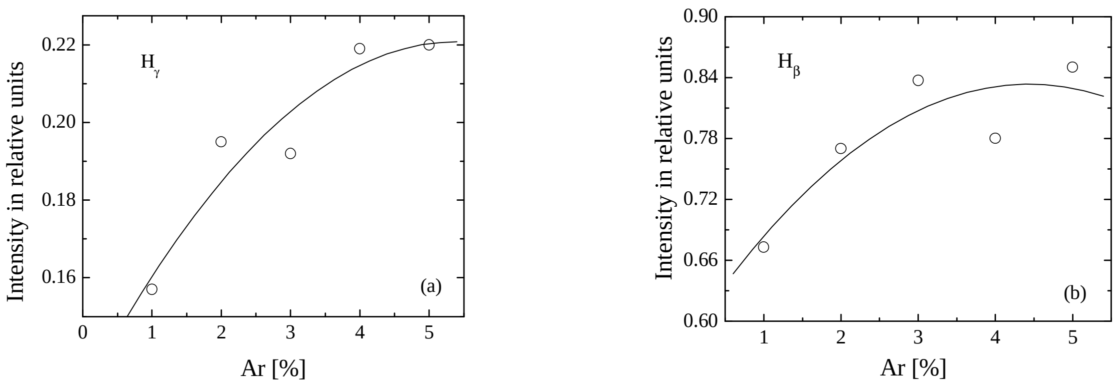

Fig. 3. Influence of argon percentage on the maximum intensities of the Balmer line H_γ in (a) and H_β in (b).

The measured dependence of the gas temperature T_g on the applied power is shown in Fig. 4. As it is expected, the gas temperature increases with the applied power. As it has been mentioned, the obtained values of T_g are used together with the measured spectral line intensity ratios for the determination of N_H (Fig. 5).

The obtained results for N_H and D (Figs. 5 and 6) do not show well pronounced dependence on the applied power (the value of D at P = 300 W is 13%, whereas at the

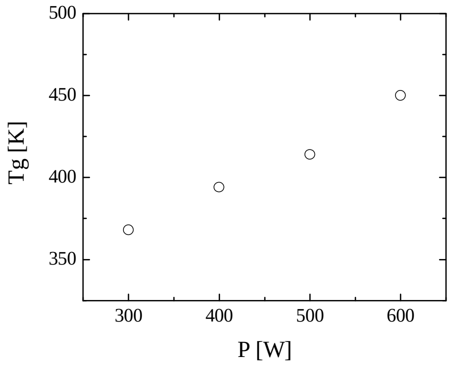

Fig. 4. Gas-temperature dependence on the applied power.

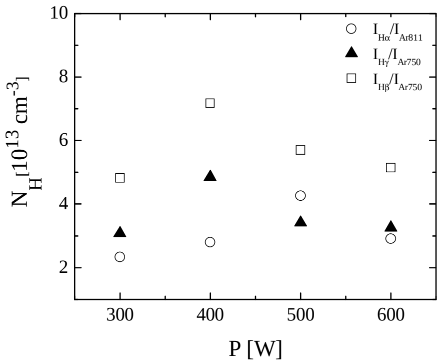

Fig. 5. Variation of the hydrogen atom density with the applied power.

P = 600 W it is 17%). This could be associated with an increase of both the dissociation and the wall H-losses with the P-increase, the former related to the increase of the electron density and latter to the increase of the wall temperature.

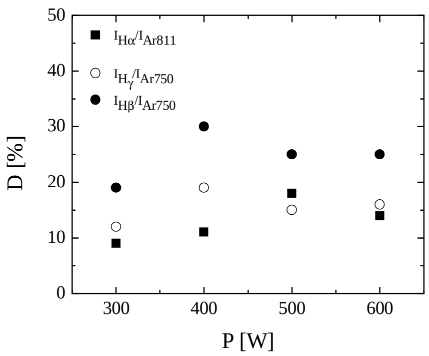

Fig. 6. The dependence of the degree of dissociation on applied power.

Conclusions

The results for plasma characteristics – gas temperature, concentration of hydrogen atoms and degree of dissociation – in the driver region of a tandem plasma source, studied by using optical emission spectroscopy methods, do not show well pronounced dependence of the concentration of the atomic hydrogen and of the degree of dissociation on the applied power.

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