GEC16-2016-000197

Abstract for an Invited Paper
for the GEC16 Meeting of
the American Physical Society

Experimental and simulation study of capacitively coupled electronegative discharges

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The application of tailored voltage waveforms, generated by using multiple harmonics of a base frequency, for the excitation of capacitive RF discharges has been recently introduced as a new method to control the ion flux and ion energy distribution at the electrodes. In plasma processing of surfaces complex mixtures of electronegative, reactive gases (e.g. CF_4, O_2) are usually required. Therefore, the question of whether this new approach to control ion properties can be applied efficiently to such systems is of exceptional importance. Here the electron heating and ionization dynamics, the possibilities and limitations of the efficient control of plasma parameters by voltage waveform tailoring in low-pressure capacitively coupled electronegative discharges are presented. The focus is on geometrically symmetric O_2 plasmas, which are investigated by PIC/MCC simulations and experimental methods. O_2 discharges driven by impulse-type and sawtooth-type voltage waveforms composed of a maximum of four consecutive harmonics are studied. Experimental results on the dc self-bias voltage, as well as the spatiotemporal distribution of the plasma emission are compared with simulation data for a wide range of operating conditions (fundamental driving frequencies of 5 MHz – 15 MHz, at pressures of 50 mTorr – 700 mTorr). Transitions between electron power absorption due to sheath expansion and the drift-ambipolar mode were induced both by changing the number of harmonics or by changing the gas pressure. A good agreement between simulation and experiment is found, which shows that the collision-reaction model for O_2 discharges underlying the simulations describes reasonably the complicated chemistry of oxygen plasmas. An investigation of the dependence of the discharge characteristics on the surface destruction coefficient of the $O_2(a^1\Delta_g)$ singlet metastable molecules revealed the crucial role of these species, which strongly affects the negative ion balance of the plasma.