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DETERMINATION OF THE TEMPERATURE DISTRIBUTION IN THE CATHODE SHEATH REGION OF HYDROGEN GLOW DISCHARGE USING Q-BRANCHES OF FULCHER-α BAND

M. M. VASILJEVIĆ[1], G. LJ. MAJSTOROVIĆ[2] and DJ. SPASOJEVIĆ[1]

[1]*University of Belgrade, Faculty of Physics, Studentski trg 12, 11000 Belgrade, Serbia*

[2]*University of Defence, Military Academy, 11105 Belgrade, Pavla Jurišića Šturma 33, Serbia*
E-mail gordana.majstorovic@va.mod.gov.rs

Abstract. Optical emission spectroscopy (OES) technique is used to measure electric field strength, rotational and gas temperature along the axis of an abnormal glow discharge parallel to the plane copper cathode surface (side-on) operating in hydrogen at low pressure. The rotational temperature of the excited state of H_2 was determined from the rotational structure of the Q branch of Fulcher-α diagonal bands using the Boltzmann plot technique while the obtained ground state temperature is assumed to be equal to the gas temperature. The population of excited energy levels, determined from relative line intensities, was used to derive rotational and gas temperature distributions in the cathode sheat region as well as relative population densities of rotational levels of the $d^3\Pi_u^-$.

1. INTRODUCTION

Glow discharges are extensively used for a wide variety of applications like e.g. as an excitation source for analytical spectroscopy of metal and alloy samples or depth profiling. Most of glow discharge (GD) source applications are based on original Grimm design, described in Grimm 1968., with direct current (DC) and more recently with radio frequency (RF) excitation.

The cathode sheath (CS) region is the most important part of an abnormal GD, therefore it's importance can't be neglected when describing or modeling GD. In this region, a lot of relevant processes for the operation and application of GD occur. All these processes are important in various fields of spectroscopic analysis, for thin film deposition, plasma etching, and depth profiling.

The understanding of plasma fundamentals, phenomena, and plasma applications requires the knowledge of discharge parameters, like the electric field strength distribution, gas, and vibrational temperature of molecules and radicals in the cathode sheath region. Among other plasma parameters, gas (translational) temperature of molecules plays an important role since it determines the rate of chemical reactions.

In this study, an estimation of the rotational and gas temperature, within the CS region will be shown. To evaluate the boundary between the CS and the negative glow (NG) region we used Stark polarization spectroscopy of hydrogen Balmer alpha line. For the gas temperature mapping Fulcher-α diagonal bands are recorded and analysed in the CS region of the Grimm GDS operating in hydrogen at low pressure by means of OES.

2. EXPERIMENTAL

A detailed description of a modified Grimm GDS source and the experimental setup is given in Majstorović et al, 2013 and Vasiljević et al. 2017. The experiment was realized in hydrogen (purity 99.999%). The axial intensity distribution of radiation has been observed side-on through the anode slot. The discharge tube was translated in approximately 0.125 mm steps. All spectral measurements were performed with an instrumental profile very close to the Gaussian form with measured full width at half maximum (FWHM) of 8.2 pm in the second diffraction order.

For the H_α experiments the radiation from discharge was polarized by a plastic polarizer. The selection of the π - polarized profile was experimentally carried out by orienting the polarizer axis parallel to the discharge axis, whereas the $d^3\Pi_u^-, v' \rightarrow a^3\Sigma_g^+, v''$ ($v' = v''$=0,1,2) band lines were observed without the polarizer.

3. RESULTS AND DISCUSSION

The electric field strength distribution in the CS region of the Grimm type GD is determined by fitting the model function (8) fully described in Ivanović et al. 2017, for the experimental profiles of π-polarised H_α line.

The temperature obtained from the Q branch of Fulcher-α band may be considered as the most reliable for the temperature estimation, see Majstorović et al. 2007. Now, we investigate the possibility of using Q branches of the $d^3\Pi_u^-, v'$=0,1,2 $\rightarrow a^3\Sigma_g^+, v''$=0,1,2 molecular system for temperature measurement in hydrogen Grimm GD.

The Q branch lines of the electronic transition $d^3\Pi_u^-, v' \rightarrow a^3\Sigma_g^+, v''$ ($v' = v''$=0,1,2) are well resolved and have a high signal/noise ratio in the 601-630 nm wavelength region, see Crosswhite, H. M. 1972.

The relative population densities of the rotational levels for $d^3\Pi_u^-$ (v'=0,1,2) state, see Fig. 2(a), are in accordance with the Boltzmann function. So, the Boltzmann plot technique, see Majstorović et al. 2007, is used for evaluation of the rotational temperature $T_{rot}(n',v')$ of the excited state. In low-pressure discharges, the number of collisions is not sufficient to redistribute the rotational population. The degree of relation between the rotational population density distribution in n',v' state, and the population of ground electronic state should be proven within the framework of excitation-deactivation balance equations, see Röpcke et al. 1998. According to the model discussed in Astashkevich et al. 1996., the temperature recalculated for the ground vibrational state $X^1\Sigma^+_g, v = 0$ can be considered as a valid estimation of the ground state rotational temperature i.e. H_2 gas temperature. Thus, values of the Q branch population of H_2 Fulcher-α band ($v' = v''$=0,1,2) were used to determine the rotational temperature of the ground vibrational state T_0 (n', v'), see Fig. 2(b).

In our case, the temperature recalculated for the ground vibrational state $X^1\Sigma^+_g, v = 0$ is two times larger than the rotational temperature of excited states in accordance with the relationship of the rotational constants for the upper $d^3\Pi_u$ and ground $X^1\Sigma^+_g$ (v =0) states, see in Table 1 of Astashkevich et all. 1996. and in Herzberg 1950.

State	T_e (cm^{-1})	B_e (cm^{-1})	α_e (cm^{-1})
$d^3\Pi_u^-$	112753	30.364	0.5520
$a^3\Sigma_g^+$	95980	17.109	0.606
$X^1\Sigma_g^+$	0	60.853	1.0492

Table 1: Molecular constants for hydrogen ground state and Fulcher-α electronic states.

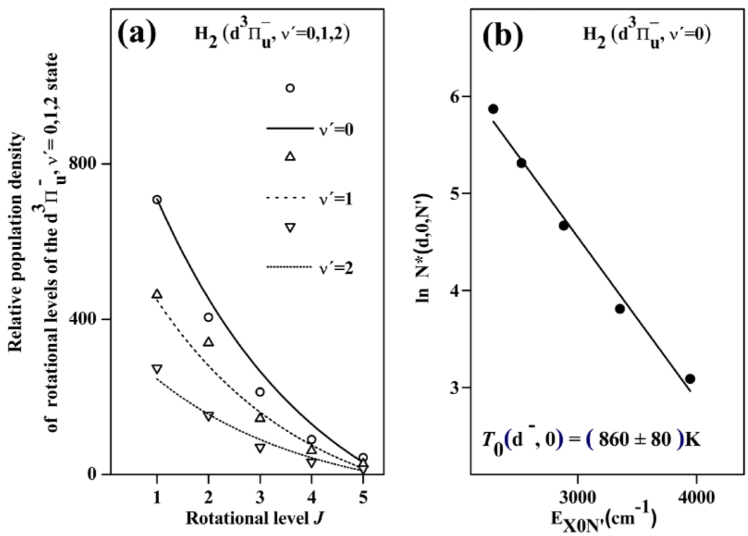

Figure 1: (a) Measured (points) and calculated (lines) values of the rotational population distribution of $H_2(d^3\Pi_u^-)$ levels. Lines represent the function exp($-B_vJ(J+1)hc/kT$) for the corresponding rotational temperatures.
(b) Semilogarithmic plot of rotational population densities of $d^3\Pi_u^-$ versus rotational energy of the molecular hydrogen ground states. Experimental conditions: copper cathode; Grimm GD in H_2 at the pressure p = 4.5 mbar; discharge current I = 11 mA; and discharge voltage U = 880V.

The technique mentioned above suggests that the thickness of the CS doesn't exceed 2.25 mm, see F 2(a). The results obtained for the temperature distribution along the CF region, presented in Fig. 2(b), show that both temperatures, T_{rot} (Q-branch; $v' = 0,1,2$) and the rotational temperature of ground vibrational state T_0, change along the cathode fall region Grimm GDS.

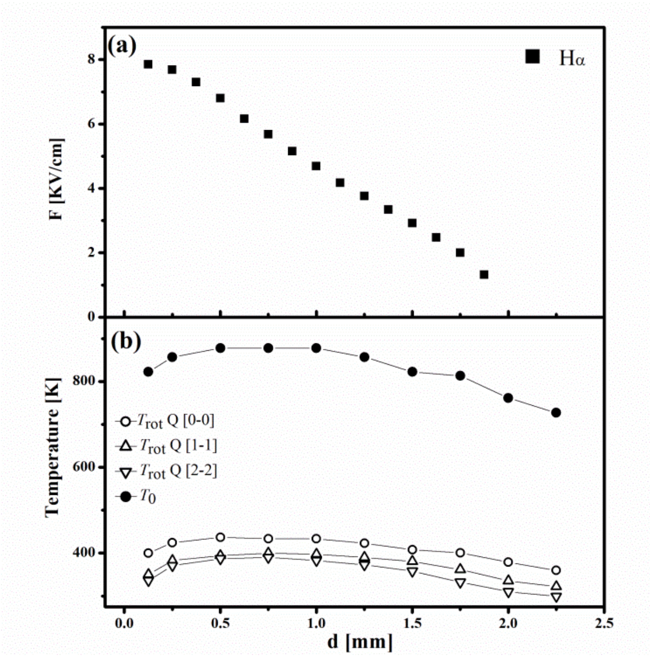

Figure 2: The dependence upon the distance from cathode *d* of: (a) Electric field strength *F* and (b) Rotational (T_{rot}) and gas (T_0) temperature distribution of the excited state $H_2(d^3\Pi_u^-)$. Experimental conditions: cooper cathode Grim GD in H_2 at $p = 4.5$mbar, $I = 11$mA, and $U = 880$V.

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