Applications of "Energy Tree" Concept on Active Control of Some Key Parameters in Collision-Dominated Low-Temperature Plasmas

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In recent years, with dramatic development of numerous applications of collision-dominated low-temperature plasmas (CD-LTPs), e.g., plasma biochemical engineering, clinical medicine, agriculture, low-dimensional materials synthesis, environmental protection and energy saving, etc., specific or even extreme demands on certain plasma parameters, e.g., electron energy and number density, heavy-particle temperature, characteristic scale like plasma action distance, area or volume, heat flux density to a treated workpiece, have become one of the important research aspects in the field of plasma science and technology. In our opinion, it is indispensable to understand deeply to the complex physiochemical processes in plasmas with energy transfer as the main line for achieving active control of key plasma parameters.

In this paper, based on our previously proposed "Energy Tree" concept [1], the synergistic non-equilibrium transport mechanisms are analyzed focusing on the mass-momentum-energy (MME)-coupling transport processes in several typical CD-LTPs. And then, examples are presented to show the applications of the preceding theoretical analyses for the active control of some key plasma parameters.

For the RF-APGD plasmas generated using a bare-metallic electrode configuration, the specific energy transfer channel is discovered, i.e., energy deposition through electron Joule heating process (Valve 1: $E_{\mathrm{Joule,E}}$) → energy transfer from electrons to heavy particles via elastic collisions (E_{el}) → energy loss to the metal electrode through the heavy-species heat conductive process (Valve 2: E_{cond}). Consequently, a novel approach is proposed to generate the RF-APGDs with independently controlled gas temperature and electron number density by controlling the energy valves mentioned above. And the helium RF-APGD plasmas are produced with a quasi-independent variation of the spatiotemporally averaged gas temperatures from −33.7 to 49.5 °C and the plasma densities from 2.7×10^{16} to 6.3×10^{16} m^{-3} on the radio-frequency gas discharge plasma experimental platform (RPX) [2].

For the atmospheric-pressure direct-current arc discharges, based on the analyses on the MME-coupling transfer processes, on the one hand, it is found that the convective and/or conductive heat transfer of heavy particles are the major energy transfer processes inside the heavy-particle subsystem itself and the dissipative processes to the environment, and thus, would play a key role for controling the non-equilibrium level of the plasmas [3]. And consequently, an argon arc plasma with low gas temperature, high electron number density and large volume non-equilibrium region is produced due to the enhancement of the convective energy transfer process in the arc core region with the introduction of a counter-flow cold gas through an annular anode on a free-burning arc plasma experimental platform (APX) [4]. On the other hand, it is revealed that the operating pressure also plays an important role by influencing the elastic collision energy exchange between electrons and heavy particles and the convective heat transfer process [3]; thus, the gas temperature, and consequently, the heat flux density to a treated workpiece may be modulated. Therefore, based on the principle of consistent heat flux density and heating time with real flight conditions, the ground simulation method for materials ablation has been developed on the multi-phase gas discharge plasma experimental platform (MPX). The experimental result show that the proposed ground simulation method can be used as a pre-test approach for effectively simulating the surface thermal environment of the component of high-speed re-entry spacecraft before costly wind tunnel experiments [5].

Based on the preceding discussions, it is indispensable to establish a model collision-dominated plasma system (mCDPS) not only for investigating the complex synergistic MME-coupling non-equilibrium transport mechanisms in CD-LTPs, but also for promoting existing or even creating novel applications of plasmas in the future.

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