Simulation of a Dually Excited Capacitively Coupled RF Plasma

Heon Chang Kim[1], **Yong Tae Sul**[2] **and Sung Jin Park**[2]
[1] Chemical Engineering Department, [2] Digital Display Engineering Department
Hoseo University, Asan, Chungnam 336-795, Korea

Abstract

In plasma processing reactors, it is common practice to control plasma density and ion bombardment energy by manipulating excitation voltage and frequency. In this paper, a dually excited capacitively coupled rf plasma reactor is self-consistently simulated with a three moment model. Effects of phase differences between primary and secondary voltage waves, simultaneously modulated at various combination of commensurate frequencies, on plasma properties are investigated. The simulation results show that plasma potential and density as well as primary self-dc bias are nearly unaffected by the phase lag between the primary and the secondary voltage waves. The results also show that, with the secondary frequency substantially lower than the primary frequency, secondary self-dc bias remains constant regardless of the phase lag. As the secondary frequency approaches to the primary frequency, however, the secondary self-dc bias becomes greatly altered by the phase lag, and so does the ion bombardment energy at the secondary electrode. These results demonstrate that ion bombardment energy can be more carefully controlled through plasma simulation.

1. Objectives and Background

In capacitively coupled rf plasma reactors, plasma density and ion bombardment energy are often independently controlled by separate external power sources simultaneously exciting primary and secondary electrodes. With chamber walls grounded, plasma density is mainly controlled by modulating the primary electrode at a high frequency. At the same time, ion bombardment energy is manipulated by driving the secondary electrode, where a substrate resides, at a relatively lower frequency. In such systems, it has been already proved experimentally that an appropriate combination of excitation frequency and rf power is important for the accurate control of ion flux and ion bombardment energy at the substrate surface[1]. Effects of secondary rf power and frequency on the ion bombardment energy have been also investigated theoretically[2], identifying their scaling relations through self-consistent simulations with a three moment model. Nonlinear dynamics of plasma reactors powered by multifrequency sources have been recently studied[3], pointing out that nonlinear interaction effects need to be considered in the design of such discharges when the secondary frequency is commensurable to the primary frequency.

This paper extends the previous scaling relations[2] by further numerically investigating the effects of phase differences between primary and secondary voltage waves driven at various combinations of commensurate frequencies.

The plasma model employed in this study consists of continuity, momentum and energy equations, for each charged species, derived from the first three moments of the Boltzmann equation. Since this three moment model has been previously described in detail[2,4], only a brief description is provided. Governing equations in this three moment model are analogous to the Euler equations of gas dynamics except additional terms quantifying elastic and inelastic collisions, electric field forces and thermal conductivity. In the present model the following assumptions have been employed. The neutral gas density is constant, neutral fluid motion is not considered, neutral and ions are in thermal equilibrium with a spatiotemporally uniform temperature, and coulomb collisions among charged species are neglected. Furthermore only ground state electron impact ionization and excitation are considered. The electric field is self-consistently determined from Poisson's equation with boundary conditions specified in a manner that Gauss's law is satisfied for all discontinuous surfaces between different materials. Use of such boundary conditions at the surfaces of powered and grounded electrodes enables evaluation of self-dc biases, in turn determination of ion bombardment energies.

2. Results

Two-dimensional simulations of a dually excited capacitively coupled rf plasma were performed in cylindrical coordinates with Ar at 70 mTorr and 323 K. Primary and secondary electrodes were simultaneously powered with sinusoidal voltage wave forms. The primary voltage and frequency were fixed at 200 V and 30 MHz, respectively. The secondary electrode was driven at 100 V with various frequencies commensurable to the primary frequency. The phase of the secondary wave with respect to the primary was also varied. Other detailed simulation parameters can be found elsewhere[2].

When the secondary frequency is substantially lower than the primary frequency, both the primary and the secondary rf powers as well as the plasma density stay almost constant. At the secondary frequency sufficiently close to the primary frequency, incremental changes in the phase lag result in a little perturbation in these properties due to interactions through nonlinear plasma medium[3]. However the plasma density remains reasonably constant. Furthermore the primary rf power is still substantially higher than the secondary rf power, clearly indicating that the plasma density is still predominantly determined by the primary rf source. However, the phasing effects on plasma potential and self-dc bias on the primary electrode are almost negligible for all cases. The secondary self-dc bias acquired at the secondary frequency of 3.75 MHz also stays constant. Meanwhile the secondary self-dc biases acquired at higher secondary frequencies are noticeably altered with the phase lag between the primary and secondary waves again due to nonlinear interactions. It implies that the energy of ions bombarding the secondary electrode vary in the same manner since ion bombarment energy approximately corresponds to the difference of plasma potential and self-dc bias, *i.e.* a sheath potential drop.

3. Impact

Through two-dimensional, cylindrical coordinate simulations of the dually excited capacitively coupled rf plasma, phasing effects of rf voltag waves applied to primary and secondary electrodes on the ion bombardment energy at the substrate surface have been investigated. The simulation results indicate that plasma potential as well as the primary self-dc bias are nearly affected by the phase lag between the primary and secondary voltage waves for all commensurate frequencies considered in this study. However the phasing effect on the secondary self-dc bias becomes more pronounced as the secondary frequency approaches more closely to the primary frequency. Consequently modulation of the secondary electrode at the commensurate frequency close to the primary frequency expands the controllable range of the sheath potential drop, in turn ion bombardment energy, near the secondary electrode. These results demonstrate that scaling relations among important process variables can be identified, for more accurate control of plasma characteristics, through a first principle based modeling and simulation approach.

4. Acknowledgements

This work is financially supported by the Ministry of Education and Human Resources Development(MOE) and the Ministry of Commerce, Industry and Energy(MOCIE) through the fostering project of the Industrial-Academic Cooperation Centered University.

5. References

[1] H. H. Goto, H.-D. Lowe and T. Ohmi, *IEEE Trans. Semicond. Manuf.*, **6**, 58, 1993.

[2] H. C. Kim and V. I. Manousiouthakis, *J. Vac. Sci. Technol. A.*, 16, 2162 (1998).

[3] S. Rauf and M. J. Kushner, *IEEE Trans. Plasma Sci.*, 27, 1329 (1999).

[4] H. C. Kim and V. I. Manousiouthakis, *J. Vac. Sci. Technol. B.*, 18, 841 (2000).