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Characterization of a modified hollow-cathode discharge plasma by optical means

R.P. Apetrei[1,2*], P. Balan[2], D. Luca[1], D. Alexandroaei, C. Ionita[2], R. Schrittwieser[2] and G. Popa[1,2]

[1]Faculty of Physics, "Al. I. Cuza" University, RO-700506 Iaşi, Romania

[2]Institute for Ion Physics, University of Innsbruck, A-6020 Innsbruck, Austria

1. Introduction

As the search for specific sputtering sources remained a priority for decades, a novel configuration based on the so-called cavity hollow-cathode (CHC) geometry [1] looks very promising. It is simple, cheap and highly efficient in terms of the use of target material. Unlike magnetron sputtering sources, the CHC overcomes the difficulties associated with sputtering of ferromagnetic materials. Additionally, due to intense substrate ion bombardment, good quality ferromagnetic films can be prepared. Implementing such a sputtering source requires further characterisation. This has been done previously, mainly by electrical diagnosis [2].

In this contribution experimental results are presented concerning the spatial distribution of the relative values of the electron plasma density within the space between the two electrodes of the hollow structure for discharge parameters relevant for the sputtering regime (Ar pressure between 6×10^{-2} and 9.5×10^{-1} mbar, discharge current about 10 mA) of a Ni target [2]. Additional measurements of the light emission have been done in front of the exit nozzle of the hollow-cathode source to correlate the optical and electrical diagnostic results, and thereby finding a scaling factor.

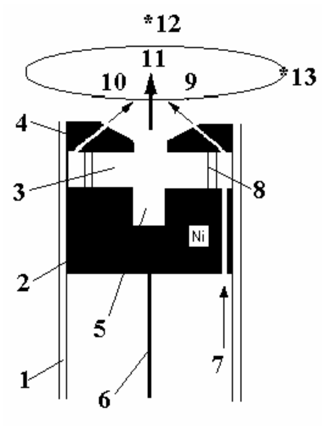


Fig.1. The schematic diagram of the cavity-hollow cathode.

The relative value of the electron plasma density was determined assuming an optically thin plasma, where excitations are produced by electron-atom collisions and de-excitation by spontaneous transitions. The radial distribution of the light intensity was measured at different positions along the distance between the two electrodes. After application of

* E-mail: rapetrei@uaic.ro

an Abel transformation to the radial distribution of the light inten sity, the quantity proportional to the electron plasma density was calculated [1].

2. Experiment

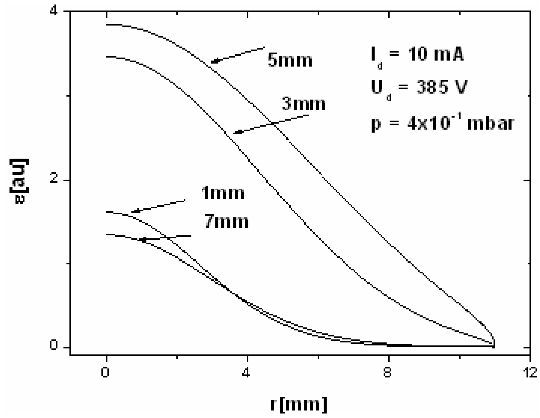
The sputtering source to deposit ferromagnetic thin films is schematically shown in Fig.1. In a cylindrical glass tube (1), two 25-mm diameter Ni disks (2) and (4) are used to enclose a 1.4 cm^3 cylindrical cathode cavity (3) within the glass spacer (8). The lower electrode (2) has a central 5 mm diameter cylindrical hole (5) to enhance the ionization rate inside the cathode chamber. A 3 cm diameter ring anode (13) is co-axially inserted 1.8 cm away from the nozzle, close to the film substrate (located in position 12). Ar gas was introduced in front of the nozzle through three inlets (7, 9, 10), while power was applied to the cathode via the electrode (6). Under normal operation, a conically shaped glowing plasma jet (11) occurs in front of the cathode, where the particle motion is controlled by electrical and pressure gradients.

Optical measurements were performed using an optical fibre, a monochromator and a photomultiplier. Using a stepper motor to move the optical fibre, the radial distribution of the light intensity was measured at different position along the distance between the two electrodes and in front of the exit nozzle of the hollow-cathode source. The light intensity was measured for 434.8 nm wavelength. This line of the optical emission spectrum corresponds to the de-excitation of singly ionized argon between the energy levels of 19.49 eV and 16.64 eV [3]. To determine the plasma emissivity, which is proportional to the electron plasma density, we use Abel inversion. In the case of cylindrical symmetry of the light source the observed projected intensities can be transformed into radial distribution within the plasma [4].

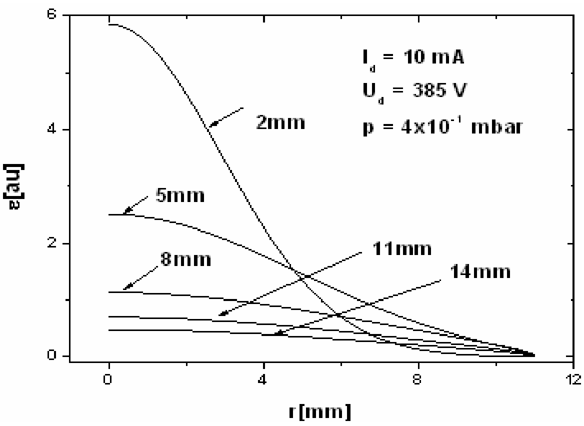
3. Results and discussion

Optical diagnostics were performed for pressures ranging between 0.4 and 0.95 mbar and a discharge current of 10 mA. The obtained curves of the light intensity were fitted using a Gaussian function with correlation coefficients R^2 more than 0.99. The Gaussian functions were used in the Abel inversion to obtain the emissivity $\varepsilon(r)$ as described below. Different positions on the symmetry axis (i.e. the z-axis), are considered going from the lower electrode to the upper one (when we are between the electrodes), and going from the upper electrode to the anode (when we are between the upper electrode and the anode).

If $I(y)$ is the measured intensity of the radiation integrated over the line of sight at a distance y from the centre, and $\varepsilon(r)$ - the local emissivity of the plasma at a distance r from the centre,



(a)



(b)

Fig.2. Plasma emissivity ε at different positions on the axis of symmetry, z-axis:
(a) between the electrodes (2) and (4); (b) between the cathode and the anode.

then $I(y)$ *is* related to $\varepsilon(r)$ by the equation:

$$I(y) = 2\int_0^{(R^2-y^2)^{1/2}} \varepsilon(r)dx = 2\int_y^R \frac{\varepsilon(r)rdr}{(r^2-y^2)^{1/2}}. \quad (1)$$

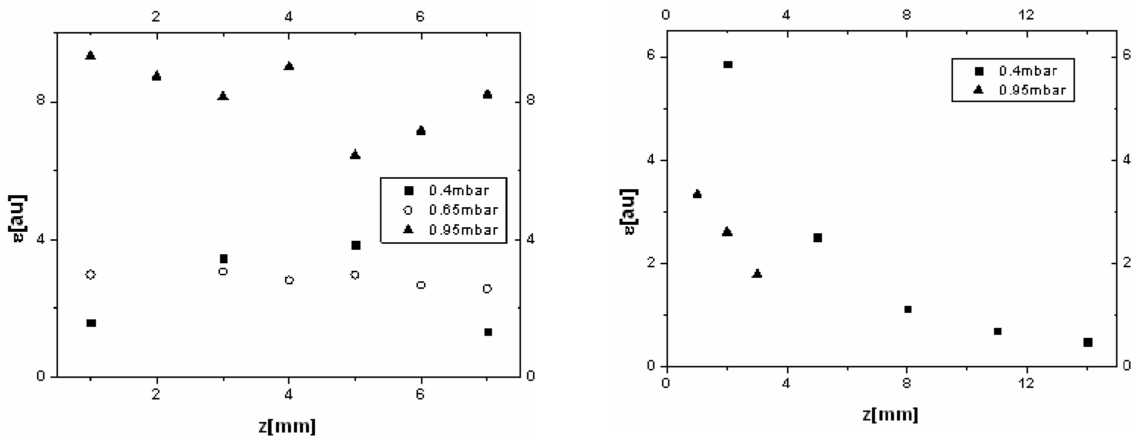
R is the radius at which $\varepsilon(r)$ becomes zero. An inversion yields the desired quantity $\varepsilon(r)$:

$$\varepsilon(r) = -\frac{1}{\pi}\int_r^R \frac{dI(y)}{dy}\frac{dy}{(y^2-r^2)^{1/2}}. \quad (2)$$

Since Eq. (1) is of Abel type, Eq. (2) is the corresponding Abel inversion.

As shown in Fig. 2(a), the plasma emissivity and the corresponding plasma density are smaller near the electrodes. It was observed that in the spacer region the plasma is confined close to the electrodes. In the mid-distance between the electrodes (2) and (4) the emissivity is larger and the plasma expands into the whole spacer. Between the upper electrode and the anode (Fig. 2(b)), the emissivity decreases drastically towards the anode. In the same time, the plasma is more dense and confined near the upper electrode.

If we monitor the plasma emissivity along the symmetry axis for different pressures, we can observe the following facts (see Fig. 3). Between the electrodes, the plasma emissivity reaches a maximum at the mid-distance between the electrodes (2) and (4) for p = 0.4 mbar. It is almost constant along the z-axis for p = 0.65 mbar, while for p = 0.95 mbar it shows a minimum in the middle of the inter-electrode distance. As shown in Fig. 3(b), the emissivity is decreasing with increasing pressure at a certain location between the anode and cathode. The emissivity decreases while approaching the anode for all pressures under investigation. A decrease of the length of the plasma jet with increasing pressure is also noticed.



(a) (b)

Fig.3. Plasma emissivity along the axis of symmetry for different pressure values:
(a) between the electrodes (2) and (4); (b) between the upper electrode and the anode.

4. Conclusion

Optical measurements were performed to diagnose the post-discharge Ar plasma jet in front of a cavity-hollow cathode post-discharge and between the electrodes. There are clear similarities between electrical and optical diagnosis. It was observed that the plasma emissivity shows a rapid monotonous decrease along 2 cm on the axis in front of the hollow-cathode, which is correlated to the evolution of the electron temperature, plasma density, and ion velocity distribution functions. This evolution is also observed by electrical methods. Optical diagnosis of the plasma inside the CHC shows that the radial distribution of the plasma density is almost Gaussian, while axially it is rather constant.

Further optical emission spectroscopy experiments are in progress to monitor the distribution of the atomic species both inside the hollow cathode and in the anode-cathode interval to get data for the design of a suitable geometry for film deposition.

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