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EXPERIMENTAL STUDY OF A HOLLOW CATHODE GLOW DISCHARGE IN HYDROGEN

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Abstract. The optical emission spectroscopy is used for the temperature measurement of excited hydrogen atoms T_{exc}, from the shape of the Doppler broadened hydrogen H_α line in a titanium (Ti) hollow cathode glow discharge operated at various pressures of hydrogen. Measurements of molecular rotational and vibrational temperatures have been carried out as well. The rotational temperature is determined from the population of the H_2 excited state $d^3\Pi_u^-$ rotational-vibrational levels ($\nu'= 0$). The vibrational temperature is measured from the H_2 Fulcher-α diagonal bands, $d^3\Pi_u^- \rightarrow a\ ^3\Sigma_g^+$ transition, Q-branches, $\nu'=2$, 3. To reveal the discharge length at various pressures in a hollow cathode, plasma potential probe measurements are performed.

1. INTRODUCTION

It has been demonstrated recently that the excessive Doppler broadening (EDB) of hydrogen Balmer lines may be used for discharge-cathode surface interaction monitoring [1]. The EDB of hydrogen Balmer lines in low-pressure DC discharges operated with hydrogen isotopes and in inert gases with small admixtures of H_2 have been studied recently in some details, see e.g. [1-3] and references therein. The characteristic shape of these lines exhibits unusual multi component behavior, see Figure 1. The presence of high-energy hydrogen atoms in discharge may induce change of the vibrational energy levels population, see cross section data [4]. In this case modeling of cold hydrogen plasma should include these processes as well.

The aim of the present work is to study whether fast hydrogen atoms present in discharge influence other discharge parameters like rotational and vibrational temperature. To achieve this goal precision measurements of the rotational T_{rot} and vibrational temperature T_{vib} must be performed.

The experiment [1] is carried out by observing hollow cathode discharge end-on. This work is an extension of the earlier studies [2,5,6] with an emphasis to the influence of hydrogen pressure in Ti HC discharge to T_{rot}, T_{vib} and EDB of the H_α line.

2. EXPERIMENTAL

The hollow cathode glow discharge (HCGD) source with two symmetrically positioned kovar anodes and Ti cathode is used as a discharge source. The HC tube was 100 mm long with 6 mm internal diameter and 1 mm wall thickness. The construction details of HC discharge source are described elsewhere [2].

All HCGD experiments were carried out with hydrogen. The continuous flow of H_2 was 50-350 cm^3/min (at room temperature and atmospheric pressure). The working gas was sustained at the pressure in the range 2-8 mbar by means of needle valve and two-stage mechanical vacuum pump. To prevent oil vapor back streaming from the vacuum pump, the zeolite trap is placed between discharge chamber and the pump. The gas pressure measurements are performed on the both sides of discharge tube with standard U-shaped oil manometers.

To operate discharge in a DC mode, a current stabilized power supply (0–2 kV, 0–100 mA) is used. The air-cooled variable 10 kΩ ballast resistor is placed in series with the discharge and power supply. For all measurements, the anode was grounded. During the discharge operation, the cathode was either air cooled with a fan (110 mm dia; AC 220V/13W), placed 150 mm from discharge tube, or gradually heated by changing cooling rate of the fan. The temperature of the outer wall of the HC tube is measured by a K-type thermocouple.

To determine discharge length at various pressures a plasma potential probe was used. The probe, made of thoriathed tungsten rod 250 mm long with 2 mm dia, was pushed from the back side of HCGD source along the optical axis towards discharge located inside cathode. The discharge length is determined when probe reaches potential of 25V. This potential was chosen arbitrarily and it was constant in all measurements of discharge length.

The spectra recordings were performed with unity magnification and discharge was run between HC and front anode. The light from the discharge was focused with an achromatic lens (focal length 75.8 mm) onto the entrance slit of PGS-2 spectrometer (2 m focal length; reciprocal dispersion of 0.74 nm/mm with 651 g/mm reflection grating in first diffraction order). All spectral measurements were performed with an instrumental profile very close to Gaussian with measured full half-width of 0.018 nm. Signals from CCD detector (29.1mm, 3648 channels) are A/D converted, collected and processed by PC.

3. RESULTS AND DISCUSSION

The optical emission spectroscopy (OES) is used for all temperature measurements.

Three components can be distinguished in experimental H_α line shape in hydrogen, see Figure 1: central narrow peak, broader middle part and far drawn-out pedestal. The overall fit involving convolution of three Gaussians in Fig. 1 may be justified by the fact that three groups of excited hydrogen atoms are expected in the negative glow region: thermalized H^* typical for negative glow (Gauss 1); a group of H^* atoms produced by dissociation of H_2 molecules in collisions with high energy electrons (Gauss 2); and a group of H_f^* atoms generated in collisions of H_f reflected from the cathode with H_2 (Gauss 3). A subject of our main interest is the broadest Gaussian G_3, which is related to EDB and proportional to the number of fast excited atoms emitting the H_α line. Pressure trend of relative contributions G_i/G_{total} (i=1,2,3) and energies E_i (i=1,2,3) of excited hydrogen atoms obtained by fitting the H_a profiles for Ti HCGD are given in Table 1.

Table 1. Experimental conditions, relative contributions G_i/G_{total} (i=1,2,3) and energies E_i (i=1,2,3) of excited hydrogen atoms obtained by applying three Gaussian fit to the H_a profiles for titanium hollow cathode glow discharge in H_2 at *I=90 mA* and different pressures.

p (mbar)	Voltage (V)	G_1/G_{total} (%)	G_2/G_{total} (%)	G_3/G_{total} (%)	Hydrogen Atom Energy E_1 (eV)	E_2 (eV)	E_3 (eV)
2	389	74.1	22.1	3.8	0.2	4	56
4	389	73.7	22.4	3.9			50
6	388	71.0	24.8	4.2			40
8	387	68.7	28.4	2.9			41

For the rotational temperature T_{rot} determination we follow procedure described in [7]. Logarithmic plots of emission intensities of the Fulcher-α system, Q-branches lines, divided by line strengths and fourth degree of its wave number against term values for upper level are straight line whose slope is hc/k $T_{rot}(n^{'}, v^{'})$. We used Q-branches from $d^3\Pi_u^-$ state and the Hönl-London factors, for this electronic transition may be written as in [8], while rovibronic term values are taken from [7].

The transitions of the H_2 Fulcher-α diagonal bands (d $^3\Pi_u^- \rightarrow$ a $^3\Sigma_g^+$ electronic transition; Q-branches with ν′=2,3) are used for T_{vib} temperature measurement. The intensity ratio of the two consecutive vibration bands of the same sequence according to [9] is used.

The temperature of fast excited hydrogen atoms, T_{rot}, T_{vib} and discharge length at various pressures are shown in Figure 2.

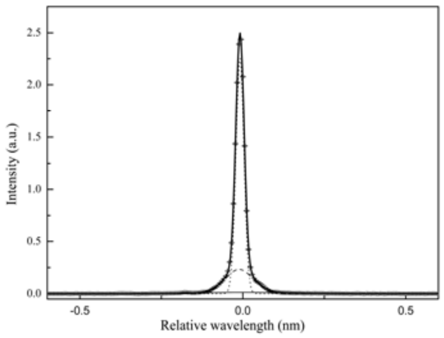

Fig 1. Typical H_α line shape recorded end-on in hydrogen with Ti cathode fitted with three Gaussians. Discharge conditions: U=388V; I=90 mA; T_{wall}=55 ^{O}C.

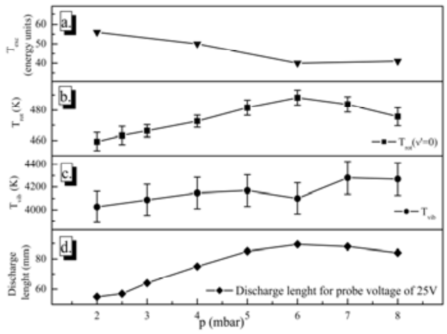

Fig. 2. (a) Fast excited hydrogen atoms energy; (b) rotational temperature; (c) vibrational temperature; and (d) discharge length in titanium hollow cathode glow versus working gas pressure p. Discharge conditions: U_{middle}=395V; I=90 mA; T_{wall}=55 ^{O}C.

In the Figure 2. one can notice different behavior of measured temperatures versus pressure. The rotational and vibrational temperatures increase with an increase of pressure up to 6 mbar. Simultaneously, the discharge length is changing with pressure and consequently the discharge current density on HC changed from 8.68mA/cm^2 to 5.34mA/cm^2 in pressure range from 2 mbar to 6 mbar. Further study is in progress and results will be reported.

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