Fine Structure of Ionisation Patterns and Confinement of Energetic Electrons in Asymmetric Capacitive Radio Frequency Discharges

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Geometrically asymmetric capacitively coupled radio frequency discharges (CCRF) are investigated by Particle-In-Cell (PIC) simulations. At low pressures, CCRF discharges promote strongly nonlinear dynamics and nonlinear electron resonance heating (NERH) is important. During sheath expansion, multiple electron beams are accelerated into the plasma bulk, which support the ionization process and frequently lead to the excitation of the plasma series resonance (PSR). At small gap sizes and low pressures, some of these beam electrons can reach the opposing sheath at different temporal phases without any collisions. Especially during sheath collapse, the confinement of these energetic electrons is inefficient, which influences the complete discharge.

Low pressure capacitively coupled radio frequency (CCRF) discharges are operated in a strongly non-local regime. In geometrically asymmetric discharges assuming cylindrical or spherical symmetry, the two opposing plasma sheaths (Fig.1: white lines) exhibit different nonlinear dynamics, e.g. in the sheath width and the sheath potential. The dynamics of such a geometrically asymmetric CCRF discharge are investigated by means of 1d3v Particle-In-Cell simulations. A spherical grid is implemented to obtain the geometrical asymmetry (including a DC self-bias). Cross-sections for electron-argon (elastic, excitation, ionization) and ion-argon (isotropic and backward elastic scattering) collisions are taken from the Phelps JILA database.

Most of the RF power is coupled into the plasma near the sheath at the driven electrode (situated at r = 20 mm). During sheath expansion (Fig.1: 10 < t < 25 ns), a bunch of energetic electrons is accelerated into the bulk region and undergo different scenarios. First, they collectively interact with bulk electrons and excite plasma oscillations (e.g. PSR). That is, cold bulk electrons are attracted back to the expanding sheath, which generates harmonics in the RF current. This process leads to the acceleration of multiple successive electron beams the number of which depends on the timescale of the local plasma frequency and the time of sheath expansion. Second, these multiple electron beams have enough energy to ionize the neutral gas, which is important to sustain the plasma. The color map plot of Figure 1 shows the spatio-temporal result of a very fine ionization pattern in an argon gas with an ionization threshold of 15.7 eV. This structure similarly represents the dynamics of all

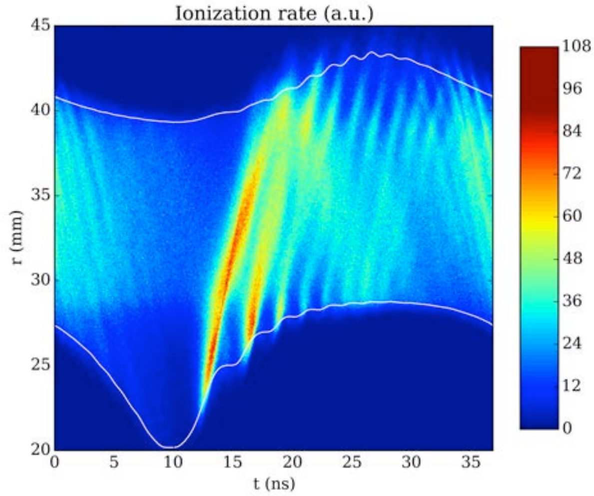

Fig.1: Ionization rate within one RF period. The white lines represent the sheath edges. The driving frequency is 27.12 MHz and the driving voltage is 700 V. The powered/grounded electrode is at r = 20/45 mm.

electron beams. Lastly, at low pressures the electron mean free path is frequently larger than the gap size. In this case, beam electrons can traverse through the discharge without hardly any collisions and interact with the opposing sheath (e.g. energetic electrons hit the sheath collapse, overcome the sheath potential and lose their energy at the wall). Especially the latter mechanism can lead to an inefficient confinement of energetic electrons, which strongly influences the discharge parameters (e.g. plasma density and ion flux). In order to obtain a better control of these mechanisms, different parameter variations (driving frequency, driving voltage, gap size, gas pressure) are studied.