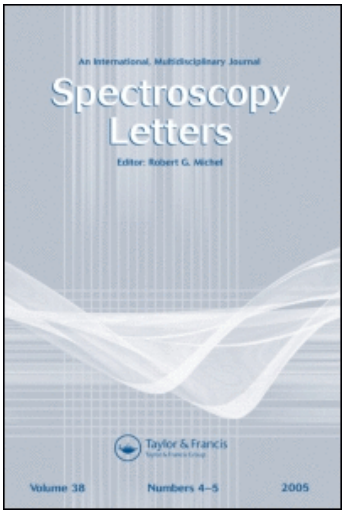

Spectroscopy Letters
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597299

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To cite this Article Zhechev, D. Z.(1993) 'Optical Probing of the Electron Energy Function Distribution in a Photoresonant Hollow Cathode Discharge', Spectroscopy Letters, 26: 9, 1725 — 1732
To link to this Article: DOI: 10.1080/00387019308010771
URL: http://dx.doi.org/10.1080/00387019308010771

SPECTROSCOPY LETTERS, 26(9), 1725-1732 (1993)

OPTICAL PROBING OF THE ELECTRON ENERGY FUNCTION DISTRIBUTION IN A PHOTORESONANT HOLLOW CATHODE DISCHARGE

KEY WORDS: Resonant Light Irradiation, Hollow Cathode Discharge, Electron Energy Function Distribution, Spectral Line Intensity

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ABSTRACT

Optical probing of electron gas in photoresonant negative glow is considered.By monitoring the spectral line intensity it can be concluded that the transfer of excitation energy to the probe atoms is mainly due to the electron gas.

INTRODUCTION

The behaviour of the Electron Energy Function Distribution (EEFD) is known to be responsible for certain spectroscopic properties of the Hollow Cathode Discharge (HCD).Recently we analyzed another effect,

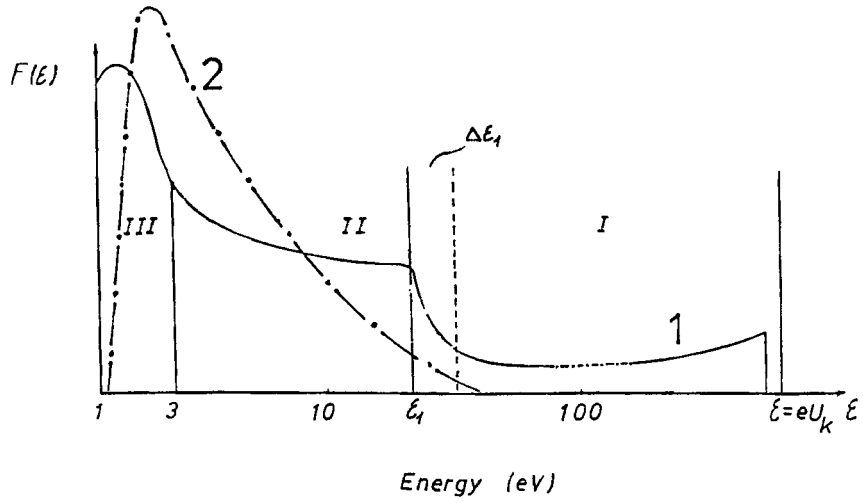

FIG.1. Electron Energy Function Distribution $F(\varepsilon)$ in HCD(1) and Optical Function of Excitation(2). I-III - high-low energy parts of $F(\varepsilon)$.

i.e. the possible reaction of the EEFD to resonant light illumination [1]. The function $F(\varepsilon)$ determining the number of the electrons in $\varepsilon, \varepsilon + d\varepsilon$ interval and in the whole cathode, was found to change for ε_1, $\varepsilon_1 + 1.4\varepsilon_1$ when the irradiated gas is hellium (ε_1 is the threshold of the excitation). This influences the formation of the optogalvanic response, connected with the electron channel and, in general, all step like processes.

The detection of $\Delta F(\varepsilon)$ reaction, however, is a complicated problem due to the amount of the transfered electrons, which is insignificant in respect to the background $\varepsilon^2 F(\varepsilon) d\varepsilon$ for $\varepsilon < \varepsilon_1$ (Fig.1). Here an optical approach for $\Delta F(\varepsilon)$ analyses based on spectral

line intensity is substantiated and some preliminary measurements are performed.

ANALYSES

1. The main point of this consideration is the addition of a supplementary probe element to the discharge medium. The probe atoms should obey two requirements: their optical transitions should not be connected with the level structure of the carrier gas and the probe spectral line threshold excitation $\mathcal{E}'_t$ should lie in or near the region of the first maximum of EEFD, which is mainly formed by the carrier gas (Fig.1, III). Hence the optical function of excitation $F'_o(\mathcal{E})$ of the probe line covers the energies $\mathcal{E} < \mathcal{E}_t + \Delta\mathcal{E}_t$

Introducing the potential of acceleration V in place on $\mathcal{E}$ we can write the intensity I'_{ki} of the probe line (k - i transition) as:

$$I'_{ki} = aN'N_e \int_{V'_1}^{V_c} F'_{ok}(V)F(V)VdV \qquad (1)$$

where N' and N_e are the amounts of the probe atoms in the ground state and the electrons, the factor a depends on the maximum of the effective cross section excitation q'_m, the frequency ν_{ki} and the other optical transitions $\sum_{r \neq i} A_{kr}$ from the upper level, V_c is the cathode fall potential.

If the absorbed photons perturbe EEFD, the intensity I'_{ki} should increase or decrease for $V \lessgtr V_1 + \Delta V_1$ according to Ref.[1]. The new intensity I'_{kip} is:

$$I'_{kip} = aN'N_e \left[\int_{V'_1}^{V_1+\Delta V_1} F'_{ok}(V)F_p(V)VdV + \int_{V_1+\Delta V_1}^{V_c} F'_{ok}(V)F(V)VdV \right] \qquad (2)$$

where $F(V)$ is the perturbed part of EEFD. Apparently, the experimental fact that $I'_{ki}=I'_{kip}-I'_{ki}\neq 0$ should be already the argument for $\Delta F(V)\neq 0$ based on

$$I'_{ki}= aN'N_e \int_{V'_1}^{V_1+\Delta V_1} F'_{ok}(V)\Delta F(V)VdV \qquad (3)$$

2. The specific character of EEFD in the whole interval $(0 \div V_c)$ does not allow its approximation as a Maxwellian. But in the region of the first maximum (Fig.1,III) $F(V)$ is adopted as a Maxwellian. The localization of the perturbance of $F(V)$ within $(0 \div V_1 + \Delta V_1)$ values, therefore, is a reason the reaction $\Delta F(V)$ to be expressed by T_e parameter. Then the measured probe line intensity I'_{kip} according to expr.(2) is (4)

$$I'_{kip}= aN'N_e \left[\int_{V'_1}^{V_1+\Delta V_1} F'_{ok}(V)V^{1/2}\exp(-V/T_{ep})dV + \int_{V_1+\Delta V_1}^{V_c} F'_{ok}(V)F(V)VdV \right]$$

If $F'_{ok}(V)$ is of the type $F'_{ok}(V)\longrightarrow 0$ when $V\longrightarrow V_1+\Delta V_1$ the intensities I'_{ki} and I'_{kip} are both determined by T_e and T_{ep} in globally taking into account that the second integral in expr.(4) goes to zero:

$$I'_{ki} = aN'N_e \int_{V'_1}^{V_1+\Delta V_1} F'_{ok}(V)V^{1/2}\exp(-V/T_e)dV \qquad (5)$$

and every increasing (decreasing) of the intensity at

resonant light irradiation depends on the change of the parameter T_e.

The values of $I'_{ki} = \varphi(T_e)$ from expr.(5) can be computed. The approximation in Ref.[2], i.e.

$$F'_{ok}(V) = (V-V'_1)(V_m - V'_1)^{-1}\exp.\left[1 - (V-V'_1)/(V_m-V'_1)\right]$$

(V_m is the localization of $q'_m(V)$) simplifies the calculation:

(5')

$$I'_{ki} = aN'N_e(b-1)(2 + bV'_1/T)b^{-3}\exp(-V'_1/T)$$

where $T = 2T_e/3$, $b = 1 + T(V_m-V'_1)^{-1}$, $a = A_{ki}q_m h\nu_{ki}/\sum A_{kr}$.

A systematical error has place when

$$\int_{V'_1}^{V_c} F'_o(V)F(V)VdV \neq 0$$

and this value is not negligible in respect to the first integral in expr.(4). But this error can be evaluated.

3. The relation of two spectral lines intensity I'_{ki}/I'_{gn} is also suitable for T_e determination based on exprs.(5, 5'):

(6)

$$\frac{I'_{ki}}{I'_{gn}} = \frac{q'_{m_k}\nu_{ki}}{q'_{m_g}\nu_{gn}} \frac{\int_{V'_{1k}}^{V_1+\Delta V_1} F'_{ok}(V)V^{1/2}\exp(-V/T_e)dV}{\int_{V'_{1g}}^{V_1+\Delta V_1} F'_{og}(V)V^{1/2}\exp(-V/T_e)dV} = \varphi(T_e).$$

In this way the value N_e is eliminated and the suitable pair of spectral lines provides a more sensitive procedure of ΔF description. We hope to develop measurement procedure based on expr.(6).

APPLICATION

Some preliminary diagnostic measurements are per - formed according to the consideration in p.2.

A HCD in Ar carrier gas is irradiated by Ar^+ laser lines. The combination Ar - Ar^+ is of interest since the absorbing plasma component is the ionic one and we look for the response of F(V) function, formed by the basic Ar component (the Ar^+ ions concentration is of the order of the electron one, i.e. 10^{11} cm^{-3}; the Ar atoms concentration is 10^{11-13} cm^{-3}). One should note the sufficiently large interval within the upper level irradiated and the Ar^+ ion potential of ionization (more than 8 eV).

Cd and Mg atoms sputtered from the cathode surfaces are used as probing components in two experiments. The intensity I'_1 of the resonant CdI 228.8 nm spectral line is measured. It should depend mainly on F(V) because of its resonant character. The chossen low current i regim of operation (0.6 + 3.5) mA stimulates the direct electron impact excitation of the resonant level CdI 5^1P_1, which is proved by the linear behaviour of the intensity $I'_1(i)$. The optical function F'_{01} consists of a sharp increase from V'_1 = 5.42 eV and a plateau like piece according to Ref.[3]. Therefore only one part of I'_1 should be perturbed by the laser light irradiation, i.e. within 5.42 eV and about 20 eV. Indeed, it is established that the laser beam (514.5 nm, 15 mW, 0.9 mm^2) increases the probe line intensity, emitted

from HCD (p_{Ar} =3.5 Torr, diameter 3 mm, length 13 mm), i.e. $\Delta I/I' = 0.2 \div 0.3$. This reaction coincides in phase with the augmantation of the laser upper level population and with the measured optogalvanic signal.

The singlet - triplet structure of the MgI spectrum is a reason for expr.(6) to be used because of the distinguishable F_o' functions, describing the singlet and triplet spectral lines. Our first measurements concern the sensitivity of MgI 285.2 nm, MgI 516.7 nm and MgI 552.8 nm lines to laser induced change of their intensities. One should note that the second line forms its intensity in (5.11 ÷ 20) eV region entirely according to Ref.[3].

In order to exclude the laser induced surface effects a through Mg cylinder (diameter 8 mm, length 40 mm) is used as cathode. The laser beam (514.5 nm, 500 mW, 1.8 mm^2) propagates slant-wise through the cavity.

A laser induced increase of the spectral lines intensity is observed, too. For example, MgI 516.7 nm augments 38% at i= 14 mA and p_{Ar} = 0.8 Torr. The phase relations are the same as the abovementioned ones.

The q(V) curves for both MgI 285.2 nm and MgI 516.7 nm shown in high V- resolution and in equal scales in Ref.[4] allow to determine ΔT_e. Since absolute measurement of the spectral line intensities is not performed we are able only to estimate the sign of ΔT_e. It turns out that the irradiation warms the discharge electron gas.

CONCLUSION

The considered optical approach allows the reaction of the EEFD in photoresonant HCD to be analyzed. The results based on the measurements in Ar HCD prove

the transfer of the absorbed photon energy by means of the electron gas when the discharge is irradiated by ArII($4s^2P$- $4p^4D^o$) optical transition.

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Date Received: May 28, 1993
Date Accepted: July 9, 1993