MEASUREMENTS OF AXIAL POTENTIAL PROFILES OF DOUBLE LAYERS IN A LOW-PRESSURE MERCURY-ARC DISCHARGE

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Abstract

Measurements of the axial potential profiles of electrostatic double layers (DL) have been performed in the positive column of a discharge of high current density (3.0 – 8.0) 10^3 A/m^2, operating at low-pressure mercury vapor (2.0 – 14.0) 10^{-2} Pa. Ordinary DL having a monotonic potential profile as well as multiple layers are shown to form by driven the discharge towards current limitation combined with the effect of a magnetic field produced by a single coil or a Helmholtz coil placed coaxially with the discharge tube. This low intensity B-field of the coil (70 – 100) Gauss acts just locally such that its has minor effects on the plasma adjacent to the DL, nevertheless it plays a key role to determine the space charge structure of the stationary DL formed close to the coil position. The motion of the DL along the column is controlled by the displacement of the coil in the axial direction. This technique allowed potential measurements to be taken across the DL and on the adjacent plasmas by means of a self-emissive probe located at the axis of the discharge tube. These potential profiles were investigated regarding the effects of the operational parameters, namely the gas pressure, the discharge current and coil current. The results show that using the conjugated effects of these parameters a controllable modification of the space charge structure can be promoted being possible to produce weak or strong DL in the plasma column. It is noticeable that an electron hole, which is symmetric triple-layers with a bell shape potential profile, can easily be formed by this experimental technique.

1. Introduction

A plasma Double Layer (DL), is usually identified by a discontinuity in the plasma potential. The DLs are regions of non-neutral plasma, which induce a large potential drop thereby originating very strong local electric fields. Current driven DLs are shown to form in low pressure arc-discharges as the current density is increased to a critical value, see Maciel and Allen [1]. In this work the DL is formed at a desired place of the cylindrical plasma column by producing a magnetic constriction of the plasma column using a single coil (or a Helmholtz coil). The field of the magnetic coil acts just locally on the plasma thereby increasing the current density and consequently the thresholds conditions for the formation of electrostatics layers are reached in that region. The double layer formed comprise normally multiple space charge layers being possible to produce a continuous modification of their space charge structure by acting on the discharge current and on the magnetic coil current. It is noticeable that by this process a perfect electron hole can easily be formed. This electrostatic electron hole is a symmetric triple-layer (a positive layer between two negative layers) and has a bell shape potential profile. Electron holes of small amplitudes have been studied theoretically and numerically in the collisionless and weakly collisional approximations in a current carrying plasma [2]. In our case these structures are stationary and they can be generated with pick voltage higher than 100 V, characterizing thus strong electron-holes in a plasma column where the typical electron temperature is about 5 eV.

2. Experimental apparatus and methods

The experiments were performed in a tube discharge similar to that of Maciel and Allen [1]. The central region is a Pyrex tube 1.0 m long and 30 mm internal diameter. Measurements were made with mercury vapor pressure, in the range of (2.0–14.0) 10^{-2} Pa in the central region and discharge current in the range of (1.0 – 5.0) A. The potential profiles of the DLs were obtained by the technique of self-emissive probe for measurements of electrostatic potential. The probe was positioned at the axis of the discharge tube while the double layer, once formed, was axially displaced by just following the motion of the coil. This displacement starts with the probe initially in the anode region with respect to the DL, being the probe self-heated by the own anode plasma. The floating potential of the probe is recorded during the excursion of the probe for about 30 cm as it follows closely the motion of the coil towards the anode.

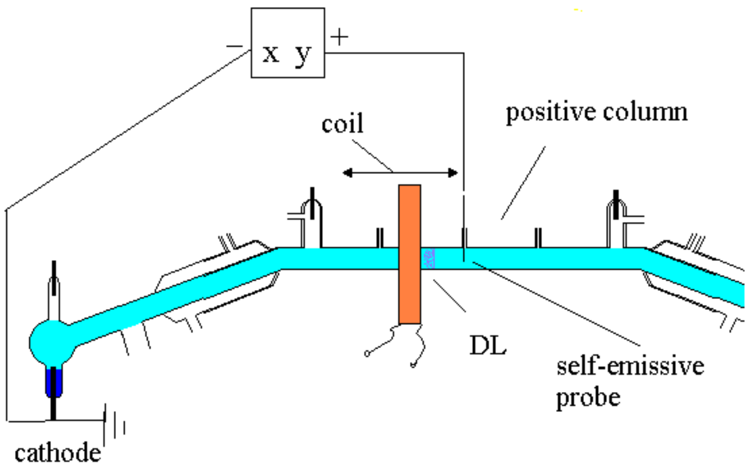

Figure 1. Circuit used for the determination of the floating potential of the self-emissive probe. The DL crosses the probe by moving along with the magnetic coil. The details of the discharge apparatus are better described by Maciel and Allen [1].

3. Experimental results and discussion

The curves of Figure 2 represent the potential profiles obtained for fixed values of pressure (P) and coil current (Ib) and for different values of discharge current.

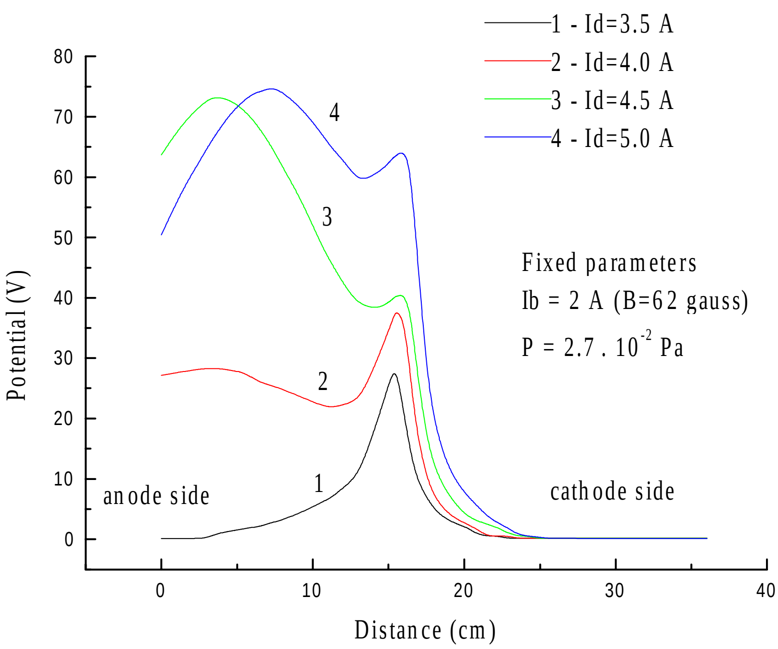

Figure 2. Effect of the current discharge (Id) on the potential profile. The coil current (Ib) was fixed at 2 A producing a magnetic field (B) of 62 Gauss. The mercury vapor pressure was fixed at 2,7 10^{-2} Pa in the central tube.

Initially –curve 4- we observe an approximately monotonic profile (but already with evidence of a weak electron hole). By lowering the discharge current, the height of the potential pick is gradually reduced keeping however in the same position. Lowering further more the discharge current makes the anode plasma potential to approach the cathode plasma potential, the profile becomes gaussian shape which is typical of a symmetrical electron-hole, as depicted in curve 1. When the electron-hole is formed at a certain value of Id its potential amplitude can be varied by dealing with the pressure and with the coil current. The curves of Figure 3 show the effect of the pressure on the electron-hole potential profile. The width and amplitude of the electron-hole potential profile increase as the pressure decreases and it is remarkable that very strong electron-holes can be generated by lowering the vapor pressure in a short pressure range.

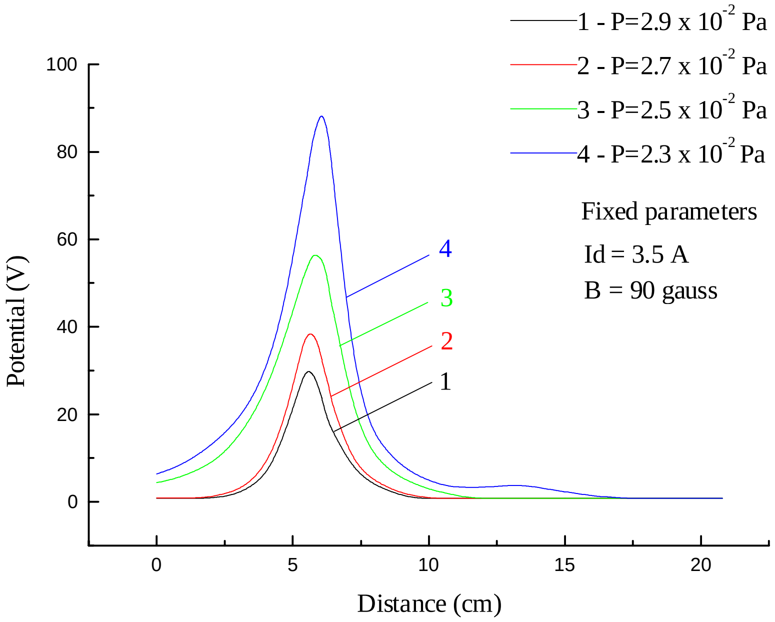

Figure 3. Effect of the mercury vapor pressure on the potential profile of the electron-holes.

The family of curves of the Figure 4 illustrates the effect of the coil current on the potential profile of the electron-hole. We observed that the amplitude is quite sensitive to the coil current and that the electron-hole only exists above a minimum value of Id. In fact, in previous work, Maciel and Allen have not observed the formation of symmetrical electron-hole in a magnetic field free plasma column.

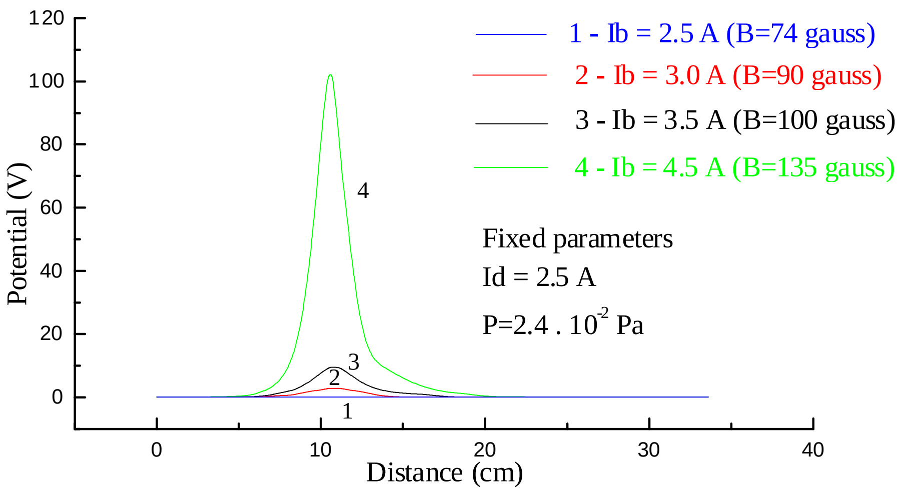

Figure 4. Effect of the magnetic field on the potential profile of a perfect electron hole.

Figure 5 is representative of the kinetic structure of a electron hole measured in the plasma column. The space charge structure comprises three populations of charged particles namely, the plasma electrons that can be described by a drifting-Maxwellian distribution function of electron velocities, the plasma ions trapped at each side of the electron-hole that can be described by a Maxwellian without drift and an ion-beam that crosses the electron-hole from anode side to cathode side. This energetic ion-beam should exist to create the preponderant positive space charge in the central region of the electron-hole.

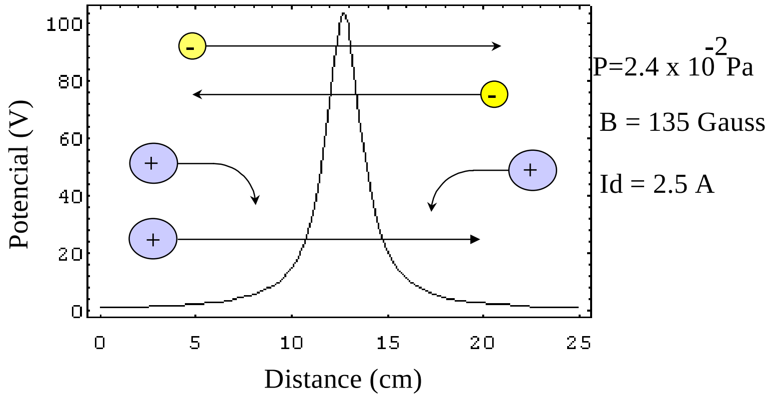

Figure 5. Potential profile of an electron-hole indicating the population of constituent particles of the space charge.

4. Conclusions

In the present work we showed that the use of a single coil to apply a weak magnetic field in a short region of the positive column of a low- pressure mercury -arc discharge is a reliable means to induce the formation of stationary double layers. Moreover the DL follows concomitantly a gently displacement of the coil making possible to record its potential profile as it crosses a Langmuir probe during the axial excursion of the coil. The probe is heated by the plasma and becomes self–emissive making the recorded floating potential a good approximation of the space potential. The modification of the electrostatic structure of DLs is shown possible to be made by dealing with the operational parameters of the discharge namely the vapor pressure, the discharge current and the coil magnetic field. Almost ordinary DL having a monotonic potential profile as well multiple layer due to the appearance of an electron hole on the anode side can be formed depending on these operational conditions. Pure electrostatic electron-holes can be formed by that means. In this case there is not a net potential drop between anode side and cathode side consequently no electric energy is dissipated across the electron-hole. However, a kinetic analysis of this space charge structure leads to the conclusion that an ion-beam capable of crossing the potential barrier presented by the electron-hole must exist. This ion beam comes from to anode region and builds up positive space charge in the center of electron-hole as it slows down when crossing the electron-hole. The discussion on the origin of this ion-beam is not in the scope of this work.

References

[1] H.S. Maciel and J.E. Allen: "Free double layers in mercury-arc discharge", Journal of Plasma Phys. 42, 321(1989)

[2] J. Korn and H. Schamell: J. Plasma Phys. **56**, 339 (1996)