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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 has been carried out. In particular, the following configurations have been modeled: 27/2 MHz system with an electrode separation of 2 cm, 60/2 MHz system with a gap of 4.5 cm, and 162/13.56 MHz system with a gap of 3.2 cm. It is 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 are compared.

Keywords: Dual-frequency; Capacitively coupled plasma; Etcher; Particle simulation; Monte Carlo collision

Single-frequency CCP faces difficulties in providing an independent control of the ion flux and the ion energy, for which dual frequency systems have been studied [1–3]. 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 ion bombardment energy is controlled by the secondary low frequency (LF) source. In this paper, plasma discharge characteristics with various conditions in DF-CCP are studied by a modified electrostatic 1d3v PIC/MCC code (xpdc1) [4]. It is 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. The neutral gas used in all simulations is argon at 40 mTorr. The plasma density in asymmetric dual frequency discharge increases linearly with RF voltage as shown in Fig. 1(a). In the cases where the low frequency voltage varies, high frequency voltages have been chosen to produce the same plasma peak density: the high frequency voltages are held constant at 720 V (27 MHz), 180 V (60 MHz) and 60 V (162 MHz). The secondary low frequency source is driven at 2 MHz or 13.56 MHz. Fig. 1(b) shows that the peak value of plasma density increases with the low frequency voltage in most regimes.

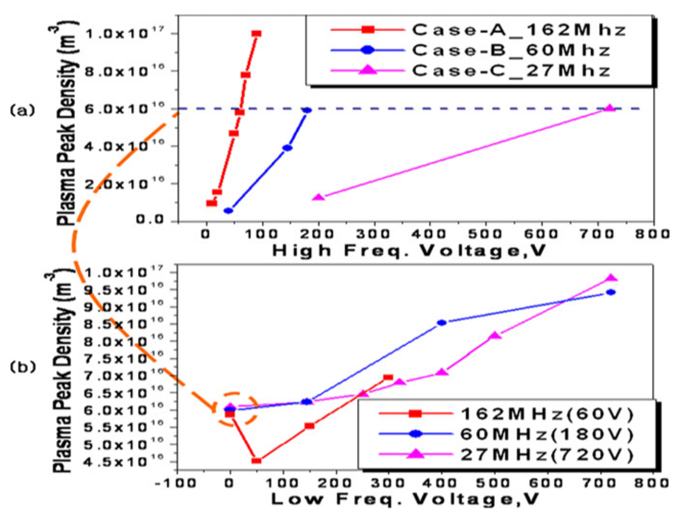

Fig. 1. (a) High frequency voltage variations at same plasma peak density without low frequency source. (b) Plasma peak density vs. low frequency voltage variations at fixed high frequency voltage.

Fig. 2 demonstrates the principle of controlling the substrate self-bias voltage by varying the low frequency voltage with fixing the high frequency voltage. As the low frequency voltage is increased, plasma potential is almost constant but the self-bias is increased. The self-bias voltage has almost a linear dependence on the low frequency voltage. The initial self-bias

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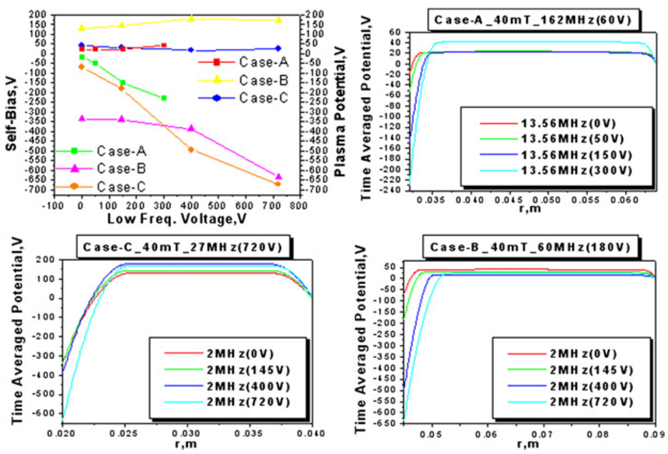

Fig. 2. Time average potential profiles and self-bias voltages.

and plasma potential are determined by high frequency voltage without low frequency source at same plasma peak density. Due to the high frequency source, the self-bias voltage in the cases with the low frequency source is lower than the initial self-bias, even though low frequency source is controlled. Accurate control of self-bias in the low range (<300 V) cannot be achieved. When high frequency is high (162 MHz, 60 MHz), it is possible to control self-bias in the low range due to the low initial self-bias related to the high frequency voltage (60 V, 180 V).

The ion energy distribution function (IEDF) for various low frequency voltages is shown in Fig. 3. When only the high frequency source is applied, the ion transit time across the sheath is much longer than 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. As the low frequency voltage is increased, the sheath becomes more collisional and the potential drop increases. The maximum ion energy increases with the potential drop. 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. For typical values of plasma density of 10^{16} m^{-3}, the ion plasma frequency for Ar ions is on the order of 6 MHz. For low frequencies below 6 MHz, ions follow the instantaneous potential, not the averaged one. As the low frequency voltage is increased,

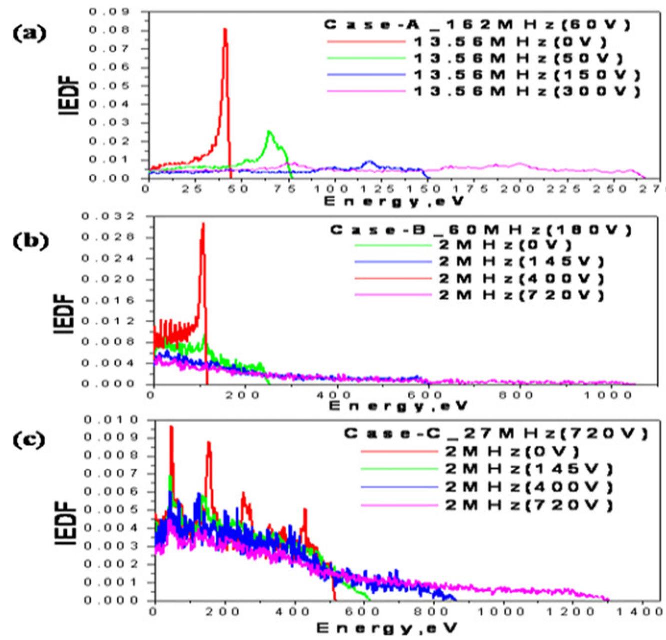

Fig. 3. The IEDF at the electrodes for various low frequency voltages in (a) 162/13.56 MHz system, (b) 60/2 MHz system, and (c) 27/2 MHz system.

the maximal ion bombardment energy increases. That results in broader ion energy spectrum.

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References

[1] H.H. Goto, H.-D. Lowe, T. Ohmi, J. Vac. Sci. Technol. A 10 (1992) 3048.
[2] T. Kitajima, Y. Takeo, Z.Lj. Petrovic, T. Makabe, Appl. Phys. Lett. 77 (2000) 489.
[3] K. Maeshige, G. Washio, T. Yagisawa, T. Makabe, J. Appl. Phys. 91 (2002) 9494.
[4] C.K. Birdsall, IEEE Trans. Plasma Sci. 19 (1991) 65.