THE INFLUENCE OF EXTERNAL MAGNETIC FIELD ON THE RADIATION EMITTED BY NEGATIVE GLOW OF A DC GLOW DISCHARGE*

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This work represents a first attempt to use the cylindrical coaxial magnetron discharge (CCMD), obtained in air, as a light source. The main purpose was to realize a high efficiency of conversion of electric power to visible light and to optimize the operating conditions to minimize the cost of the light source, employing a cheap gas (air) and moderate voltage in the range of several hundreds volts. A mathematical model regarding the dependence of relative increase of total visible intensity (TVI) by magnetic field and discharge voltage was developed.

Key words: cylindrical coaxial magnetron discharge; total visible intensity.

1. INTRODUCTION

It is known that the direct – current (d.c.) glow discharge (GD) plasma is generated by supplying energy to a neutral gas leading to the formation of charge carriers [1, 2]. There are various ways to supply the necessary energy for plasma generation to a neutral gas. A common method of generation and sustaining low-temperature plasma for different technological and technical applications are to apply an electric field to a neutral gas from a discharge vessel using interior electrodes. Charge carriers accelerated in external electric field transfer their energy into the discharge plasma via elastic and inelastic (excitation and ionization) collisions with the neutral particles.

Low pressure GDs exhibit characteristic luminous structures: negative glow (NG), positive column (PC) and the anode glow. The NG is a part of the cathode region immediately next to the high field cathode fall. The NG is a highly nonequilibrium region of GD, with high electric field, where a high-energy electron beam accelerated in the cathode fall produces an intense bright light via excitation collisions [1–3]. The NG has the property to be the brightest part of a GD. In this work we try to exploit this property.

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If an additional transverse magnetic field (B) is present, the efficiency of the electron-neutral collisions can be increased significantly. Lorentz force induces a circular motion of the electrons with the cyclotron frequency, if there is a velocity component perpendicular to B direction. The magnetic field perpendicular to the electric field increases the effective path of the electrons and ensures a high electron-neutral collision rate [3, 4]. The studies on electron neutral collisions are of substantial interest in various areas of gas discharges, experimental and health physics [1, 2]. An understanding of excitation collision phenomena is crucial in a broader comprehension of the macroscopic behavior of devices as spectral lamps and light sources [5–8].

Depending by the application requirements, there is a large variety of discharge lamps that include low-power low-pressure compact fluorescent lamps and high-intensity high-pressure discharge lamps. Generally, fluorescent/ discharge lamps are based on discharges in pure gases or in controlled mixtures of rare gases, at a few Torr, plus mercury vapors at a few mTorrs [5–8]. However, a very small effort has been made to investigate the effect of electrodes geometry configuration [6–8] and, practically was no interest to consider the role of the magnetic field to increase the brightness performances of the NG of a GD.

In this work our investigations were focused on the NG of a GD obtained in the CCMD configuration, which can be used as converter of the electric energy into radiation. Additionally, we use for the first time the air as working gas. The final purpose was to obtain a very efficient and cheap light source. The results obtained are encouraging.

2. EXPERIMENTAL SET-UP

Experiments were carried out using a coaxial cylindrical dc GD system whose geometry was reported in a previous paper [9]. The cylindrical discharge chamber, made by Pyrex glass with 4.2 cm in diameter was equipped with two stainless steel coaxial electrodes: an external cylinder with 4.0 cm inner diameter and a central (co-axial) wire 0.1 mm in diameter (Fig. 1). Both electrodes have 12 cm in length.

A voltage Ud in the range of 500–1000 V was applied between the electrodes that can play alternatively the role of the anode (A) and cathode (C). An axial magnetic field was produced using a system of two coils (H) co-axially placed. The magnetic field is constant along the anode (cathode) wire (Fig. 1).

The discharge can work in a “cylindrical magnetron configuration” (CMC) when the central electrode is the cathode (C) and respectively in “inverted cylindrical magnetron configuration” (ICMC), when the central electrode is the anode (A). In both configurations the discharge works in crossed $\vec{E} \times \vec{B}$ fields.

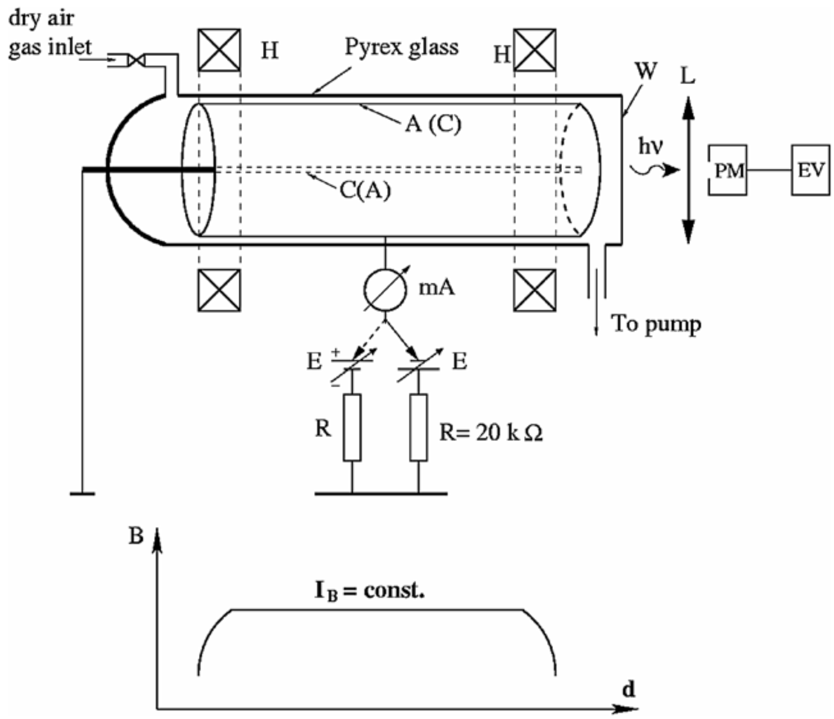

Fig. 1 – Experimental set-up.

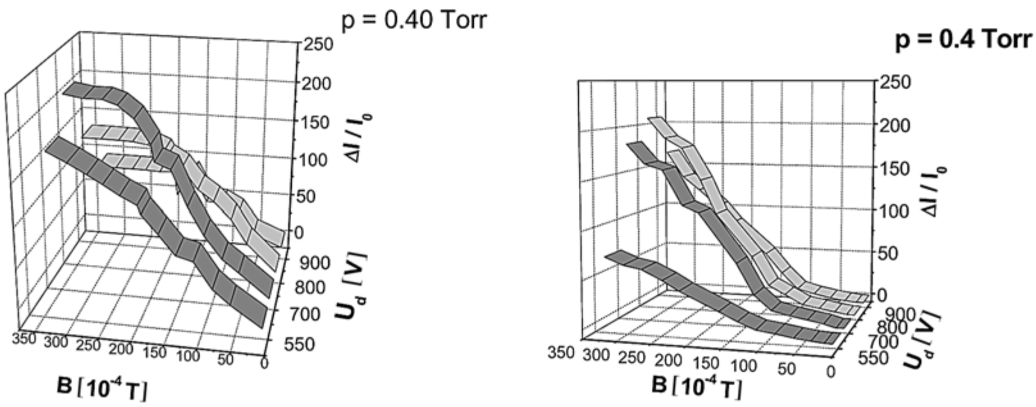

Fig. 2 – The relative variation of the TVI ($\Delta I/I_0$) versus magnetic field (*B*) for different values of discharge potential (*U*) in the two configurations: a) CMC (central electrode cathode) and b) ICMC (central electrode anode).

The discharge chamber was evacuated up to 10^{-3} Torr using a fore pump alone. The chamber was then refilled with dry air with a flow rate of 1–5 litter/h and the pressure range of 0.1–1.0 Torr. For the dc operation a high voltage supply (E, Fig. 1) which could provide voltage up to 1 kV was used. A ballast resistor was connected in series ($R = 20$ kΩ) to limit the discharge current. The discharge control parameters (gas pressure and discharge voltage) were chosen so the GD was strongly abnormal and the whole discharge chamber is filled with NG (the anode is situated in the NG).

The total visible intensity (TVI) emitted by the excited species from the discharge, incident on the lens L (Fig. 1) was focused onto the entrance slit of a photomultiplier tube (PM) coupled with an electric voltmeter (EV).

3. EXPERIMENTAL RESULTS AND COMMENTARY

The effects of magnetic field strength and discharge voltage on TVI at 0.40 Torr discharge gas pressure are shown in Fig. 2a for CMC and in Fig. 2b for ICMC, respectively.

As expected, the relative variation TVI ($\Delta I/I_0$) increase strongly with magnetic field due to enhanced electron-neutrals collision in the NG plasma. $\Delta I = I - I_0$ where I_0 is the TVI for $B = 0$ and I is TVI for different values for B. For a certain value of magnetic field strength ($B = 26 \times 10^{-3}$ T), the characteristics $\Delta I/I_0$ versus discharge voltage Ud in the two configurations are shown in Fig. 3a (CMC) and Fig. 3b (ICMC). These dependencies indicate the possible existence of an optimum discharge voltage for which $\Delta I/I_0$ has a maximum.

It was observed that the magnetic field has a great effect on the TVI. The increase of relative variation TVI $\Delta I/I_0$ for $p = 0.40$ Torr is over 200% in comparison with the situation when $B = 0$ (Figs. 2 and 3). The effect is more important in ICMC (see Fig. 3b). In this configuration the emissive surface of cathode (external cylinder) is greater than in CMC.

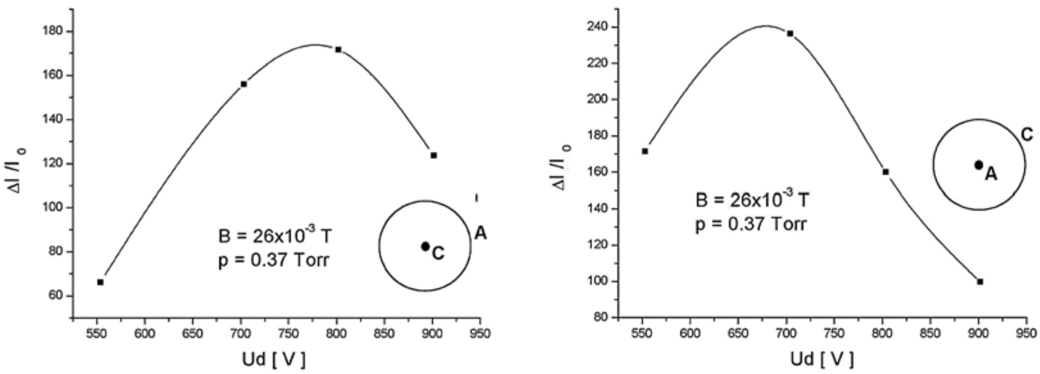

Fig. 3 – The dependence $\Delta I/I_0$ *versus* U in the two discharge configurations: a) CMC and b) ICMC.

Moreover, for ICMC the discharge works in cylindrical hollow cathode configuration (the hollow cathode is open at both ends). In this configuration, high-energy electrons which are emitted perpendicular to the cathode surface can oscillate in a potential well formed inside of cylindrical cathode [10].

The hollow cathode effect together with the effect of transverse magnetic field on the trajectory of electrons (Fig. 4) significantly enhances the excitation rate playing thus a crucial role in highly increasing of the light emission of the discharge (Fig. 3a).

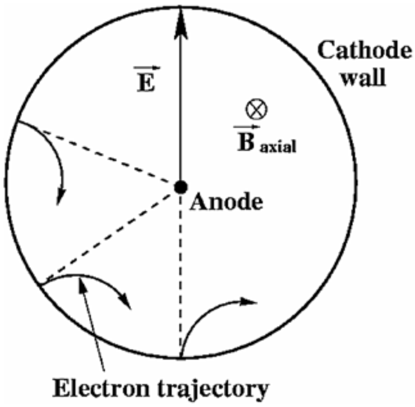

Fig. 4 – Electron trajectories in crossed $\vec{E} \times \vec{B}$ fields.

4. MATHEMATICAL MODEL

In order to establish the best conditions for a DC discharge in air, a mathematical model was proposed to describe the dependence of the relative variation of TVI on the external magnetic field based on the results obtained both in the two DC discharges CMC and ICMC.

A relation of the type (1) has been obtained.

$$\frac{\Delta I}{I_0} = a + bB + c\sqrt{B} \qquad (1)$$

The coefficients of the dependence (1), the correlation coefficient and the standard deviation for the two types of DC discharge obtained using a multiregression correlation [11] are listed in Tables 1 and 2.

The values of the magnetic field corresponding to the maximum of the relative total intensity are listed in the both tables. The positive values of $\left(\Delta I/I_0\right)_{\max}$ show an increase of TVI in the presence of the magnetic field. The negative values indicate a diminishing of the TVI when the magnetic field is applied. Our mathematical model predicts an increase of the light source efficiency at lower values of the discharge voltage for CMC and for higher values

Table 1

The coefficients from (1) at different *Ud*; correlation coefficient *R*; standard deviation *SD*; magnetic field strength B_{max} and relative total intensity variation $(\Delta I/I_0)_{max}$ corresponding to the maxim efficiency of the CMC dc GD

Nr.	*Ud* [V]	*a*	*b*	*c*	*R*	*SD*	B_{max} [mT]	$(\Delta I/I_0)_{max}$
1	550	29.978	29.053	25.554	0.986	18.20	0.193	24.36
2	700	48.568	14.936	0.016	0.969	29.31	0.000	48.57
3	800	11.320	1.514	58.385	0.996	10.66	371.784	–551.56
4	900	13.905	2.716	60.435	0.986	16.99	123.786	–322.29

Table 2

The coefficients from (1) at different *Ud*, correlation coefficient *R*, standard deviation *SD*, magnetic field strength B_{max} and relative total intensity variation $(\Delta I/I_0)_{max}$ corresponding to the maxim efficiency of the ICMC dc GD

Nr.	*Ud* [V]	*a*	*b*	*c*	*R*	*SD*	B_{max} [mT]	$(\Delta I/I_0)_{max}$
1	550	–11.235	5.155	7.059	0.995	6.86	0.469	–13.65
2	700	–24.640	6.206	14.116	0.974	21.68	1.293	–32.67
3	800	–43.127	–0.946	42.917	0.970	14.93	514.54	–31.79
4	900	–22.537	–0.167	25.036	0.960	12.37	5618.71	915.79

of the discharge voltage for ICMC. Moreover, it was shown that the maximum efficiency of light source was obtained for ICMC at a voltage of about 900 V, when the relative variation of TVI has increased with approximately 900%.

The relative variation of TVI depends on *Ud* as predicts relation (2). The parameters of the dependence (2), correlation coefficient *R*, as well as standard deviation *SD* are contained in Table 3. The values of *Ud* corresponding to the maximum dc GD efficiency and the corresponding values of the relative variation of TVI are also given in this table.

$$\frac{\Delta I}{I_0} = A + BU_d + CU_d^2 \tag{2}$$

Table 3

The coefficients from (2) at different *B* (for CMC in the first row and for ICMC in the following two rows), correlation coefficient *R*, standard deviation *SD*, discharge voltage $(Ud)_{max}$ and relative TVI variation $(\Delta I/I_0)_{max}$ corresponding to the maxim efficiency of the DC discharge

Nr.	$10^3 B$ [T]	*A*	*B*	*C*	*R*	*SD*	$(Ud)_{max}$ [V]	$(\Delta I/I_0)_{max}$
1	26	–1201.71	3.586	–0.0023	0.996	7.46	779	196.04
2	18	–814.480	2.824	–0.0020	0.976	13.66	706	182.39
3	26	–991.96	3.565	–0.0026	0.953	29.29	685	230.04

5. FINAL REMARKS

The results reported represent a first attempt of a comprehensive study on the cylindrical coaxial magnetron discharge obtained in air, used a light source.

It was confirmed the expectation that this device could act as a very efficient source of visible light. The problem was to find the experimental conditions to obtain a higher conversion efficiency of the electric energy injected in the discharge into visible radiation. Our preliminary results have shown that the NG of a dc GD in the cylindrical magnetron configuration can be used as a light source.

The effect of external magnetic field on TVI emitted by the excited species of a molecular mixture (dry air) from the negative glow in a coaxial geometry configuration has been evaluated.

It was proved that the magnetic field strength and the discharge voltage can control the efficiency of electron neutral excitation frequency. Moreover, the use of air as working gas can diminish considerable the costs of the light source. It was shown that the highest efficiency of the light source has been obtained in the inverted coaxial magnetron configuration (ICMC).

A mathematical model was developed to predict the experimental conditions (values for the magnetic field strength B and the discharge voltage Ud) to obtain the highest values of TVI. It was found a good concordance between the experimental data and the results from the mathematical model.

Further work will include the optimization of the light source based on a discharge in air, from the point of view of magnetic field strength, neutral gas pressure and discharge voltage, using the proposed mathematical model.

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