Kinetic Plasma Simulations for Three Dielectric Etchers

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Abstract

Particle-in-cell Monte Carlo collision (PIC/MCC) modeling of dual frequency asymmetric capacitively coupled plasma (CCP) sources was carried out. In particular the following configurations have been modeled. : 27/2MHz system with an electrode separation of 2cm, 60/2MHz system with a gap of 4.5 cm, and 162/13.56MHz system with a gap of 3.2cm. It was found that both the ion flux to the electrode and the ion bombardment energy can be controlled independently in dual-frequency CCP (DF-CCP). Through kinetic modelings, many of the kinetic characteristics of the plasma discharge of three major dielectric etchers were compared.

Key words: dual-frequency; capacitively coupled plasma; etcher; particle simulation; collisional Monte Carlo

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Single-frequency CCP faces difficulties providing an independent control of ion energy, for which dual frequency systems have been studied. The dual RF excitation setup allows the plasma density to be determined by one high-frequency (HF) or very high-frequency (VHF) source while the substrate self-bias voltage is controlled by the secondary low frequency (LF). In this paper, plasma discharge characteristics with various conditions in DF-CCP were studied by a modified one- and two-dimensional electrostatic 1d3v PIC/MCC code (xpdc1). It was found that both the ion flux to the electrodes and the ion bombardment energy on the electrodes can be controlled independently. PIC simulation is a well-established tool for kinetic modeling in plasma physics. Three reactors have been considered in this paper. The neutral gas used in all simulations is argon at 40mTorr. We observe the plasma density in asymmetric dual frequency discharge. The plasma density increases linearly with RF voltage for all cases. We find high frequency voltages at almost the same plasma peak density. The high frequency voltages of three cases are held constant at 720V (27MHz), 180V (60MHz) and 60V (162MHz). The second, lower frequency is then driven at 2MHz or 13.56MHz, where a variable voltage source is applied. In Fig. 1. (b), we show that the peak values of plasma density have increasing trends except for some part, as the low frequency voltage is increased.

Figure 2 demonstrates the principle of controlling the substrate self-bias by varying the low frequency voltage where the high frequency voltage of each case is fixed. As the low frequency voltage is increased, plasma potential is almost constant but the self-bias is increased. The self-bias voltage, which depends on low frequency voltage, has almost a linear dependence on the driven voltage. The initial self-bias and plasma potential are determined by high frequency voltage without low frequency source at same plasma peak density. Due to high frequency voltage, it is difficult to obtain the self-bias which is lower than the initial self-bias, even though low frequency source is controlled. Accurate

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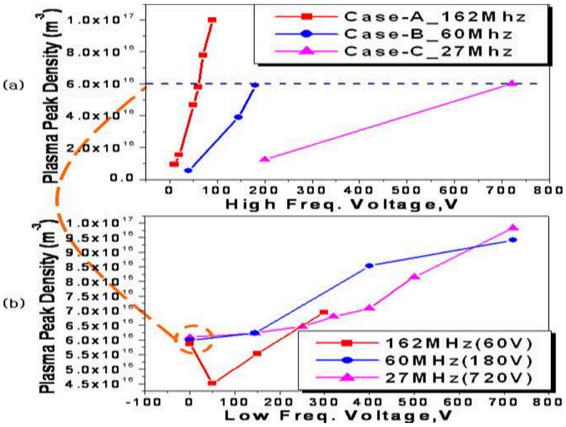

Fig. 1. (a) High frequency voltage of each case at same plasma peak density without low frequency source, (b) Plasma peak density driven low frequency voltage of each case at fixed high frequency voltage.

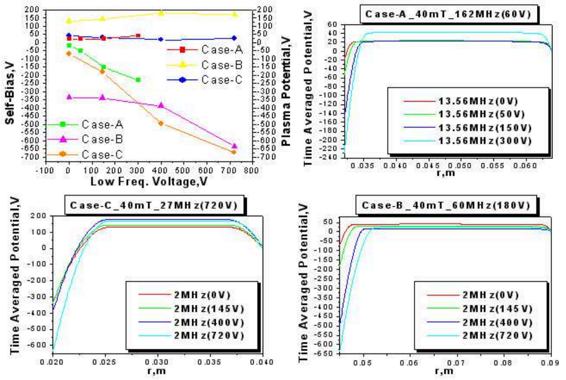

Fig. 2. Time average potential profile and self-bias of three cases.

control of self-bias in the low range (< 300V) cannot be achieved. When high frequency is high (162MHz, 60MHz), it is possible to control self-bias in the low range due to the low initial self-bias related to the high frequency voltage (60V, 180V).

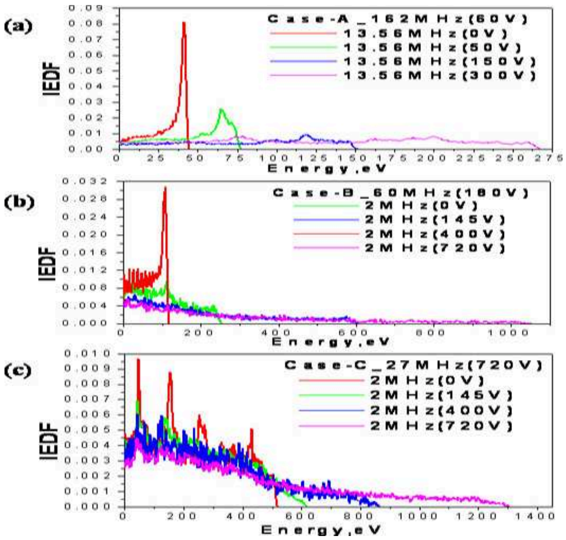

Fig. 3. The IEDF at the electrodes for various low frequency voltages in (a) 162/13.56MHz system, (b) 60/2MHz system, (C) 27/2MHz system.

The ion energy distribution function (IEDF) for various low frequency voltages are shown in Fig. 3. The ion transit time across the sheath is significantly greater than the period of the operating frequency. Most of ions traverse sheath and experience the time averaged sheath voltage causing the main peak and some collisions causing small peaks. As the low frequency voltage is increased, the sheath becomes more collisional and the plasma potential increases. The maximum ion energy increases with the potential. The shape of IEDF loses its single-peak structure and this structure is destroyed, because the ions experience the instantaneous low frequency voltage as they traverse the sheath. The total range of ion energies does not correspond to the mean potential drop at the electrodes. For typical values of plasma density of $10^{16}\ m^{-3}$, the ion plasma frequency for Ar ions is the order of 6MHz. For low frequencies below 6MHz, ions follow the instantaneous potential, not the average. As the low frequency voltage is increased, the maximal ion bombardment energy increases. That results in broader ion energy spectrum.

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