

Radial inhomogeneity in a shape of spectral line emitted from hollow cathode discharge

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The Lorentzian width of the spectral line HeI 504.7 nm emitted in the negative glow of a hollow cathode discharge (HCD) was found to increase depending on the distance from the emitting volume to the cathode axis. This effect manifests itself at low buffer gas pressures $p_{He} \in (0.0-0.28)$ Torr. The later is typical for the experiments on SFS, radiative width and other constants. Thus, the observed radial inhomogeneity concerns the accuracy of these measurements. It is checked by determination of radiative width of the HeI 504.7 nm line emitted by two regions along the radius of HCD.

Keywords: hollow cathode discharge, shape of spectral line, convolution, radiative width.

1. Introduction

Hollow cathode discharge (HCD) is known as widely used light source in both absorption and high-resolution spectroscopy. The unique sputtering-excitation properties have lately also traced much interest to HCD within modern spectroscopic investigations, i.e., magneto-optic [1], opto-galvanic [2], and magneto-galvanic [3] ones. These application fields stimulate further studies of HCD emission and electric characteristics under wide region of buffer gas pressure [4].

Earlier, we observed radial inhomogeneities in spectral line shape emitted from HCD at low gas pressure $p \in (0.2-2.2)$ Torr [5]. They were ascribed to the electric field, which penetrates from cathode dark space to the negative glow at low enough gas pressure. Two effects, i.e., broadening $\Delta\nu(R_i)$ and shift $\delta\nu(R_i)$ of the spectral line were observed from different regions R_i along the HCD radius R . These effects rise at both gas pressure decreasing ($\Delta\nu \propto p^{-1}$ and $\delta\nu \propto p^{-1}$) and distance R_i from the cathode axes R_0 , i.e., $\Delta\nu \propto R_i$ and $\delta\nu \propto R_i$. This result concerns the accuracy of various measurements by HCD usage.

In this work, behaviour of the Lorentzian half-width $\Delta\nu_L(R_i)$ of HeI 504.7 nm line at the gas pressure $p_{He} \in (0.09-0.28)$ Torr is investigated. The results are discussed within the frames of its radiative width.

2. Experiments

Aluminium end-to-end HCD of the diameter $2R = 25$ mm and length $l = 30$ mm installed in a covar cylinder is used. The bottomless cathode allows both monitoring of HeI 504.7 nm

absorption by using a reflecting mirror and excluding effects at the cathode bottom. The cathode walls are liquid air-cooled. The ratio $2R/l$ has been taken based on consideration of HCD stability at the suitable low-pressure range $p_{He} \in (0.09-0.28)$ Torr. The discharge at discharge current 4 mA is driven by a current-stabilized power supply. Shapes of spectral line HeI 504.7 nm are recorded since its small oscillator strength $f = 0.0082$ minimizes the effect of reabsorption [6]. A scanning two-position Fabri-Perot interferometer (FPI) is used (Fig. 1).

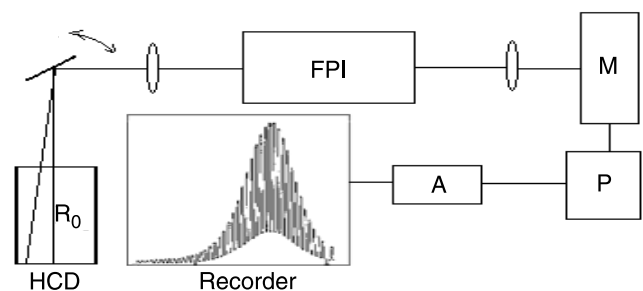


Fig. 1. Experimental scheme. FPI is the Fabri-Perot interferometer, M is the monochromator, P is the photomultiplier, and A is the amplifier.

The optical scheme contains a reflecting mirror. The periodic variation of the mirror inclination permits simultaneous recording of two line shapes, each one emitted from different regions R_i along the cathode radius. Thus, the shapes may be compared in all parameters correctly. A cylinder with a base of 1 mm determines space resolution, limited by the optical system and source geometry.

Every FPI contains the profile emitted from the plasma along the axis R_0 (Fig. 2, case 2) – as a standard and along another R_i (Fig. 2, case 1).

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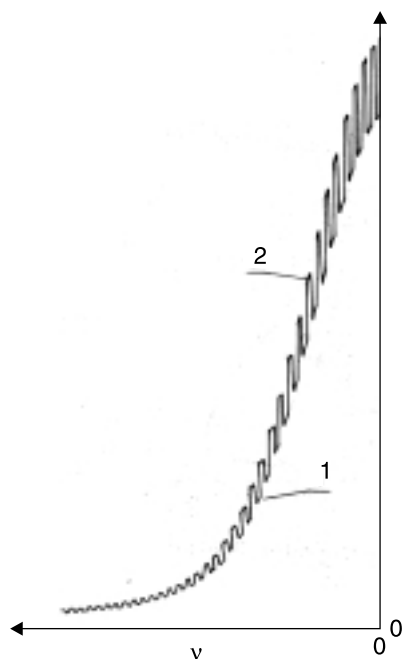


Fig. 2. Two-position interferogram of the spectral line HeI 504.7 nm emitted at a distance of 4 mm from the axis (1) and along the cathode axis (2).

The Lorentzian Δv_L and Gaussian Δv_G half-widths [width of the line shape at $I(\nu) = I_{max}/2$] of FPI are obtained by using the Balik's method [7].

3. Results and discussions

The recorded FPIs were found broadening when the emitting gas discharge region R_i has not been localized along the cathode axes R_0 . Their deconvolution suggests that the Lorentzian causes this anomalous tendency.

Table 1. Lorentzian width L in the profile of HeI 504.7 nm emitted along the axis R_0 and at a distance 4 mm R_4 from the axis.

P_{He} (Torr)	0.28		0.2		0.13		0.09	
R_i (mm)	R_0	R_4	R_0	R_4	R_0	R_4	R_0	R_4
$\Delta v_L \times 10^{-3} \text{ cm}^{-1}$	50	51	47	50	43	48	41	47

Table 1 consists of the Lorentzian widths Δv_L obtained from interferograms by deconvolution. Everywhere $\Delta v_{L_{R_4}} > \Delta v_{L_{R_0}}$ and the inequality rises at lower pressure since $\Delta v_{L_{R_4}} \propto p_{He}^{-1}$. On the other hand this inequality also rises with the distance R_i , i.e., $\Delta v_{L_{R_i}} \propto R_i$ at a given pressure. The relation $\Delta v_{L_i} \propto p_{He}^{-1} R_i |_{R_i \neq R_0}$ suggests that the real Lorentzian contains an additional component due to the observed inhomogeneity at low buffer gas pressure. This component may influence the value of any parameter, consisting in Δv_L .

The last consideration is checked by determining of radiative width of the HeI 504.7 nm line emitted by two emitting regions along the radius of HCD.

Generally, the Lorentzian width consists of one light source proper component Δv_S and that of instrumental broadening Δv_a

$$\Delta v_L = \Delta v_S + \Delta v_a. \quad (1)$$

In order to eliminate the entirely broadening Δv_a , the same interferogram (at $p_{He} = \text{const}$) has been recorded at different distances t between the mirrors of the interferometer; the following extrapolation $\Delta v_L \rightarrow \Delta v_L^0$ at $t^{-1} \rightarrow 0$ gives the real value of Δv_S .

The value Δv_S in our case includes the radiative width Δv_N , the broadening due to the pressure Δv_p and the term $\delta v_{L_{i-0}}$ concerning established dependence $\Delta v_L \sim R_i, (\Delta v_{L_{i-0}} = \Delta v_{L_i} - \Delta v_{L_0})$

$$\Delta v_S = \Delta v_N + \Delta v_p + \delta v_{L_{i-0}}. \quad (2)$$

One should note the dual acting of gas pressure in Eq. (2). The term $\Delta v_p \propto p$ describes the normal collisional interaction and does not depend on the parameter R_i , i.e., it manifests itself everywhere in HCD. The other term was found as $\Delta v_{L_{i-0}} \propto R_{i \neq 0} p^{-1}$ and it may dominates Δv_p at both enough low p and long R_i . The contribution of the collisions Δv_p is estimated according to Ref. 8. The value of Δv_p turned out to be $0.22 \times 10^{-3} \text{ cm}^{-1}$ at the particle density of $5 \times 10^{11} \text{ cm}^{-3}$. This component was eliminated by Lorentzian width extrapolation to zero pressure. Then the width Δv_S was found to be

$$\Delta v_S |_{R=R_0} = (13 \pm 1) \times 10^{-3} \text{ cm}^{-1};$$

$$\Delta v_S |_{R=R_4} = (17.2 \pm 1.5) \times 10^{-3} \text{ cm}^{-1}.$$

The value $\Delta v_S |_{R=R_0}$ is in a good agreement with the radiative width measured in Ref. 9 and can be considered as radiative one, i.e., $\Delta v_S |_{R=R_0} = \Delta v_N$. On the contrary, the value of $\Delta v_S |_{R=R_0}$ exceeds in more than 1.3 times that of $\Delta v_S |_{R=R_0}$ and cannot be taken as a real radiative width because of the term $\delta v_{L_{i-0}} \neq 0$.

Obviously the accuracy of experimental data depends on both optical system space resolution and steepness of radial inhomogeneity $\partial \Delta v_L / \partial R$. Usage of a bottomed cathode introduces additionally a background of broadening.

4. Conclusions

At low operating gas pressure $p_{He} \leq 0.3$ Torr, the Lorentzian width Δv_L of HeI 504.7 nm line is found broadening when spontaneous emission of HCD is detected along the cathode radius at the distance R_i from the geometric axis R_0 . This broadening depends abnormally on operating gas pressure, i.e., $\Delta v_L \propto p^{-1}$ and rises with distance R_i .

The used operating pressure region is the suitable for the experiments on SFS, radiation constants, isotope shift, etc. and the observed radial inhomogeneities in Δv_L may compromise the accuracy of the measurements. Moreover,

the radial inhomogeneity influences the shape of the spectral line when the Gaussian is not enough dominating.

The observed broadening is analysed within the frames of the problem of radiative width. The later is found different for HeI 504.7 nm emitted by HCD plasma along the cathode axis $[(13 \pm 1) \times 10^{-3} \text{ cm}^{-1}]$ which is close to the literature data] and at distance of 4 mm from the axis $[(17.2 \pm 1.5) \times 10^{-3} \text{ cm}^{-1}]$ which is influenced by radial broadening].

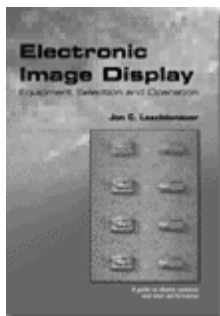
The results outline the importance of optical system space resolution at low gas pressure operation, i.e., it has to be conformed to the current inhomogeneity steepness $\partial\Delta\nu_L/\partial R$.

References

1. S. Caroli, *Improved Hollow Cathode Lamps for Atomic Spectroscopy*, Ellis Harwood, London, New York, 1985.
2. G.N. Rao, J. Govindarajan, and M.N. Reddy, in *Hyperfine Interactions(Part II)* **38**, p. 539, edited by B. Deutch, E.N. Kaufmann, and H. de Waard, 1987.
3. G. Todorov, P. Karavassilev, and D. Zhechev, "On the genesis of the magneto-galvanic effect in neon glow discharge", *Physica Scripta* **57**, 63 (1998).
4. G.M. Petrov and D. Zhechev, "Electron energy distribution function and electron characteristics of conventional and micro hollow cathode discharge", *Physics of Plasmas* **9**, 1815–1819 (2002).
5. D. Zhechev and N. Parvanova, "Broadening, shift and polarization of spectral line emitted from hollow cathode discharge", *Optics Communication* **212**, 301–306 (2002).
6. A.G. Kasabov and V.V. Eliseev, *Spektroskop tablitzii dlya nizkotemp. plazmii*, Moskow, Atomizdat, 1973. (in Russian).
7. E.A. Balik, "The response of scanning Fabry-Perot interferometers to atomic transition profiles", *Appl. Optics* **5**, 170L (1966).
8. I.I. Sobel'man, "On theory of atom spectral line width", *Uspehi Fiz Nauk* **54**, 551 (1954).
9. A.R. Malvern, J.L. Nicol, and D.N. Stacey, "The effects of excitation mechanisms on spectral profiles in helium", *J. Physics* **7B**, L518 (1974).

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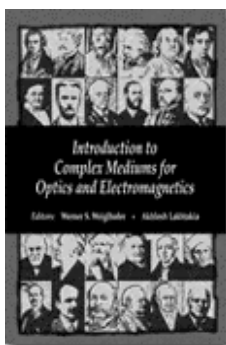


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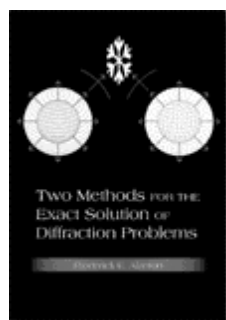


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