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Control of the state of charged dust particles via additional alternating external field

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The effect of the excitation waveform on the discharge characteristics and the levitation height of the dust layer, which is assumed to consist of monodisperse grains, is studied via simulation. The waveform tailoring and switching between different waveforms open a way to heating of the dust particle suspension similar to the second order Fermi acceleration, which may induce a transition between liquid and solid phases.

Dusty plasmas have a number of unique features attracting attention of researchers from different branches of physics [1]. The manipulation of individual dust particles and their ensembles is of great interest both for the theoretical understanding of the fundamental properties of strongly coupled systems and for applications. In the recent years a considerable progress has been made in the manipulation of dusty plasmas by lasers [1-3] and via modification of external electric and magnetic fields [4, 5].

In this paper the effect of excitation waveform on the discharge characteristics and the levitation height of the dust layer are investigated via particle-based simulations. Calculations are made for the RF discharge with a plane-parallel electrode configuration, with an electrode separation of L = 55 mm. The excitation frequency is f_{RF} = 13.56 MHz. The buffer gas is argon, at a pressure of p = 1.8 Pa, and the dust particles are assumed to have a radius of $r_d = 2.19 \mu m$. These conditions correspond to the experiments described in [6]. We consider the harmonic RF voltage excitation $\varphi(t) = \varphi_0 \sin[2\pi f_{RF} t]$ and excitation of the discharge with alternating phase of the driving voltage with an additional DC bias $\varphi(t) = \varphi_0 \sin[2\pi f_{RF} t + \sin[2\pi(2\times f_{RF})t]] + \varphi_{dc}$, where φ_{dc} is the additional DC voltage following types of driving voltage waveforms (see Figure 1), and φ_0 = 100 V.

The levitation height of the dust layer in the discharge is determined from the balance of the vertical forces acting on the particles: gravity, electrostatic, and ion drag forces. The floating potential and the electric charge of dust particles are calculated as in [7-8]: the interaction (collisions) between electrons and ions with the dust particles are described by cross sections that correspond to the Orbital Motion Limited (OML) approximation.

Fig. 2 shows the densities of electrons and ions for the three types of excitation waveform. The stronger electron heating following the fast sheath expansions in the case of the alternating-phase driving voltage leads to an increase by a factor of ~2.7 in electron and ion densities in the plasma, as compared to the harmonic RF excitation. The additional DC bias applied to the powered electrode (at x = 0) results in a decrease of the peak density and shifts the peak position of the density profiles towards the grounded electrode, as a consequence of the increasing length of the DC-biased sheath at the powered electrode. These changes in the discharge characteristics also modify the levitation height of dust particle.

Figure 3 shows the resulting total force acting on the dust particles, for the three different excitation waveforms. For the harmonic RF excitation the spatial position of the dust levitation, x_d is found to be 0.84 cm. Following the changes of the sheath length and ion fluxes under the excitation with phase-alteration, x_d decreases to 0.61 cm. The negative bias voltage leading to a longer powered sheath (see e.g. [6]) increases the position to 0.81 cm, near to the original value found at the harmonic RF excitation waveform.

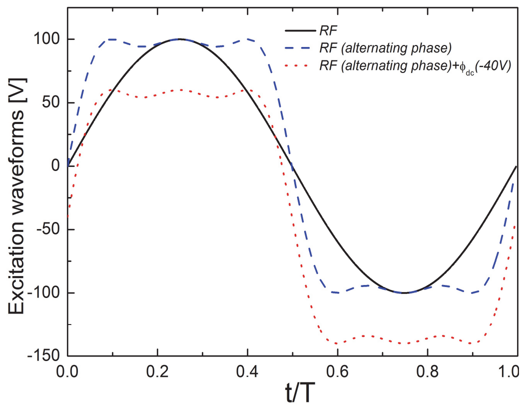

Fig. 1: Plasma excitation waveforms used in this work

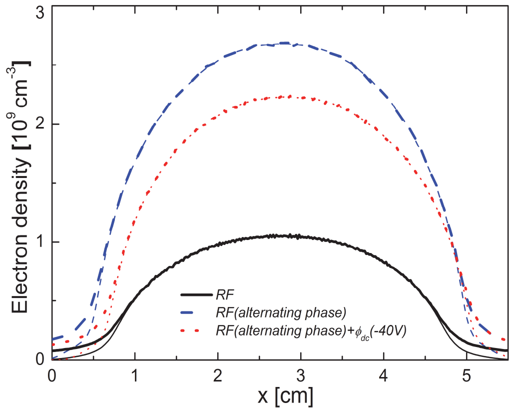

Fig. 2: Ion (thick lines) and electron (thin lines) density profiles for the different excitation waveforms considered in this work

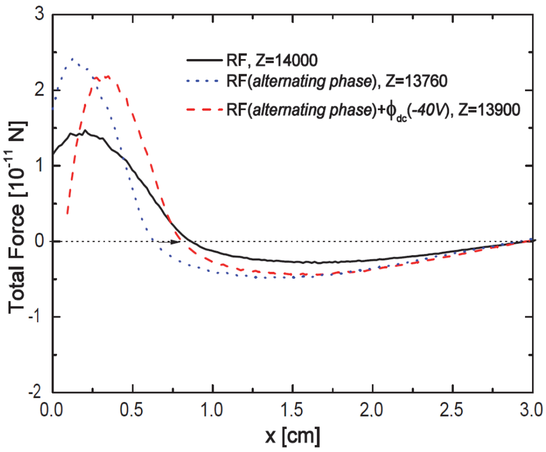

Fig. 3: Spatial dependences of the total force for the following conditions: harmonic RF excitation (solid line), alternating-phase excitation (dash line), and alternating-phase excitation with -40 V DC bias (dotted line)

These results demonstrate that the electron dynamics and the position of dust particles can be controlled in nearly independent ways, by changing the driving voltage waveform (including phase-modulation and use of an additional DC bias). As the dust charging currents obviously change with plasma density, which is in turn defined by the waveform shape, different charging scenarios can be established at otherwise (nearly) the same levitation heights. The degrees of freedom provided by the waveform tailoring and switching between different waveforms open a way to heating of the dust particle suspension similar to the second order Fermi acceleration, which may induce a transition between liquid and solid phases.

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