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Similarity properties in CF_4 capacitive radio-frequency plasmas

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The similarity law (SL) describes the invariance of physical parameters across scaled plasma discharge systems and has been validated in electropositive capacitive radio-frequency (RF) discharges [1]. However, its applicability in electronegative plasmas, such as CF_4 capacitively coupled plasmas (CCPs) widely used in materials processing, remains insufficiently explored. In this work, we employ a fully kinetic particle-in-cell/Monte Carlo collision (PIC/MCC) approach [1] to investigate the similarity properties of charged species in low-pressure CF_4 RF CCPs, across striation, drift-ambipolar (DA), and alpha discharge modes [2,3].

As demonstrated by Fig. 1, the electron density adheres to the classical SL prediction, due to the generation and loss of which is dominated by linear collisions. In contrast, ion densities (both positive and negative) exhibit a similarity factor deviating from the classical SL expectation across all modes. This deviation from the SL theory arises because ion-ion recombination reactions, involving distinct positive (e.g., CF_3^+) and negative (e.g., F^-) ions that maintain discharge quasi-neutrality, behave as linear collisions. Notably, though the ion densities overlaps in the RF averaged profile, this property is still a deviation of discharge similarity, as evidenced by differing numbers of striations in scaled striation-mode systems [4]. These findings complement the similarity theory for electronegative RF discharges, enhancing understanding of scaling behaviors in electronegative plasma systems.

References

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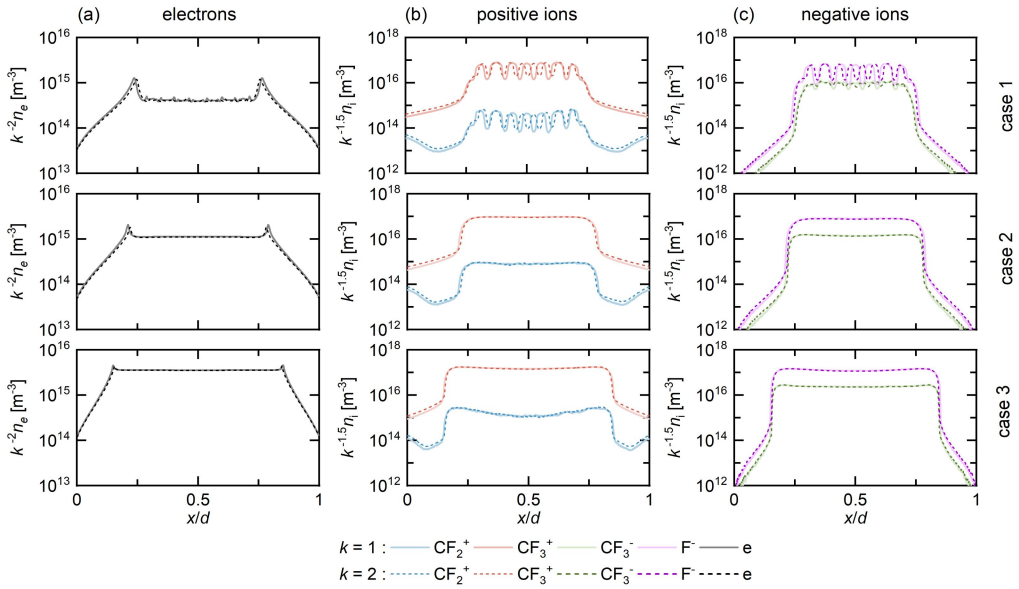

Figure 1. Similarity properties of RF averaged densities of (a) electrons, (b) positive ions and (c) negative ions in CF_4 CCPs operating in different modes. The solid and dashed lines represent the results obtained in the base case and the similarity case, respectively.