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SPACE-CHARGE SHEATHS IN DISCHARGES BURNING IN CATHODE VAPOR

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The model of the space-charge sheath formed by cold ions and electrons at a negative surface has been established by Langmuir [1] and Bohm [2]. In the framework of this model, the ions enter the sheath from the quasi-neutral plasma, are accelerated by the sheath electric field and reach the surface without suffering collisions with neutral particles, the electrons are decelerated by the sheath field and are in equilibrium with it, i.e., follow the Boltzmann distribution. This model has been widely used for description of sheaths in discharges burning in an ambient gas, such as glow discharges and low to high-pressure arc discharges on refractory cathodes (e.g., reviews [3-5] and references therein), as well for description of sheaths in discharges burning in cathode vapor, such as vacuum arcs and low to high-pressure arc discharges on volatile cathodes (e.g., [6] and references therein).

As far as discharges burning in cathode vapor are concerned, this model implies that the neutral atoms emitted from the cathode surface are ionized beyond the sheath and a part of the ions produced return to the cathode, thus forming the sheath. However, a comparison of δ the scale of thickness of the space-charge sheath with L the scale of distance which an atom emitted by the cathode travels before getting ionized shows that δ is not necessarily much smaller than L. This means that the ionization of atoms emitted by the cathode surface may occur in the space-charge sheath rather than in the quasi-neutral plasma.

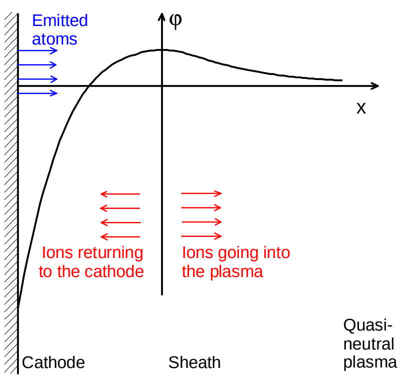

Fig. 1: Schematic of a space-charge sheath on a cathode emitting neutral atoms.

Thus, the conventional model of space-charge sheath with ions entering the sheath from the quasi-neutral plasma may be not justified under conditions typical of discharges burning in cathode vapor and a model accounting for ionization of emitted atoms inside the sheath may be more appropriate. One could think of a model which is schematically shown in Fig. 1 and is characterized by the following features. The distribution of electrostatic potential in the sheath possesses a maximum. There is a maximum also in the distribution of the electric field, which means that the sheath is actually a double layer. There is a flux of atoms emitted by the cathode surface which are gradually getting ionized. The kinetic energy of the atoms is much smaller than the electron energy hence one can assume that the ions are generated at rest. The ions produced before the maximum of potential return to the cathode surface and those produced after the maximum escape into the plasma.

The above model has some features in common with the model of a collisionless positive column of a plane glow discharge enclosed by two parallel absorbing walls, introduced by Tonks and Langmuir [7]. In particular, there is a potential hump in both problems with the ions generated at rest on both sides from the hump and moving away from it. On the other hand, there is a very important feature in the above model that seems to have no immediate analogue in the literature: the ions that are produced beyond the potential hump move in the direction from the sheath into the plasma, rather than the other way round as in conventional sheath models. There should be some resemblance with the problem of a double sheath on a cathode with electronic emission ([8,9] and references therein), however the mathematical description will not be the same; in fact, it does not seem obvious that a sheath with ions moving in the direction into the plasma is possible at all.

A simple mathematical model describing movement of the ions beyond the potential hump into the plasma is obtained by assuming that the ionization occurs in a narrow vicinity of the point of maximum of potential, after which the ion flux remains constant. In this model, an infinite plate is considered from which singly charged positive ions are emitted into the plasma with a very low velocity. There are also electrons in the plasma. The electric field is directed from the plate and accelerates the ions in the direction into the plasma. The plasma far away from the plate is neutral. The ions suffer no collisions while crossing the sheath and the electron density in the sheath is related to the potential distribution by the Boltzmann relation.

An analytical solution has been obtained. It is shown that such sheath is possible provided that the sheath voltage is equal to or exceeds approximately $1.256kT_e/e$. This limitation is due to the space charge in the sheath and is in this sense analogous to the limitation of ion current in a vacuum diode expressed by the Child-Langmuir law. The ions leave the sheath and enter the neutral plasma with a velocity equal to or exceeding approximately $1.585(kT_e/m_i)^{1/2}$.

The full model, accounting for ionization inside the sheath of atoms emitted by the cathode surface, is treated numerically. Extensive numerical results are given and discussed.

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