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THE EFFECT OF THE LOW FREQUENCY VOLTAGE ON THE CHARACTERISTICS OF THE CAPACITIVELY COUPLED DUAL FREQUENCY RF DISCHARGES

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Abstract. In this paper, a Particle-in-cell Monte Carlo collision (PIC/MCC) modeling of dual frequency (DF) asymmetric capacitively coupled plasma (CCP) sources has been performed. In particular, the following configuration has been modelled: 27/2 MHz system with an electrode separation of 2cm and the gas pressure of 45 mTorr. The characteristics of dual-frequency argon discharge are studied for a wide range of low-frequency voltages.

1. INTRODUCTION

In practical application of the capacitively coupled plasmas (CCP) involves utilization of multiple-frequencies to control the plasma parameters (Goto et al. 1992, Kitajima et al. 2000, Robiche et al. 2003, Wakayama and Nanbu 2003, Kim and Lee 2004). In a typical dual-frequency discharge, the plasma density, and hence the ion flux at the plasma boundary are proportional the current density, which is controlled by the higher frequency, while the ion energy at the boundary depends mainly on the bias voltage, and this is mainly controlled by the lower frequency. In this paper, plasma discharge characteristics with various conditions in dual frequency capacitively coupled plasma (DF-CCP) are studied by a modified electrostatic 1d3v PIC/MCC code (xpdc1) (Lee et al. 2004, Verboncouer 2005). It is found that the low frequency voltage affects both the plasma density and the potential, while on the other hand, the kinetic energy of particles weakly depends on the variation of the low- frequency voltage (Donko and Petrović 2006, Turner and Chabert 2006).

2. SIMULATION CONDITIONS

PIC modeling techniques have been well documented in previous publications (Birdsall 1991, Verboncouer et al. 1993) so only a brief description of the code will be given here. In PIC simulations, the so-called "superparticles" move in the discharge space through an artificial grid on a time step basis. Only charged particles are simulated. At the beginning of the simulation, superparticles are distributed in the simulation domain and a self-consistent potential distribution is determined based on the superparticles positions and the externally applied voltage. This is done by weighting the

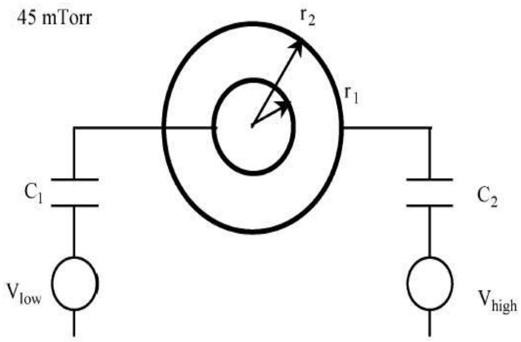

Figure 1: Schematic diagram of DF-CCP (27MHz/2MHz), $V_{hf} = 400\,\mathrm{V}$, with the gap spacing of 2 cm and the gas pressure of 45 Torr. V_{lf} is varied in the range $(50 - 200\,\mathrm{V})$.

particles to the grid points and solving Poisson's equation. The simulation proceeds by calculating the electric field and weighting it to the particle positions. The force exerted by the electric field is then computed and particle velocities and positions are updated. The null-collision method introduced by Vahedi (Vahedi and Surendra 1995) is used to account for the collisional processes.

In this paper, Particle-in-cell simulations have been used to study the nature of dual frequency plasma discharges. The schematic diagram of the cylindrical DF-CCP source is shown in Figure 1. The discharge is maintained in a chamber between two electrodes separated by the gap of 2 cm. The inner electrode is capacitively coupled to power supply operating at low frequency of 2 MHz, while the upper electrode is powered by the high-frequency source at a conventional frequency of 13.56 MHz and a constant voltage of 400 V (amplitude).

3. RESULTS

The influence of the low frequency voltage on the time average value of the plasma density is shown in Figure 2a. The increase of the low-frequency voltage results in decreasing of the plasma density. At the same time, profiles are shifted toward the outer electrode as the low-frequency voltage increases.

The ion energy distribution function (IEDF) for a single frequency (SF) CCP (solid line) and DF-CCP (dash-doted line) are shown in Figure 2b. In the arrangement when only the high frequency source is applied (solid line), the ion transit time across the sheath is much longer as compared to the period of the operating frequency. Most ions traverse sheath and experience the time averaged sheath voltage causing the main peak, while ion-neutral collisions cause small peaks. The shape of IEDF loses its single-peak structure and this structure is destroyed. The total range of ion energies does not correspond to the mean potential drop at the electrodes. As the low frequency voltage is increased, the maximal ion bombardment energy increases and broader ion energy spectrum is obtained.

Figure 3a demonstrates the principle of controlling the substrate self-bias voltage by varying the low frequency voltage with fixing the high frequency voltage. As the

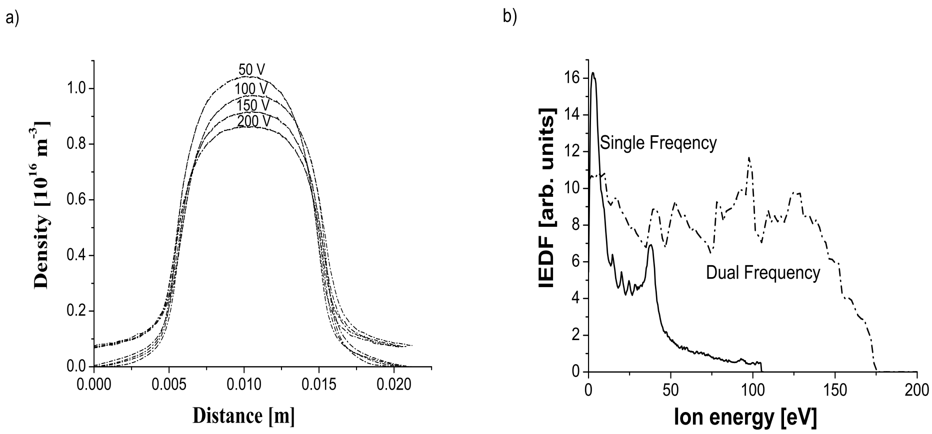

Figure 2: Effect of low-frequency voltage on: a) time average density and b) the ion energy distribution function (IEDF) at the inner electrode. DF-CCP (27MHz/2MHz), $V_{hf} = 400\,V$.

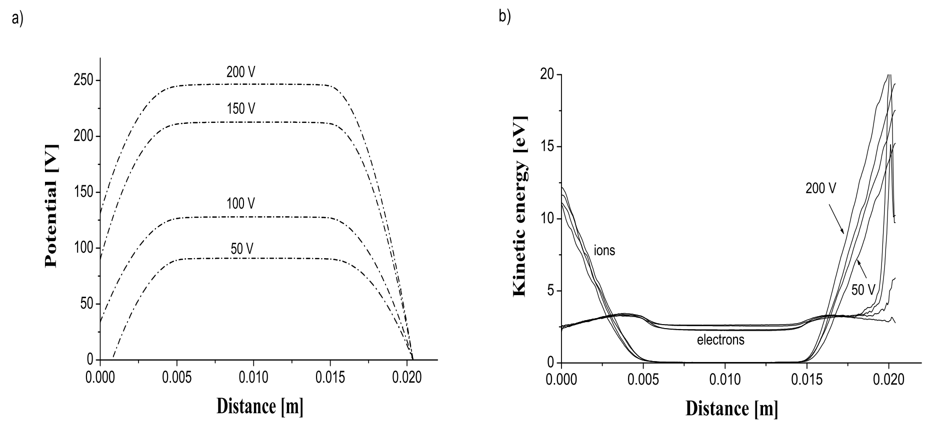

Figure 3: Changes of time-average: a) potential profile and b) kinetic energy, with the variation of the V_{lf} from 50 V to 200 V in DF-CCP (27MHz/2MHz) with a fixed $V_{hf} = 400\,V$.

low frequency voltage is increased, plasma potential is almost constant but the self-bias is increased.

As can be seen from Figure 3b, the kinetic energy of electron in the balk region is higher than the ion energy. On the other hand, in the sheath region, the ions gain a large energy that slightly depends on the low frequency voltage. The decrease of the plasma density at low frequencies is related to the increase in the plasma sheath width and therefore to the increase of the energy absorbed by ions in the sheath region.

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