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A Physically Based Temporal Multiscale Algorithm for Modeling Gas Discharges

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Because of the wide disparity of characteristic time scales of light and heavy species, e.g., electron (~10^{-10} s) and neutral species (~10^{-3}-1 s), how to properly couple gas discharge and gas flow in low-temperature plasma simulation has been considered a challenging problem. It is important to resolve all the time scales presented in the plasma for a high-fidelity modeling, especially when the convection and diffusion of neutral species becomes important. In the past, there has been nearly no study in addressing this important problem, except very few on global (zero-dimensional) modeling [1] and very recently TMA for 1D case [2]. Thus, it is the major objective of this paper to model the 2D gas discgarge by properly hybridizing gas discharge and gas flow.

The major idea of TMA employed in the current study is to exchange proper amounts of source terms among various species with different time scales. The species are classified into two groups, including fast and slow ones, in which the former refer to those respond (oscillating) well with the discharge and the latter refer to those nearly frozen during discharge simulation with a short physical time. In addition, the simulations are further divided into three major types, which include gas flow simulation, gas discharge fluid modeling simulation and convection-diffusion-reaction simulation of slow species. The procedures are summarized as follows: 1) The cold gas flow simulation is run to obtain initial steady-state background gas flow properties (velocities, densities, temperature); 2) Plasma fluid modeling is performed to obtain gas discharge properties, cycle-averaged source terms (momentum and energy) related to the gas flow solver and cycle averaged properties (number densities of fast species, source terms of slow species caused by fast-fast rection processes and rate constants) related to the convection-diffusion-reaction solver; 3) Gas flow solver is run until steady state is reached to obtain updated gas flow properties based on the cycle averaged source terms and properties resulting from Step 2); 3) The convection-diffusion-reaction simulation for slow species is performed to the required physical time or steady state based on those properties and source terms collected in Steps 2) and 3); 4) The simulations are repeated from Step 2) through Step 3) until both gas flow and gas discharge properties are converged.

Fig. 1 illustrates the gas temperature distribution of the modeled axisymmetric capacitively coupled plasma (CCP) at 500 mtorr driven by a 60 MHz power source with a heated substrate at 500K. 151x31 (4,681) computational cells are used. Time step for the plasma fluid modeling and convection-diffusion-reaction simulation is 8.33E-10 s (200 timesteps per cycle) and 1E-4 s respecitvely. In each coupling iteration, 1,000 cycles (1.67E-5 s) and 10,000 time steps (1 s) is run for the former and the latter respectively. The results show that after 10 times of couple the gas heating phenomena is obvious, which is otherwise impossible to catch for one-way coupling. More detailed plasma properties will be presented in the meeting.

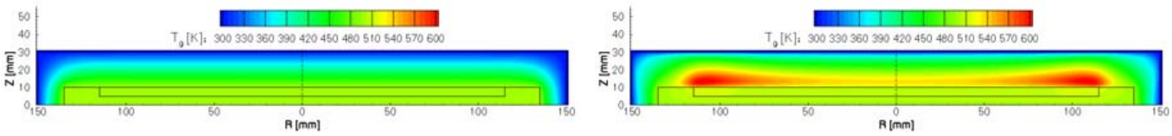

Fig. 1 Argon gas temperature distribution within a capacitively coupled plasma chamber with one-way couple (left) and two-way couple (right).

Fig. 2 shows that typical flow and plasma properties of round helium jet driven by a 25 kHz sinusoidal power source impinging into a grounded substrate with a dielectric layer. Note the helium containing traced amounts of oxygen, nitrogen and water vapor is considered in the simulation. More detailed results will be presented in the meeting.

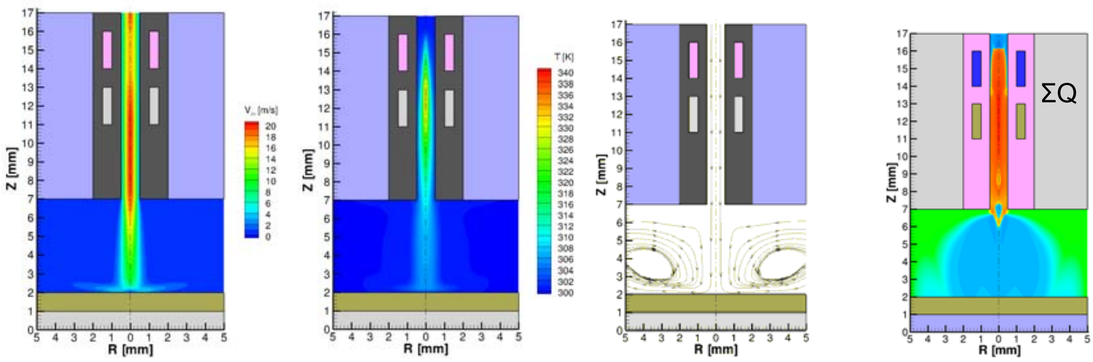

Fig. 2 Typical flow and plasma properties a 25kHz-power driven round helium jet impinging onto a grounded substrate.

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