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Fluid simulation studies of low temperature plasmas using COMSOL Multiphysics Software

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Plasma, made up of electrons, ions, neutrals, and excited species, exhibits both fluid-like behavior and electrical conductivity due to the presence of charged carriers. Low-temperature plasmas are non-equilibrium discharges and collisional in nature. These discharges have plethora of applications. The design and development of plasma sources used to create various plasmas involves computational studies or simulations. There are two methods widely used for plasma simulations: one is the fluid approach, and another is the particle-in-cell approach. Both have their pros and cons. COMSOL Multiphysics is extensively used for plasma simulation, especially nonsymmetrical plasmas. Software solves partial differential equations. There are drift-diffusion approximations for ions, a quasi-neutrality assumption for electron flow, reduced Maxwell equations for electromagnetic fields, electron energy, electron temperature, and the Navier-Stokes equation for neutral background gas [1, 2]. Magnetic field is employed in the low temperature plasma devices basically enhance the plasma parameters and it creates anisotropy in plasma which originate the E × B drift. One of our studies, Capacitively Coupled Plasma (CCP) generated using parallel plate electrodes under the influence transverse magnetic field affected by E × B drift. Such open drift forms 'S' shaped structures in the plasma. Discharge is formed in glass chamber and some of part of plasma is not probe to diagnose. To investigate the formation of 'S' structure in magnetized CCP discharge three-dimensional fluid model of the discharge has been developed using COMSOL Multiphysics. The top and bottom parallel plate electrodes are loaded with RF voltage having frequency 13.56 MHz and phase difference 180° with each other. The static magnetic field with magnitude ~ 7 mT is applied perpendicular to the discharge gape while oscillating RF electric field is along the vertical direction and resultant E × B drift occur along the length of the plate. Figure 1 shows the experimental observation while figure 2 shows 3D electron temperature plot simulated using COMSOL [3] [4]. Both shows the same kind of 'S' structure.

The computational simulation of the DC hollow cathode discharge under the influence of an axial magnetic field was carried out using COMSOL Multiphysics software. In this study, the long-magnetized plasma column was sustained in the APPEL (Applied Plasma Physics Experiments in Linear) device by E × B drift. The aim of this study is to calculate the length of the plasma column and validate the analytical relation [5]. Length calculated for plasma column by analytical relations and COMSOL simulation nearly match with each other. The first plasma experiment conducted in APPEL device showed a high-density steady-state elongated horn-shaped plasma column with a length of 3.5 m and a density of the order of 10^{17}– 10^{18} m^{-3} with a relatively low discharge power of around 0.5 kW [6][7][8].
Apart from that, magnetized low-pressure ICP discharge using a spiral antenna was also simulated using COMSOL Multiphysics to understand and explore the low-pressure magnetized plasma simulation capabilities of the software. The simulation carried out for a magnetized argon plasma column (a) for pressure 2 × 10^{-2} mbar and (b) for pressure 3.5 × 10^{-4} mbar [9].

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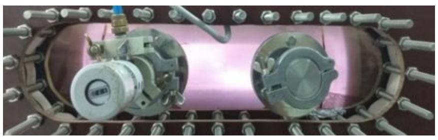

Figure 1 Photograph of magnetized CCP discharge.

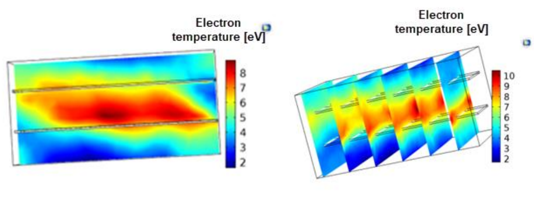

Figure2. Electron temperature plot magnetized CCP