EHD-driven air entrainment affects the evolution of APPJ

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Atmospheric pressure plasma jet (APPJ) is known as highly periodic ionization-wave packets that propagate along a neutral gas channel released into ambient air. Space charged particles generated within the channel drive electrohydrodynamic (EHD) force, perturbating the helium flow [1]; the resulting air entrainment, in turn, alters the discharge. Despite its importance, this mutual dependence has been usually overlooked because this unique feature of APPJ is not fully understood. In this study, we elucidate the transient ignition dynamics of a kHz-driven helium APPJ. First, the EHD phenomenon emerging in the helium gas channel is visualized by high-speed schlieren imaging, revealing an almost instantaneous rise in air entrainment after breakdown. To further understand the impact on plasma evolution, helium metastable atom (He^m, 2^3S_1), who is an energy-carrying species, is quantified by using tunable diode laser absorption spectroscopy. Increasing the voltage amplitude and repetition frequency elevates the peak He* density and shortens the time required for the jet to reach steady state. Note that the discharge current stabilizes earlier than He^m, indicating that EHD-driven disturbances outside the nozzle dominate the early-time behavior. Besides, the ignition duration scales with the number of voltage cycles, not with absolute time, reinforcing the central role of waveform–flow coupling. By contrast, the decay time of He* depends solely on the voltage amplitude and remains constant throughout ignition, implying that ambient-air mixing is confined to a thin rim at the jet boundary. Our findings highlight the pivotal yet underappreciated influence of EHD-induced flow distortion on APPJ ignition and offer practical guidance for achieving rapid, stable plasma formation.

[1] S. Park et al., Nature Communications 9, 371 (2018).

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