Topic number: 10

MULTI-DIMENSIONAL MODELING OF ATMOSPHERIC PRESSURE DISCHARGE IN HELIUM-AIR GAS MIXTURE

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An effective understanding of atmospheric pressure discharge (APD) is developed by an analysis of the physical properties in He-air operating gas. The multi-dimensional coupled system of fluid model equations are numerically solved for the weakly ionized discharge plasma in the presence of species and clusters, such as He^+, He_2^+, N_2^+, O_2^+, O^+, N^+, NO^+, O_4^+, N_4^+, H_2O^+, H_3O^+, $H_2O.H_3O^+$, e^-, O^-, O_2^-, O_3^-, O_4^-, CO_3^-, CO_4^-, He (2^3S and 2^1S), He_2 ($a^3\sum_u^+$), O (^1D) and O_2 ($^1\Delta_g$) [1].

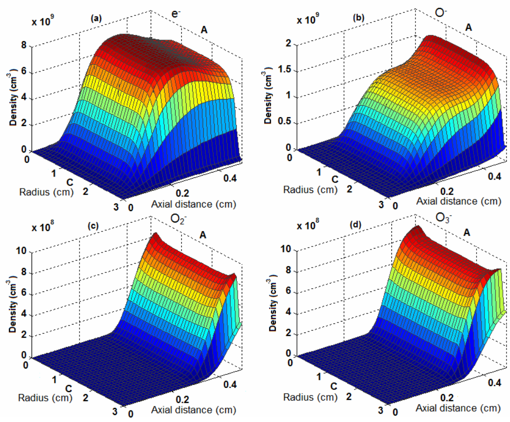

Fig. 1 (a - d): Two-dimensional profiles of electrons, O^-, O_2^- and O_3^- at 30 kHz and 1.5 kV in He-air gas.

The pattern of spatial distributions of electrons and negative ionic species densities are described in the breakdown phase as shown in figure 1 (a - d), when their sharp peaks exist near the momentary cathode (C) and anode (A) barriers at the maximum conduction discharge current density. As the electrons acquire maximum density in the negative glow region during the development of glow discharge plasma as displayed in figure 1 (a), the noticeable quantity of O^- ions is also present in the positive column and its maximum value exists near the momentary anode barrier as shown in figure 1 (b). The strong generation of electrons is balanced by the attachment processes, which provide the formation of negative ions (O_2^-, O_3^-, O_4^-, CO_3^- and CO_4^-). It is apparent from the figure 1 (c, d) that the higher densities of negative ions (O_2^- and O_3^-) are emerged in the form of distorted profiles near the momentary anode barrier as compared to the electrons and O^- ions.

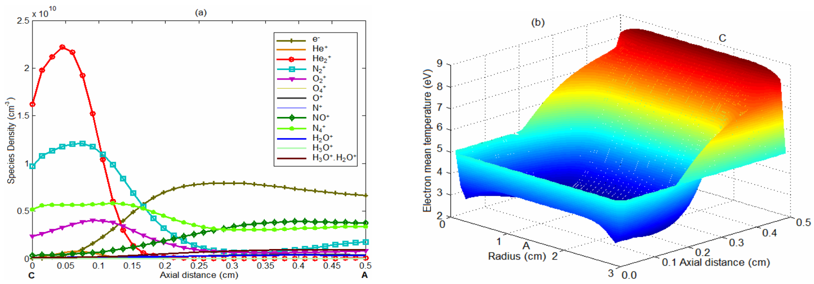

Fig. 2 (a, b): Line averaged densities of electrons and ions, and electron mean temp at 30 kHz and 1.5 kV.

The line averaged density of electrons, ionic species and clusters are elaborated by their onedimensional spatial profiles during the formation of cathode fall layer (CFL) as displayed in figure 2 (a). It is evident from the spatial mean distribution that the higher peak corresponds to the molecular helium ions than other ions in the cathode fall region. The molecular nitrogen and oxygen impurity ions have higher values of density near the cathode barrier and become very small away from the glow discharge region. The significant amounts of N_4^+ and NO^+ ions are observed throughout the reactor gap, whereas the smaller densities of ions (He^+, O^+ and N^+) and clusters are perceived than other heavy ions. The above distributions provide an overall view of the electrons, ions and clusters in the atmospheric pressure discharge. The electrons in the discharge plasma absorb energy from the mean electric field of the reactor gap, which is twisted near the cathode barrier. The electron density becomes very small in the CFL and the positive ions are responsible for the energy transformation in this phase. The electron mean temperature is indicated in figure 2 (b) with the abrupt falling trend in the cathode fall region, which reduces from the higher to lower values and slightly rises again near the anode barrier (A). The electron mean temperature is varied from ~ 8.5 to 3.0 eV near the momentary cathodic barrier (C).

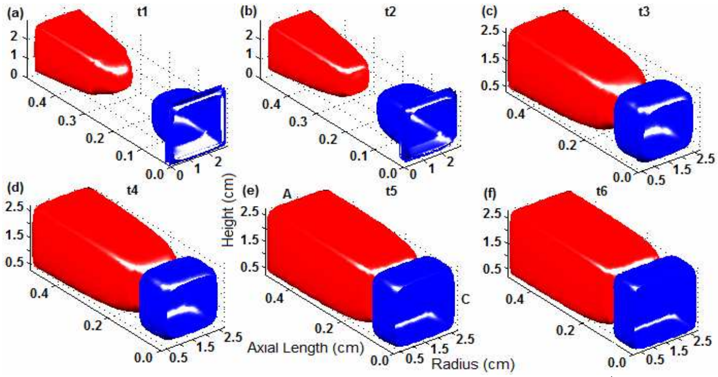

Fig. 3 (a - f): Phases of spatial volume three-dimensional distribution of He_2^+ ions (blue) and electrons (red) at 30 kHz and 1.5 kV in He-N_2 gas.

The evolution of uniform volume distributions of electrons and He_2^+ ions densities are discussed from the time t1 to t6 in the three-dimensional space for 30 kHz. Initially, the spatial structures of electrons and He_2^+ ions density are examined in the pre-breakdown phase as displayed in figure 4 (a - c) from t1 to t3 with an interval of ~ 1 μs. In the last structure of pre-breakdown in 4(c), the electrons and He_2^+ ions densities acquire the numerical values of ~ 5.0×10^9 and 1.0×10^{10} cm^{-3}. The figure 4 (d) exhibits the species density in the start of breakdown phase at t4, while the electrons and ions proceed towards their respective anode and cathode barriers and attain the values ~ 6.0×10^9 and 1.6×10^{10} cm^{-3}. The rapid movement of electrons exhibit that the ionization flit quickly travels towards the cathode barrier and the volumetric densities of electrons and He_2^+ ions advance to ~ 8.0×10^9 and 2.6×10^{10} cm^{-3} as shown in figure 4 (e). It is clear from the figure that the electrons occupy in the large space of gap due to higher mobility and He_2^+ ions squeeze near the surface of cathode barrier. The change in He_2^+ ions density is larger than electrons and it varies from ~ 4.0×10^9 and 3.0×10^{10} cm^{-3}, while the electron density shifts from ~ 3.0×10^9 and 8×10^9 cm^{-3} during the progression of atmospheric pressure glow discharge from t1 to t6. Consequently, the evolvement of pre-breakdown, breakdown and formation of cathode fall region are recognized from the spatio-temporal distributions of electrons and He_2^+ ions. Thus the dynamic activities of electrons and He_2^+ ions density can be distinctly observed from the above six distributions, which develop a smooth and profound impression of initialization and breakdown phases of a half cycle.

References

[1] K. R. Stalder, G. Nersisyan and W. G. Graham, J. Phys. D: Appl. Phys. 39, 3457 - 3460, 2006.