

CHARACTERIZATION OF A DC PLASMA WITH HOLLOW CATHODE EFFECT

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Abstract. As Gunterschultze showed, the hollow cathode effect (HCE) is essentially an effect of the strong ionization produced by fast electrons in the cathode region of a glow discharge. These fast electrons are accelerated in the cathode sheaths, then electrostatically confined to oscillate between cathode surfaces. This is the so-called pendulum effect responsible for the HCE. Contradictory suppositions about the role of the UV radiation generated in the discharge were launched: Little and von Engel considered that UV enhancement of the secondary emission is large enough to play a major role in the HCE, while Pillow concluded that the role of photons and metastable is less significant. Today, it is considered that the dissipation of the energy into the bulk plasma is mediated by the fast electrons which have acquired a considerable kinetic energy in the cathode space-charge sheaths. The density of those electrons is large due the increased flux of the ion which are incident on the cathode surface. Consequently more γ -electrons are released in the secondary emission processes due to this ion bombardment and the number of the diffusion of charge carriers to the wall decrease. The discharge tube that is used in the following experiment has an inner diameter of 40 mm and it is cross - shaped. Metallic electrodes are placed in each branch of the tube, allowing experiments with one, two or three cathodes. The pressure range of Ar was $5 \cdot 10^{-2}$ Torr – $5 \cdot 10^{-1}$ Torr, the voltage range was 300 V – 1000 V and the discharge currents range was between 1 mA and maximum 25 mA. The scope of our work was to measure the external parameters, such as the breakdown potential and the discharge voltage-current characteristics.

Key words: hollow cathode effect, breakdown potential, V-I characteristics, three plane parallel cathodes

INTRODUCTION

Hollow cathodes discharges (HCD) are split in two big groups: conventional hollow cathode (CHC) and modified hollow cathode (MHC) [1]. The conventional hollow cathode discharge device was developed by Paschen in 1916. The HCD are characterized, in their conventional form, by cathode surface (planar, cylindrical, spherical or other geometry) which contain the negative glow while the anode is placed outside the discharge cavity. The modified hollow cathode discharge (MHCD) has the anode inside the cavity [2]. For example, discharge electrodes can be placed in an alternate manner on the same cylindrical surface. Although all these geometries yield HCDs, there are some differences in electrical

properties. For example, in MHCs one can find somehow higher voltages, higher slope resistances and enhanced ionization, excitation and sputtering rates. A HCD plasma source can be operated, for example, in Ar over a range of pressures 10^{-5} Torr – 10 Torr; a typical range of currents would be 20 mA – 200 mA and typical discharge voltages are about 500 V. In some recent works [3] HCE was observed in high - pressure (10^2 Torr – 10^3 Torr) discharges produced in microcavities.

THEORY

To understand the working principle we show the followings. For beginning, we consider two parallel metallic plates in a vacuum discharge tub filled with a low pressure ($\sim 10^1$ Torr) gas. For a given inter-electrode (anode and cathode) distance d_0 and gas pressure p there is an optimum value of the product $d_0 \cdot p$ such that the discharge voltage becomes minimum in perfect agreement with Paschen Law.

HCE consists in increasing of current intensity with decreasing of the pressure or of the inter-cathodes distance or the product of them. This phenomenon appears at low pressure, less than 1 Torr, when the simple discharge with one cathode burn at low discharge currents [4]. If the product between the gas pressure and the distance between cathodes is less than the critical value, $p \cdot d'$, the electrons reaching the opposite cathode fall are removed from the bulk plasma; in consequence the excitation and ionization rates decrease. [5]. Thus the hollow cathode is working in an abnormal regime of the glow discharge.

The discharge current density for the simple cathode is given by the following relation between various similarity parameters:

$$\frac{j_0}{p^2} = k \frac{V_k^{3/2}}{(pd)^{3/2}} \quad (1)$$

For the case of a double cathode we have:

$$jp^{1/2} = k \frac{V_k^{3/2}}{D^{3/2}} \quad (2)$$

In these equations V is the cathodic potential, d is the width of the dark space, p is the gas pressure, D is the distance between the hollow cathode and the anode and k is a gas - dependant constant. With these equations we can plot the Gunterschultz characteristics [6].

There are experimental evidences for the existence of three groups of electrons, in the negative glow which are trapped between the two plane-parallel cathodes by the electrostatic field. The three electronic populations are the fast (primary) electrons, the hot (secondary) electrons and the cold (ultimate) electrons [7]. Fast electrons, the least numerous but with great energy, are overwhelming the atoms' first ionization potential and they are responsible for ionizing processes and they define the volt-ampere characteristic. In the mean time they excite gas

particles. The cold group of electrons is dominant and they are responsible for plasma density, current transport and the potential shaping. The ionization produced by the fast electrons in the cathode region of a glow discharge is essential; they are emitted perpendicular to the cathode surface, moving like a beam parallel to the axial normal on the two opposite cathodes [8]. According to Little and von Engel, HCE appears when the negative glow of the two cathodic sides of the discharge are unified. HCE also has an optimal development when primary electrons emitted from one side of the cathode come to produce ionizations in Crookes dark space opposite to the side from which they were emitted. There are two reasons for the enhancement of the ionization rate: first, pendulum effect due to the electrons which are trapped many times in the bulk plasma being accelerated, and second, the decrease of the radial loss of charge carriers, ions and electrons, to the wall. Meantime the increase in the current intensity produces an increase of the discharge light emission [9]. When a magnetic field is applied, the radiation emission is growing up. The light emission increase is a reason to consider that the applied magnetic field is increasing the effectiveness of HCE [10].

EXPERIMENT AND RESULTS

The used experimental setup is presented in Fig. 1. We used a cross – shaped, Pyrex – type glass discharge tube with the inner diameter of 40 mm. The two horizontal sides of the tube are 90 cm in length and have mobile electrodes;

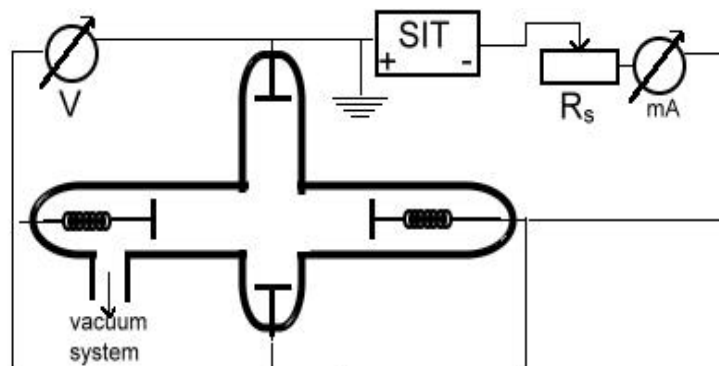


Fig. 1 - Experimental setup

this allows the inter-electrode distance to be varied from 4 to 30 cm. The other two sides are containing two electrodes placed 30 cm one from the other. This setup allows experiments with one, two or three cathodes. The electrodes are made from Ni and they have 30 mm in diameter. The discharge tube has, on one side, a quartz window with a diameter of 50 mm used for optical investigation of the discharge

(Fig. 2). On the opposite side is placed a Langmuir probe. The tube is connected to a vacuum system consisting from a rough vacuum pump, an oil diffusion pump, and the Argon reservoir. The investigated pressure range was $5 \cdot 10^{-2} - 5 \cdot 10^{-1}$ Torr. Power supplies like SIT 5060 (5 kV, 60 mA) and STATRON RFT typ (1.5 kV, 200 mA) were used. The voltage range was 300-1000 V and the discharge currents range was between 1 mA and maximum 25 mA. For measuring the current through and the voltage drop over the discharge tube we used digital multimeters.

We measured breakdown curves and VI characteristics using Ar as filling gas and Ni as cathode material in the following conditions: pressure range $5 \cdot 10^{-2}$ Torr – $5 \cdot 10^{-1}$ Torr, discharge voltage range 300 V – 1000 V and discharge current range 1 mA – 25 mA. The results are shown in Fig. 3-6.

The breakdown curve shows that there is a value for $p \cdot d$, for which the breakdown voltage becomes minimal, in agreement with the electrical breakdown theory. In the V-I characteristics we have found a good agreement between our measurements of HCE and the experimental data of other authors and the laws of the HCE.

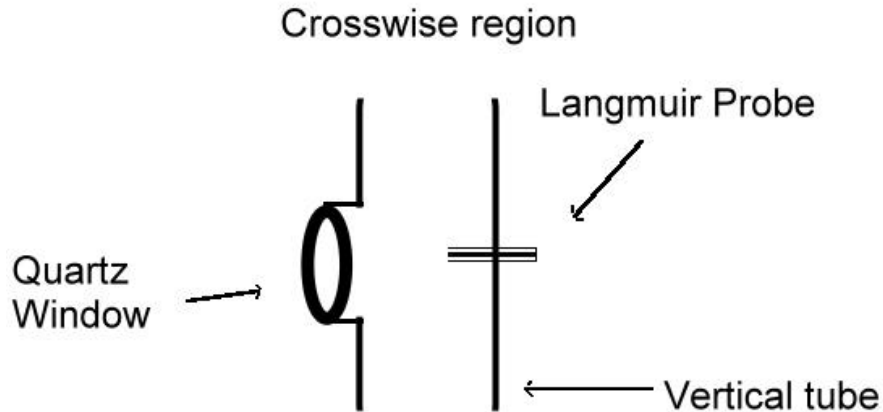


Fig. 2 - Detail of the area where the four branches of the tube are connected. A quartz window for optical investigation and a Langmuir probe for electric diagnostics can be seen.

In the VI characteristics one can see that the discharge voltage is saturated for high range current intensity values. This proves that HCE occurred. It can be seen that the HCE appears to be more effective for pressures starting at about 0.3 Torr (Fig. 4-6).

Due to the system symmetry, one may assume that the discharge current is split equally between cathodes. This assumption is not valid at low currents, where, due to slight differences in geometry and electrical properties of the three electrodes, the discharge covers only one cathode. In this situation the HCE is not present. This peculiarity can be seen in the low-current range of Fig. 4-6.

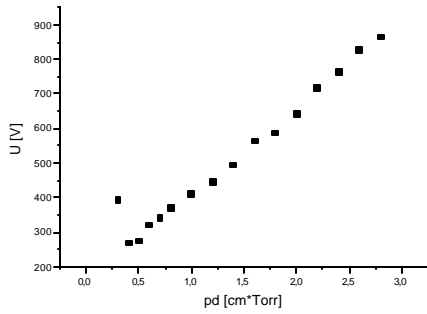


Fig. 3 - Breakdown potential curves for a discharge in Ar with simple cathode

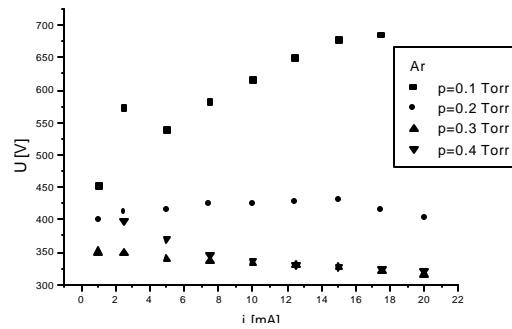


Fig 4 - V-I characteristics for a discharge in Ar with simple cathode

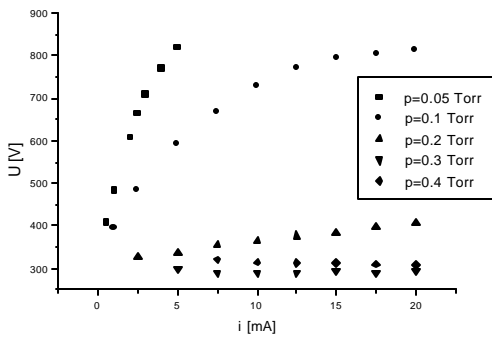


Fig. 5 - V-I characteristics for a discharge with Ar with double cathode

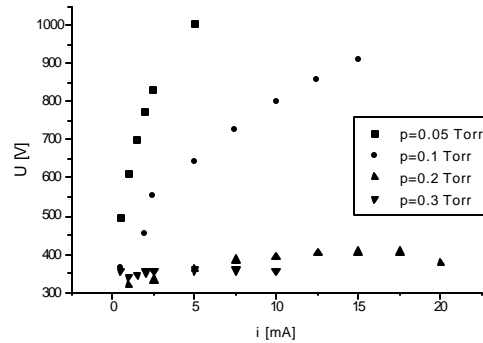


Fig. 6 - V-I characteristics for a discharge with Ar with triple cathode

CONCLUSIONS

Hollow cathode discharges have been used for many years as a spectral sources for atomic emissions. HCDs have been widely investigated both theoretically and experimentally with many results in technological and scientific applications. In this work, a system with three plane and parallel cathodes is presented. The discharge produced in this device has all the characteristics of a hollow cathode discharge. This is demonstrated by the slow increasing of the voltage drop over the discharge with respect to the increase of the discharge current.

In the future works we intend to investigate the HCE by optical and electrical techniques (see Fig. 2). Also, a system consisting in two independent crossed discharges can be created and studied. Another issue could be the use of a magnetic field for the intensification of hollow cathode effect. On this setup, electron density, ion density, electron temperature, breakdown potential, floating potential, plasma potential, voltage-current characteristics of the discharges and the electron energy distribution function in discharge can be measured. This work shows the HCE with three plane parallel cathodes.

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