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Numerical Simulation of Thermally Sustained Micro Discharge at Atmospheric Pressure by PIC/MCC-DSMC Coupled Method

Pengze Xiao[1], Xiandi Li[1], Wei Jiang[1], Ya Zhang[2], Hongyu Wang[3],
[1]School of Physics, Huazhong University of Science and Technology, Wuhan 430074
[2]Department of Physics, Wuhan University of Technology, Wuhan 430070, China
[3]School of Physics, Anshan Normal University, Anshan 114007, Liaoning, China
e-mail (speaker): pengzephysics@gmail.com

High-pressure micro-discharge has broad industrial applications, such as material processing and surface modification.[1] Micro plasmas can be sustained by thermal emission and field emission, or alternatively transition into the glow discharge mode.

This study investigates the thermal characteristics of direct-current (DC) micro-discharges in hot cathode systems through a multiscale coupling simulation framework. We use the PIC/MCC [2] method to model plasma, the DSMC [3] method to simulate neutral gas, and one-dimensional heat conduction to model the temperature distribution of the plates.

We analyze the thermal conduction between neutral gases and plasma to electrodes during micro-discharge processes, along with the distributions of neutral gas temperature and pressure. As illustrated in the middle section of Figure 1, by coupling the evolution of plasma, neutral gas, and electrode temperatures across multiple timescales through transient heat flux transfer from electrodes and dynamic updates of neutral gas temperature-pressure distributions, the research reveals distinct outcomes compared to conventional models that assume constant background temperatures.

Refer to the right section of Figure 1, the thermal conduction of neutral gases cools the cathode plates, suppressing thermionic emission, while the elevated gas temperature between the plates reduces ionization. Both effects synergistically lower the plasma density. From a spatial distribution perspective, the higher gas temperature near the cathode reduces the gas ionization rate, leading to an enlarged cathode sheath. Conversely, near the anode, the lower gas temperature enhances ionization, shrinking the cathode sheath and resulting in a higher plasma density in the anode-proximal region. Key findings demonstrate the critical role of time-resolved gas-electrode thermal interactions in shaping plasma dynamics and thermal management under transient conditions.

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References

[1] L. Sun et al, J. IEEE Transactions on Plasma Science. **52**, 32463256 (2024)
[2] Xiandi Li et al, J. Phys. D: Appl. Phys. **56**, 175202 (2023)
[3] S. J. Plimpton et al, J. Physics of Fluids, **31**, 086101 (2019)

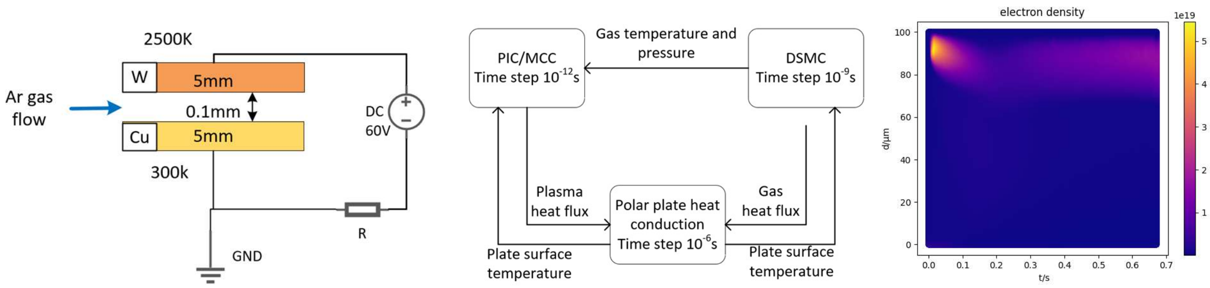

Figure 1. Discharge diagram model (left) , Multi-Scale Couple method: The evolution of plasma, neutral gas, and electrode temperature is coupled through key parameters (middle) and Electron density evolution (right).