Four Dimensional Fokker-Planck Solver for Electron Kinetics in Collisional Gas Discharge Plasmas

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Gas discharge plasmas are widely used in many modern technologies. Unique properties of these weakly-ionized plasmas are determined by their highly non-equilibrium state: distributions of electrons and ions substantially deviate from (equilibrium) Maxwellian distributions. These deviations are especially important for electrons which are responsible for ionization processes and plasma maintenance. The mean energy (temperature) of electrons usually exceeds the gas temperature by two orders of magnitude in both non-thermal atmospheric pressure discharges, and the low pressure plasma reactors operating in the mTorr range of gas pressures. In the low pressure reactors, an additional factor further complicates the problem - the electron distribution function is substantially *non-local*, i.e. its shape at a given spatial position is determined not only by the plasma characteristics at this point but also by the plasma properties in a certain vicinity of the point.

To account for *non-equilibrium* and *non-local* kinetic effects, we have developed a general purpose kinetic solver based on two-term Spherical Harmonics Expansion (SHE) of the Boltzmann Transport Equation (BTE). This approach reduces the six dimensional BTE to a four-dimensional (3 spatial coordinates + energy) Fokker Planck Equation (FPE) offering a very good compromise between physical accuracy and numerical efficiency. The kinetic solver is coupled to electromagnetic, chemistry and other modules enabling self-consistent hybrid simulations of non-equilibrium gas discharge plasmas. The FPE is solved for the Electron Energy Probability Function (EEPF) and provides macroscopic characteristics such as electron density, flux, and rates of electron induced chemical reactions. Using these quantities, the transport of ions and neutrals in multi-component plasmas is simulated using continuum model.

We will presents several examples of hybrid kinetic simulations of plasma systems ranging from low-pressure Inductively Coupled Plasma (ICP) and Capacitively Coupled Plasma (CCP) reactors used for microelectronics manufacturing, to atmospheric pressure dielectric barrier discharges (DBD) used for sterilization and decontamination. We will discuss the importance of non-equilibrium and non-local effects for different gases including oxygen, methane and nitrogen/oxygen mixtures. We will also discuss specifics of electron kinetics at low and high pressures and peculiarities of plasma simulations under different conditions. The developed kinetic solver enhances accuracy and fidelity of plasma simulations.

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