*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-4.049 (2009)*

Controlling wall potential with small amount of energetic electrons

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In our previous work, the effect of a small amount of energetic electrons on plasma properties was examined for afterglow plasma and for the plasma of a short (without positive column) DC discharge with a hot cathode [1]. It was shown that in those cases the energetic electrons have free diffusion to the wall while slow electrons follow ambipolar diffusion. Due to this the flux of energetic electrons to the wall can be greater than the corresponding flux of ions, even though the density of ions is upwards of 10^5 times that of energetic electrons, due to the large difference in free and ambipolar diffusion coefficients. To maintain quasi-neutrality in the plasma, self-trapping of the energetic electrons at the walls takes place. Regulation of the density of the energetic electrons and/or application of additional potentials to the walls can change conditions for self-trapping of the energetic electrons, which in turn can change the plasma properties [2]. This control of the plasma parameters via self-trapping of energetic electrons could be useful for technological applications.

It is possible to expect that this effect is also significant in the short discharges with a cold cathode but, to date, experimental evidence for this type of discharge device has not been reported. The main point of the present paper is the experimental confirmation of the existence of large wall potentials due to the energetic electrons for some experimental conditions in a DC discharge with a cold cathode.

The plasma of a short discharge with cold cathode contains two groups of electrons with much different energies. The two groups consist of: a) a group of slow electrons with average energy well below 1 eV which are the majority, and b) a minority group (a small fraction of one percent of the majority) of energetic electrons, created in the volume of the plasma and accelerated in the near-cathode sheath. The energetic electrons can have much greater energies than the bulk electrons (up to hundreds of eV, depending on the discharge voltage). Those electrons can also be produced by processes in the volume of the plasma. Slow electrons are created via inelastic collisions of energetic electrons with atoms. Usually in the discharge the anode potential is differ from the plasma potential by not more than a few tenths of an eV [3].

Experiments in a short DC discharge with a cold cathode were conducted to confirm the existence of the effect of charging the discharge tube walls by energetic electrons in the cathode region. Fig. 1 shows a schematic of the experimental device. The discharge occurred between plane disk-shaped, molybdenum cathode (**C**) and anode (**A**) while the inter-electrode gap was bounded by a thin, cylindrical stainless steel tube, termed wall (**W**). The cathode and anode were each 2.5 cm in diameter, and the inter-electrode gap was 1.2 cm. The discharge device was enclosed in a pyrex chamber that could be evacuated to a residual pressure of 10^{-7} Torr and then filled with spectrally pure inert gas; He, Ne, and Ar gases were used here. The inert gas pressure ranged from 0.2 to 15 Torr, and the discharge current varied from 0.2 to 10 mA. In all experiments, the anode was grounded and the potentials of the cathode and wall were measured.

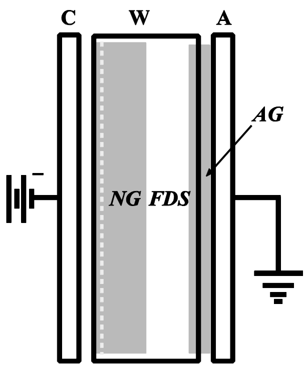

Fig. 1. Schematic diagram of experimental device consisting of: cathode (**C**), anode (**A**), and cylindrical wall (**W**). Typical structures of the discharge plasma are illustrated including the negative and anode glows, **NG** and **AG**, respectively and Faraday dark space **FDS** between the negative and anode glow. The cathode sheath boundary, located approximately in the negative glow, is indicted by the dashed line.

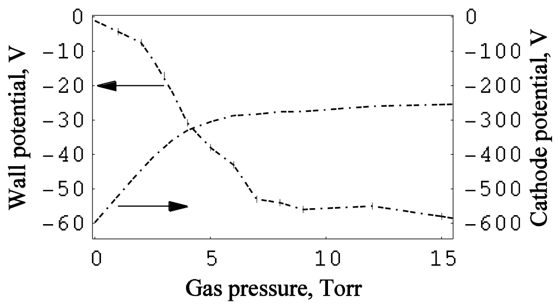

Fig. 2. Floating wall (left hand scale) and cathode potentials (right hand scale), indicated corresponding arrow, in Ar discharge. Discharge current is 3 mA.

Typical results of the floating wall, V_w, and cathode, V_c, potential as a function of gas pressure (with Ar gas and a discharge current of 3 mA) are shown in Fig. 2. Similarly, Fig. 3 shows a typical dependence of the floating wall potential and cathode potential as a function of discharge current for a constant gas pressure (0.2 Torr Ar). In Figs. 2 and 3, it can be seen that the wall potentials vary from a few volts to about 60 V depending on the discharge conditions and are always lower than the maximum energy of energetic electrons, which is calculated from the cathode potentials (RHS axes in the figures).

The results of our measurements can be explained as follows. The sheath boundary, in practical terms, coincides with the maximum emission in the negative glow (**NG**) and is illustrated as a dashed line in Fig. 1. In the near-cathode sheath (left of the dashed line), the electric field is very strong and directed perpendicular to the cathode face giving rise to a strongly anisotropic EEDF. Electrons originating in the near-cathode sheath region will have energies up to the energy corresponding to the discharge voltage. Due to the strong anisotropy, the majority of electrons in this region will be directed roughly parallel to the wall and few will reach and contribute to charging of the wall. Further from the cathode, past the sheath (to the right of the dashed line), energetic electrons lose their energy in collisions. The energy of the energetic electrons is thus distributed between the maximum energy and lower energy, with their energy diminishing with distance from the near-cathode sheath. Along with their energy, the energetic electrons also lose their directed velocity due to collisions, becoming more isotropic as they travel further from the near-cathode sheath (dashed line). The charging of the walls by energetic electrons thus varies with distance from the sheath. The variation of wall charging with distance may be important for devices with non-conducting walls but cannot be observed with the conducting wall used here. The charge on the wall will be the average over the entire wall. Wall potentials much higher than the corresponding electron temperature can only be achieved for cases when the flux of energetic electrons to the wall, averaged over the wall surface, is greater than the corresponding ion flux.

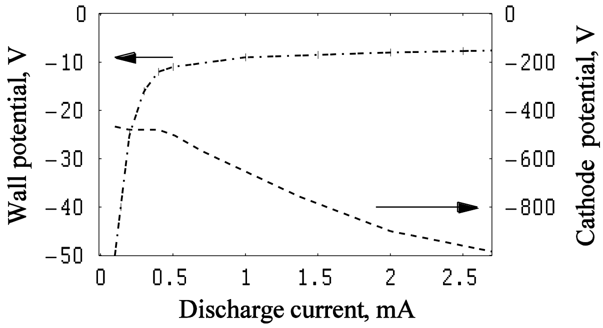

Fig. 3. Floating wall (LHS) and cathode potentials (RHS) for varying discharge current in 0.2 Torr Ar discharge (graph scales indicated by arrows).

The wall potential, shown in Fig. 2, increases (becomes more negative) with increasing cell pressure. The increase in wall potential with cell pressure is because the energetic electrons undergo more collisions with increasing pressure leading to greater randomization of the electron velocity direction and resulting in an increased flux of energetic electrons to the wall. Fig. 3 shows a decreasing wall potential with increasing discharge current. At higher discharge current (and discharge voltage), the electron velocity distribution is expected to be more anisotropic, i.e., directed from the cathode. Thus, at constant pressure, the flux of electrons reaching the wall should decrease with discharge current as the anisotropy of the electron velocity increases. The electron velocity anisotropy will increase as their energy increases with discharge voltage.

To demonstrate experimentally the presence of energetic electrons in the discharge, the cylindrical metal wall was used as an electric probe to measure the higher energy portion of the EEDF. Details and justification of those experiments will be published elsewhere. Fig. 4 shows the first and second derivative of the electron wall current as a function of the wall potential in a helium discharge. The wall current (LHS axis) is the lower curve with a sharp change in slope at roughly 1 V while the derivative curves are the upper curves. The first derivative curve is the smoothly decreasing curve and the second derivative curve shows peaks at approximately 15 and 20 V. The signature of energetic electrons produced from metastable atom is more easily seen in the second derivative curve which is also shown in Fig. 4.

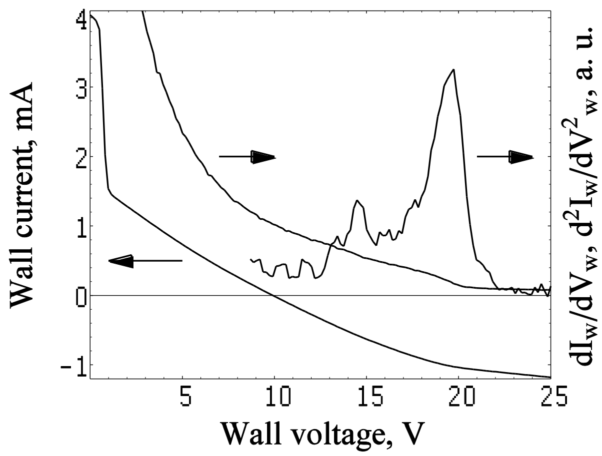

Fig. 4. Wall current (LHS), first (smooth curve) and second (curve with two peaks) derivatives (RHS) of electron wall current to the discharge wall as a function of applied voltage for a 4 Torr, 5 mA helium discharge. Two peaks correspond to energetic electrons arising in plasma.

In summary, it was shown experimentally that energetic electrons, accelerated from the cathode sheath, in a DC discharge with a cold cathode can charge the discharge walls to potentials much greater than the bulk electron temperature. The wall potential depends on the particular discharge conditions, e.g., gas pressure, discharge current, etc., and does not depend on the electron temperature. It was also shown that energetic electrons produced from reactions with metastable atoms in volumetric processes can be partially responsible for charging the walls. This work was supported by the AFOSR.

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