NEGATIVE GLOW PLASMA AS A CONVERTER OF ELECTRIC ENERGY INTO RADIATION

M. Toma[*]

Plasma Physics Department, Faculty of Physics, "A. I. Cuza" University,
Iasi-700506, Romania

Experimental results regarding the influence of external control parameters (discharge current, discharge voltage, magnetic field strength) on the intensity of radiation emitted by the negative glow (NG) of a dc glow discharge are presented. Optimal operation conditions with respect to the excitation efficiency are evaluated. The results can be used in developing and applications of a glow discharge in a coaxial cylindrical geometry as a possible light source.

1. Introduction

The most commonly used method for generation and sustaining a low temperature plasma is by applying an electric field to a neutral gas from a discharge vessel, using interior electrodes. Charge carriers accelerated in the electric field couple their energy into the plasma via elastic and inelastic collisions with neutral particles.

In elastic collisions with atoms and/or molecules, electrons retain most of their energy because of their low mass, and transfer their energy to neutrals in inelastic collisions (excitation and ionization).

Different types of discharges can be obtained depending on applied voltage and discharge current [1,2]. One of this discharges is called dc (direct current) glow discharge plasma.

In certain conditions, low pressure glow discharge (GD) exhibits a characteristic luminous structure: alternately luminous and dark regions [1]. An interesting part of a GD is the cathode region. The negative glow (NG) is a part of the cathode region immediately next the high field cathode fall. The NG is a weakly ionized plasma with a low electric field, where a high – energy electron beam accelerated in the cathode fall penetrates and, through excitation collisions, produces an intense bright light [1,2]. The NG is the brightest part of a GD.

The conversion of the electric power to visible light by means of electric discharge is extremely important in different applications such as light sources, spectral lamps, lasers, environmental clean up, displays etc [2,3]. The efficiency of this conversion depends on the frequency of electron-neutral excitation collision (ν_{en}). For a given electron energy distribution function, ν_{en} depends on the electron concentration (n_e) and on the excitation cross section for a certain spectral line [4, 7]. If an additional transverse magnetic field is present, the efficiency of the electron – neutral collision processes can be significantly increased, because the increase of the magnetic field strength is equivalent with an increase of the neutral gas pressure [5, 6].

The aim of this paper is to obtain some information about the discharge conditions in which the conversion of the electric energy injected in the discharge volume is converted to visible light with a high efficiency.

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[*] Corresponding author: mtoma@uaic.ro

2. Device description and mode of operation

The basic structure of the discharge device is schematically shown in Fig.1. The device consists of two electrodes placed in a glass envelope: an external cylinder and a coaxial wire. The central electrode is a wolfram wire 0.1 cm diameter and 12 cm length. The external electrode is a stainless steel cylinder 4 cm diameter and 12 cm length. A voltage U in 500-1000V range is applied between the two electrodes, which can alternately play the role of anode (A) and respectively cathode (C). An axial magnetic field is produced using two coils (H), co-axially placed. The proposed configuration is similar to that considered in [5] as concerning the geometrical arrangement of the electric (E) and magnetic (B) fields. The device can work in *magnetron configuration* (MC) when the central electrode is the cathode and in *inverted magnetron configuration* (IMC) when the central electrode is anode. In both above configurations the discharge works in crossed $\vec{E} \times \vec{B}$ fields.
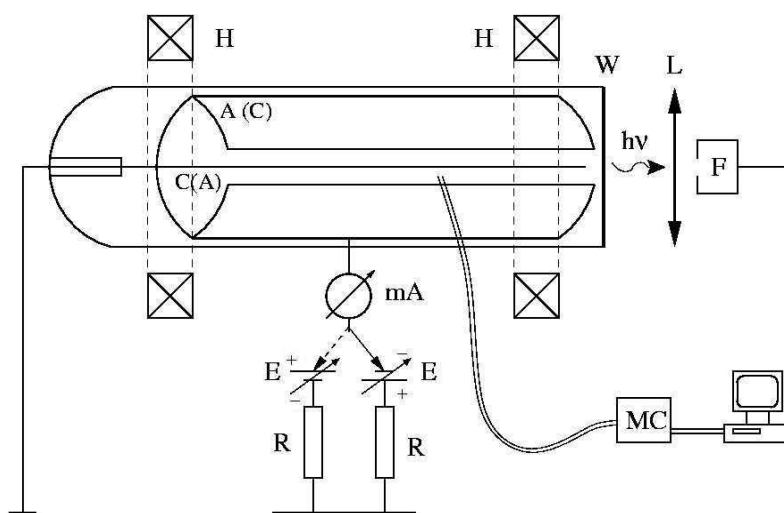

Fig. 1. Experimental set-up.

Flowing nitrogen was used as working gas in the pressure range of 0.1-1.0 Torr and with a flow rate of Q=1-5 litter/h. In the experiment was used flowing gas to avoid the impurity contamination from the discharge chamber, not outgased by the high vacuum system. The base pressure of about 0.01 Torr was obtained using a fore pump alone. Under these conditions the glow discharge is strongly abnormal and the discharge space is filled up with the NG only. The light emitted by the NG was focused using an optic fiber, onto the entrance slit of a spectrograph (ORIEL Multispec) MC coupled to a PC. The spectrograph was calibrated with Hg, for the spectral range of interest (300-800 nm). The spectrometer resolution can be adjusted to 0.02 nm. A lens L was used to focus the total intensity radiation (TIR) onto the slit of a photomultiplier tube (F).

3. Results

Using the device above described, two series of measurements were realized: a) the total intensity radiation (TIR) emitted by the NG and b) the intensity of two N_2 emission lines $\lambda_1 = 399.40$ nm and $\lambda_2 = 405.67$ nm.
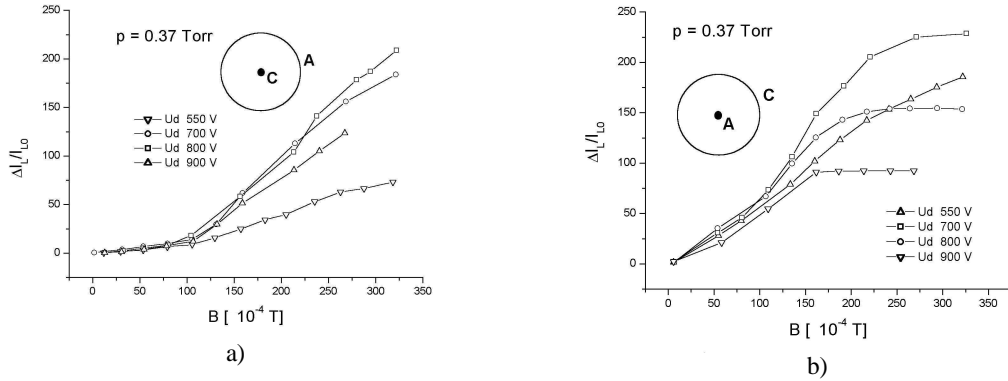
Fig. 2. The relative variation of the TIR ($\Delta I_L/I_{0L}$) versus magnetic field (B) in MC (a) and IMC (b) for different values of discharge voltage (U).

a) The total light signal was detected by the F in the axial direction, in the two modes of discharge operation: MC and IMC. The relative variation of the TIR ($\Delta I_L/I_{0L}$) versus magnetic field (B) in the two configurations, for different values of discharge voltage (U), are shown in Figs. 2 a,b. From these graphs results, for example, that at a certain value of B (B = 26 mT), the dependence $\Delta I_L/I_{0L}$ versus U has the shape shown in Figs. 3a (in MC) and 3b (in IMC). Considering the relative variation of TIR as a measure of the **e**xcitation **e**fficiency (EE), the following important remarks result: i) the EE is increasing with B increasing, with a saturation tendency at relatively high B; ii) the EE is higher in IMC than in MC; iii) for each configuration, at a certain neutral gas pressure, there is a U value corresponding to the EE maximum.
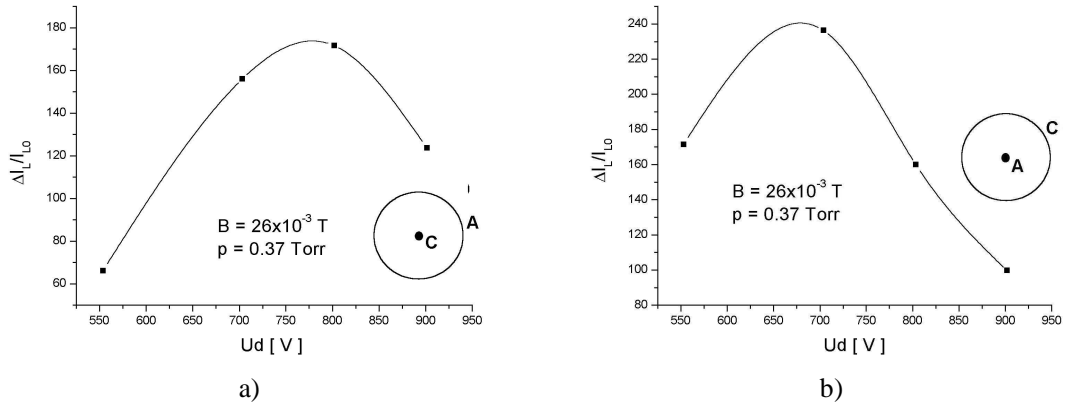

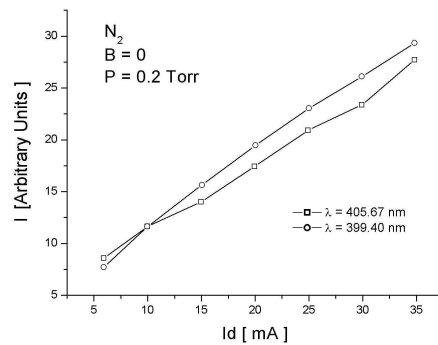Fig. 3. The dependence $\Delta I_L/I_{0L}$ versus U in MC (a) and IMC (b).

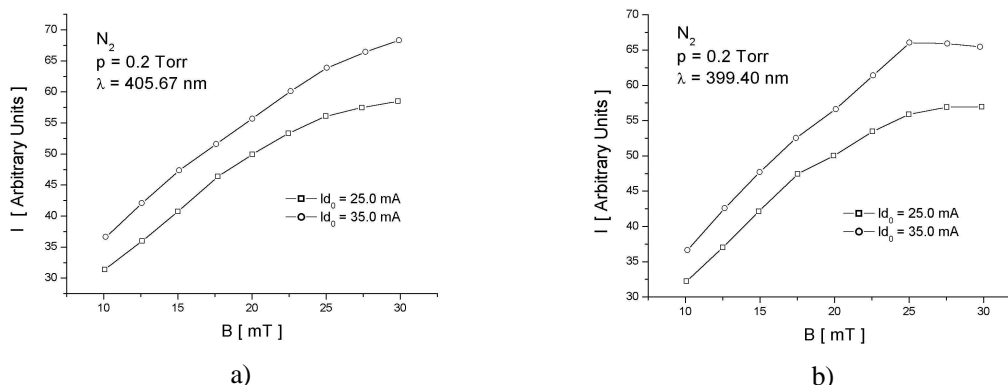Fig. 4. Spectral line intensity versus discharge current.

Fig. 5. The spectral lines intensities versus magnetic field strength.

b) We have performed a series of experiments where the neutral gas pressure was held at a constant value (p = 0.2 Torr); first, was modified the discharge current (I_d) at B = 0 and second, for a constant I_d, the magnetic field strength was modified. Generally, spectral lines intensities (I) increase with the I_d increasing. A typical dependence of the λ_1 = 399.40 nm and λ_2 = 405.67 nm spectral line intensity on the I_d is shown in Fig. 4. With the increase of B, for other constant operating conditions (p and U), the intensities of the spectral lines λ_1 and λ_2 increase, with a tendency to saturation for relatively high B (Figs. 5 a,b). I_{d0} represents the discharge current at B = 0.

From the above results it can be concluded that I_d and B can contribute significantly to the increasing of the excitation collision frequency.

4. Summary and conclusions

We have investigated the radiation emitted by the NG of a GD in the cylindrical MC and IMC configurations. We have focused on the influence of I_d, U and B on the intensity of radiation. The intensity of radiation (TIR and different line intensities) was considered as a measure of EE of the electron – neutral collisions.

The experimental results show that the intensity of radiation and, consequently, the EE, is increasing with the increase of discharge current (I_d) and also with magnetic field strength increasing (B). In the first approximation, I_d is proportional with the electron concentration n_e. If n_e is increased, the number of electron-neutral collisions increases and therefore, the concentration of excited atom system increases approximately proportional with the discharge current [4].

The magnetic field influences the collision frequency between electrons and neutral particles. The electron velocity has a component due to the motion along the electric field and other component due to the gyration around magnetic field line. So, the magnetic field has as effect a decrease of the mean free path of the electrons in the electric field direction and provides a sufficiently high excitation rate, having as effect an increase of the intensity of optical radiation. This effect is equivalent with an increase of the neutral gas pressure. In fact, in both situations, an increase of excitation cross section of the spectral lines takes place. The inverted magnetic configuration has more efficiency in conversion of the energy of electrons from NG into radiation.

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