Near-cathode layers of arc discharges and diffuse mode of current transfer to cathodes of vacuum arcs

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Analytical results on integral characteristics of near-cathode arc plasma layers, available in the literature for different limiting cases, are revisited and modified where appropriate. A complete set of ready-for-use formulas for the whole range of conditions relevant for both vacuum arcs and arcs burning in ambient gases is given. As an example, the formulas are applied to analysis of spotless attachments of vacuum arcs to cathodes made of lead or chromium.

Under typical conditions of arc discharges, both in vacuum and ambient gases, the ion flux to the cathode surface is generated in a thin near-cathode plasma layer. A reasonably accurate description of this layer is of primary importance for understanding and modelling of arc-cathode interaction, which, in turn, is indispensable for understanding and modelling of both the cathode and the arc on the whole. What is needed to this end in the first place are not detailed distributions of plasma parameters in near-cathode layers, but rather integral characteristics relevant for modelling the arc-cathode interaction. In order to facilitate practical applications, results on these characteristics should preferably be delivered in the form of analytical formulas. A number of such formulas, derived under some or other approximations by means of different integral models, are available in the literature. Note that the integral models used in the derivation, while being simple, adequately reflect the most important physical processes and are sufficiently accurate.

The aim of this work is to revisit analytical results on relevant integral characteristics of near-cathode arc layers available in the literature for different limiting cases, to modify these results where appropriate, and to present a complete set of ready-for-use formulas for the whole range of conditions relevant for both vacuum arcs and arcs burning in ambient gases. The most important such characteristics are: electric field at the cathode surface (which is needed for evaluation of the electron emission current); currents of ions and plasma electrons reaching the cathode surface; and energy and momentum delivered to the cathode surface by the ion current, which play in important role in heating of the cathode to temperatures sufficient for electron emission and formation of cathode jets and droplets.

As an example, the derived formulas are applied to analysis of spotless attachments of vacuum arcs to cathodes made of lead or chromium. For both metals, the usual mechanism of current transfer to vacuum arc cathodes cannot sustain current densities of the order of 10^5-10^6 A m^{-2} observed in the experiment. The reason is that the electrical power deposited into the electron gas in the near-cathode space-charge sheath is too low.

It was hypothesized [1] that in such cases the electrical power is supplied to the electron gas primarily in the bulk plasma, rather than in the sheath, and a high level of electron energy at the sheath edge is sustained by electron heat conduction from the bulk plasma. The density of current of ions diffusing to the sheath edge from the quasi-neutral plasma was estimated with the use of the relation between the plasma pressure at the edge of the ionization layer and the equilibrium vapour pressure, derived in this work. The obtained values are comparable to the experimental current density, which supports the above hypothesis for both lead and chromium cathodes. The difference between the plasma pressure at the edge of the ionization layer and the equilibrium vapour pressure for the case of chromium cathode exceeds that for the case of lead cathode by about a factor of 2 and produces a stronger effect over the ion current. Note that the latter effect was disregarded in the previous analysis of spotless arc attachment to chromium cathodes performed in [1].

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References

[1] M. S. Benilov and L. G. Benilova, *IEEE Trans. Plasma Sci*. (2015) **43**, 2247-2252