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Population inversion measurements in a hollow-cathode discharge by optogalvanic spectroscopy

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Abstract

An experimental method for population inversion detection between two energy levels of some species present in a plasma discharge is described. In particular it was possible to detect this mechanism on the $2p_4$–$3s_2$ (Paschen notation) neon levels in a hollow-cathode tube by measuring the optogalvanic effect induced by a HeNe laser.

The optogalvanic effect (OGE) can be observed in an electric discharge if electronic transitions of atomic or molecular species contained in the plasma are induced by resonant light radiation [1]. The optogalvanic signal (OGS) is detected as an impedance (or voltage) change in the discharge. The two major mechanisms that contribute to this effect have been pointed out by Keller et al. [2], Dréze et al. [3] and Kopeika [4]. The first two authors consider the increase in the plasma temperature, through electron collisions with atoms excited by the laser radiation, as the main mechanism that leads to the discharge impedance change. Kopeika, on the other hand, considers the possibility of atomic excitation followed by ionization due to collisions with other species. It is accepted that both the above mechanisms do occur simultaneously and the contribution of each one depends on the levels involved in the transition.

Theoretical and experimental investigations were carried out in order to explain the optogalvanic effect magnitude, sign, and temporal evolution as a function of several parameters such as gas pressure, discharge current, light intensity, geometrical factors, and others [5–7]. Some simplified theoretical models have been developed and the behaviour of the discharge voltage variation could be estimated by solving the rate equations related to the induced electronic transitions [5,6,8]. In any case the results showed that for modulated cw or pulsed laser radiation, and for non-metastable level excitation, the optogalvanic signal magnitude is directly proportional to the factor $(n_1 - n_2)$, where n_1 and n_2 are of the lower and the upper levels density normalized by their respective degeneracy. A review on the subject was published by Barbieri et al. [9]. The OGS or ΔV, can be written as:

$$\Delta V = -A(n_1 - n_2), \qquad (1)$$

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where A is a positive proportionality factor that depends both on atomic properties and on discharge parameters. In order to investigate this population dependence, a 3 mW HeNe laser beam (632.8 nm), 1.2 mm in diameter, was used to induce the $2p_4$–$3s_2$ neon transition in a uranium–neon hollow-cathode tube coupled to a diffusion pump system and a liquid N_2 trap. The cathode was a uranium plug 5/8 inches long with an inner bore of 3/16 inches in diameter. The details of the lamp construction are described elsewhere [8].

The laser radiation was modulated at 27 Hz by a mechanical chopper and the reference signal was connected to a lock-in amplifier (PAR mod.186A) that sincronously measured the voltage variation ΔV in the discharge. With such experimental conditions the ratio $\Delta V/V$ was obtained for several helium–neon pressure ratios. In an attempt to prevent variations on the A factor of Eq. (1) other parameters, like discharge current and laser light intensity, were kept constant during the experiments. The total gas pressure in the lamp was measured by a Baratron MKS type 170M. It must be pointed out that the voltage discharge varied from 290 V for low gas pressure (0.5 Torr) to 187 V for high pressure (6 Torr) with a constant discharge current of 30 mA. The atomic density of the $3s_2$ neon level could be increased by the well known excitation transfer reaction between He* $2\,^1S_0$ metastables and Ne ground state atoms [10]. This is the process that leads to the population inversion in the HeNe laser between the $3s_2$–$2p_4$ states. As the atomic density of the $3s_2$ level increases, the population difference between the upper and lower levels $(n_1 - n_2)$ related to the transition induced by the HeNe laser decreases. As a consequence the optogalvanic signal induced by the HeNe laser decreases in magnitude and changes sign when n_2 becomes higher than n_1 in the hollow cathode discharge.

This population inversion can be observed for a suitable HeNe pressure ratio. The results of the measurements are shown in Fig. 1, where the ratio $\Delta V/V$ is plotted as a function of the total gas pressure in the tube. In this figure, curve 1 was obtained with the tube filled with pure neon. In curve 2 the measurements were made for a fixed neon pressure of 2 Torr plus additional helium gas. Curves 3 and 4 were obtained for fixed neon pressures of 1 Torr and 0.5 Torr, respectively. For all conditions of HeNe mixture ratios the signal goes to zero for high values of the total pressure. A visible dark space starts to grow in the cathode centre axis toward the inner bore surface as the pressure is further increased. A possible explanation for this fact is that the electron–atom collision mean free path becomes shorter and the electrons emitted by the cathode surface lose their kinetic energy in a very short distance. This way, the central region of the cathode, where the laser radiation is more intense, will contain less excited atoms that interact with the laser beam. The curves show that the population inversion occurs for approximately 1 Torr He, 0.5 Torr Ne mixture (curve 3), remaining nearly constant for further increase in the He pressure. For the 0.5 Torr Ne pressure a maximum inversion is observed for He pressure in the range from 2 to 3.5 Torr. The population inversion magnitude decreases for total gas pressure higher than this maximum point, following to some extent the behaviour of the HeNe laser output power curve obtained as a function of the HeNe mixture ratio, shown in Figs. 4.24 to 4.27 of Ref. [10]. The discrepancy between the curves may be due to the different operation characteristics of the positive and negative glow discharges of the HeNe laser and the hollow-cathode tube, respectively. It should be mentioned that it was not possible to run the discharge for Ne pressure below 0.5 Torr, due to the limitations imposed by the hollow-cathode dimensions, according to the condition for hollow-cathode operation given by Eq. (3.21) of Ref. [10].

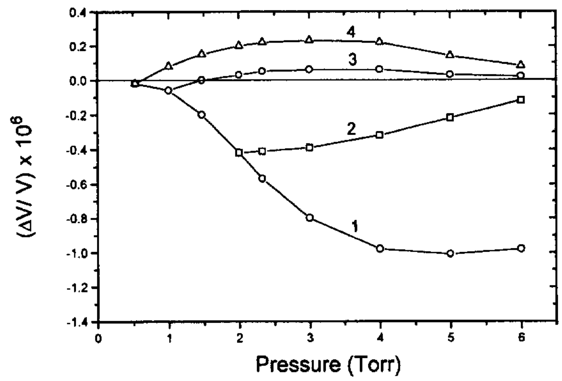

Fig. 1. OGS/voltage ratio measurements as a function of the total gas pressure. Curve 1: pure neon. Curves 2, 3, 4: 2 Torr, 1 Torr, and 0.5 Torr neon plus additional helium, respectively.

In summary, the experimental results shown in Fig. 1 and the particular conditions in which they were taken, lead us to conclude that there are strong evidences showing that the optogalvanic signal behaviour follows the population inversion of the $3s_2$–$2p_4$ Ne transition in the hollow-cathode discharge. The advantage in using the optogalvanic detection technique is its high sensitivity for measuring small photon absorption or small signal gain in a gas discharge, compared to the usual process of light intensity measurements. A signal to noise ratio of one or two orders of magnitude higher than the direct light intensity measurements can be attained.

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References

[1] R.B. Green, R.A. Keller, G.G. Luther, P.K. Schenck and J.C. Travis, Appl. Phys. Lett. 29 (1976) 727.
[2] R.A. Keller and E.F. Zalewski, Appl. Optics 19 (1980) 3301.
[3] C. Dréze, Y. Demers and J.M. Gagné, J. Opt. Soc. Am. 72 (1982) 912
[4] N.S. Kopeika, Appl. Optics 21 (1982) 21.
[5] G. Erez, S. Lavi and E. Miron, IEEE J. Quantum Electron. QE-15 (1979) 1328.
[6] A. Ben-Amar, G. Erez and R. Schuker, J. Appl. Phys. 54 (1983) 3688.
[7] T. Fujimoto, Y. Uetani, Y. Sato, C. Goto and K. Fukuda, Optics Comm. 47 (1983) 111.
[8] A. Mirage, D. Pereira, F.C. Cruz and A. Scalabrin, Il Nuovo Cimento 14D (1992) 605.
[9] B. Barbieri, N. Beverini and A. Sasso, Rev. Mod. Phys. 62 (1990) 603.
[10] C.S. Willet, An Introduction to Gas Lasers: Population Inversion Mechanisms (Pergamon Press, Oxford, 1974) ch. 4.