Similarity laws and scaling networks for radio frequency plasmas

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Similarity laws can be used for designing and optimizing low-temperature plasmas across various dimensional scales. In this talk, we introduce recent advances in the similarity theory and the scaling methods for radio-frequency (rf) plasmas [1]. The similarity relations are examined via fully kinetic particle-in-cell/Monte Carlo collision simulations for low pressure capacitive rf plasmas in geometrically similar chambers. The scale invariance of electron density and electron power absorption is demonstrated [2]. The effects of chamber geometry, driving frequency, and magnetic field on the validity of the similarity laws are confirmed [3] and its application to inductive rf plasmas with thermo-hydrodynamic coupling effects is investigated [4]. Most recently, similar rf discharges have been experimentally demonstrated via phase-resolved optical diagnostics, and the similarity-based scaling networks are proposed [5]. Figure 1 shows spatiotemporal distributions of the excitation rate dynamics for two similar rf discharges [(000) and (111)] and the six intermediate states. The sheath edges determined based on the PIC data and Brinkmann's criterion [6] are superimposed for visualized comparison. The top row [(a1)–(a8)] shows the experimental results and the bottom row [(b1)–(b8)] presents the corresponding PIC simulation results. The sheath edges are superimposed to both the experimental and simulation results for visualized comparison. The experimental tendencies of the excitation dynamics transitioning from (000) to (111) agree well with the simulation results. For example, compared with (000), both the experimental and simulation results show that the sheath is thinner for (101) but becomes wider for (010). The spatiotemporal evolutions of the excitation dynamics under similarity conditions are rather the same [see Figs. 3(a1) and 3(a8)], which is rigorously confirmed by the PIC simulations [see Figs. 3(b1) and 3(b8)]. The demonstration of the similarity laws enables cross-comparison and parameter mapping for plasma regulation at different dimensions, which provide valuable guidance for developing upscaled and downscaled plasma sources for industrial applications.

References

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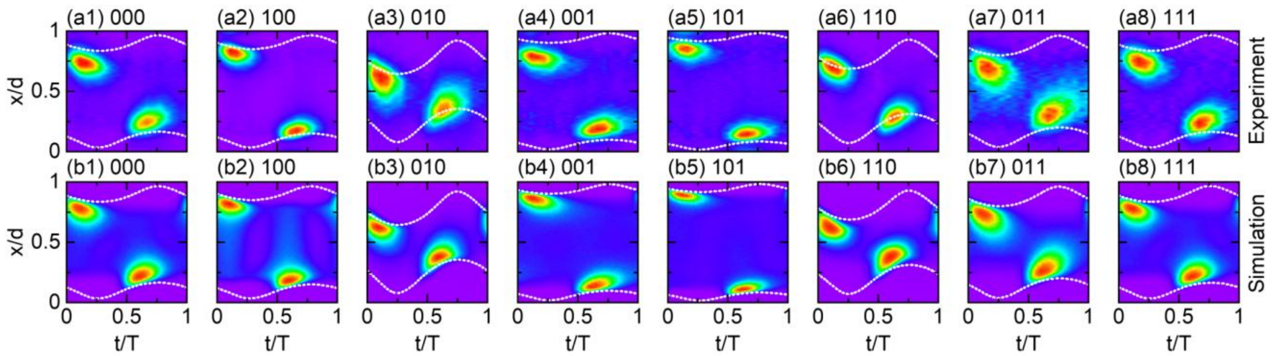

Fig.1 Spatiotemporal distributions of the excitation rate in rf discharges demonstrate the similarity-based scaling networks, consisting of three control parameters gradually tuned. Case 000 is the base case, case 111 corresponds to the similarity state, and other cases are at intermediate states.