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On the interaction of a complex plasma with external electric fields

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Introduction

If dust particles are injected into a plasma, they become negatively charged by the currents towards the particles and can be confined in the discharge. The spatial distribution and movement of dust particles in a low-temperature plasma is a consequence of several forces acting on the particles. The charged particles interact with the electric field in front of the electrode. The electrostatic force has to be balanced by various other forces in order to confine the particles. These forces, which have been dicussed extensively by several authors (Daugherty et.al. 1993, Bouchoule 1999), are the gravitation, the neutral and ion drag, thermophoresis and photophoresis. But only some of these forces will play a role in laboratory complex plasmas. Commonly, the electrostatic field and the gravitational force are important. Superposition of both effects result in a parabolic potential trap (Homann et.al. 1996).

In our experiments, the influence of additional electric fields on the confined dust cloud has been investigated. The additional electrostatic forces are supplied either by inserting floating walls which are placed perpendicular to the rf-electrode or by an external ion beam supplied by an ECR ion source EC/A 125 (Zeuner et.al. 1996).

The superposition of the fields of the electrode and the wall results in a characteristic movement of the particles along the wall which looks like a wetting liquid by surface tension. We also try to describe the effect in the light of this physical phenomenon. The effect of such an ion beam is threefold :

- change of the sheath structure and the electric field,
- recharging of the dust particles,
- variation of the ion drag force.

Studies on the ion effect of the additional ion beam might also help to clarify the questions coming up with void formation in a plasma crystal under microgravity conditions which could be caused by ion drag forces (Thomas et.al. 2001).

Experimental

The experiments have been performed in a reactor PULVA1 which is schematically drawn in Fig.1. The plasma sources (rf-plasma, ion beam gun) as well as different diagnostics (video, thermal probe) are mounted in a spherically shaped vessel. The effects of the different forces can be distinguished by a variation of the plasma density which is influenced by the gas pressure (10^{-1} … 10Pa), the rf-power (0 … 20W), and the power of the ion source (500 … 800W). The kinetic energy of the ions are determined has been varied by the beam voltage (0 … 1000V).

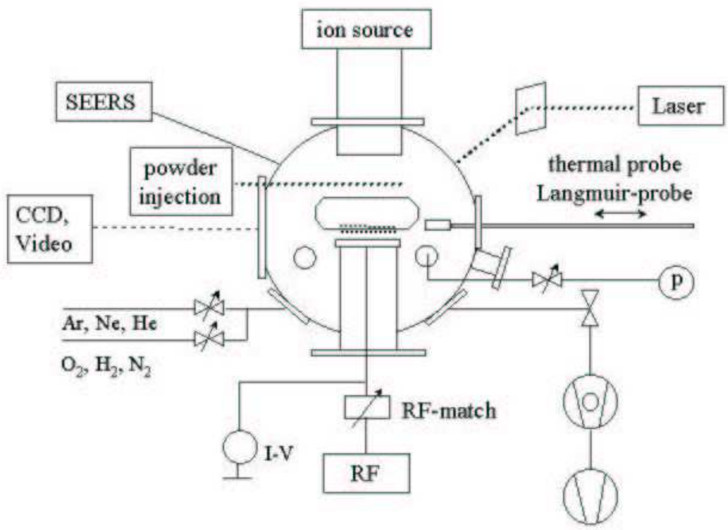

Fig.1: Scheme of the experimental set-up PULVA1.

As measured by a thermal probe (Kersten et.al. 2001), the energy influx increases with increasing beam voltage due to the higher kinetic energy of the ions. The ion current density itselfs shows only a weak dependence on the beam voltage but a strong dependence on the power which determines the ion production in the source. Whereas the mean ion density in the confining rf-plasma is in the order of $5 \cdot 10^8 cm^{-3}$, the external ion beam supplies an additional energetic ion flux of about $300 \mu A/cm^2$ which interacts with the particle cloud.

Results and Discussion

Charging, confinement, and movement of the dust particles are essentially influenced by the presence of electric fields. The potential difference in the sheath in front of the rf-electrode causes an electric force which balances the gravity of the powder particles – they float at the position where both forces are balanced. However, if additional forces act, the trapping behaviour will be remarkably changed. In our experiments, we added an additional force by the external ion beam to simulate the influence of ions.

The measured height of the dust particle cloud above the rf-electrode in dependence on the ion beam voltage is plotted in Fig.2. For small beam voltages (< 200V) there is almost no influence. Due to a variation of the sheath width, which is influenced by gas pressure and rf-power, the trapped particles follow only the variation of the rf-plasma. The beam voltage is not sufficiently high enough to extract a remarkable amount of ions into the dust region which is about 210mm away from the grid system of the ion source. When the beam voltages increases, the height of the dust particles decreases. That means the originally planar dust cloud forms a parabolic shape and moves into the direction of the rf-electrode. For higher power of the rf-plasma and, hence, for higher bias voltage of the electrode the particle cloud is levitated in a higher position than for smaller rf-power. This observation is due to the electric field (potential) in front of the powered rf-electrode. At higher bias voltages, the field can compensate the influence of the external ion beam more efficiently (Fig.2).

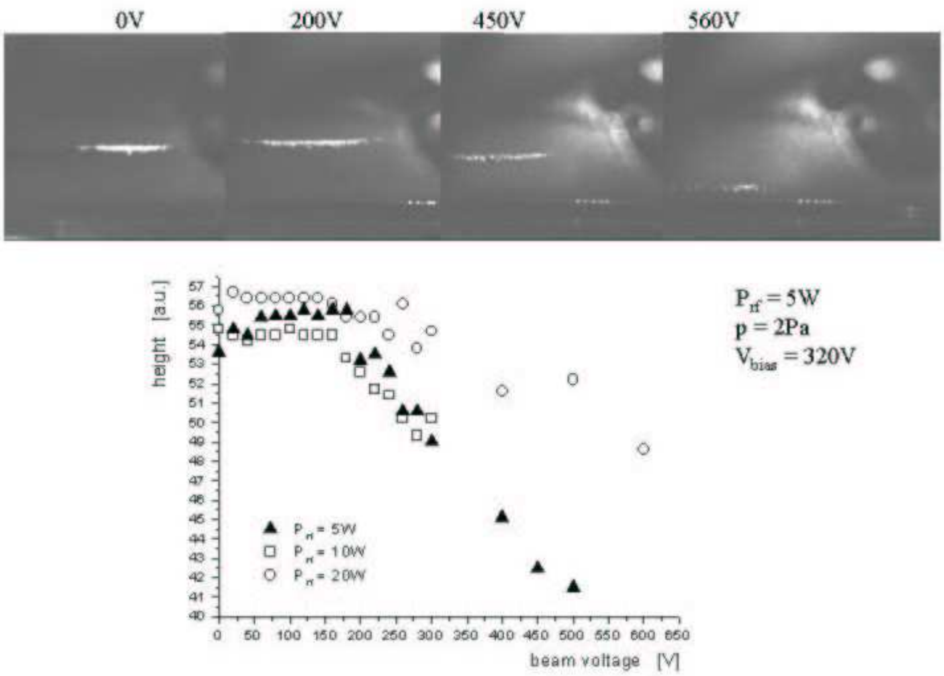

Fig.2: Particle cloud in front of the rf-electrode at different ion beam voltages, and the measured height of the particles.

Since the additional ion supply by the external ion beam interacts with the rf-plasma, the plasma density in the trapping region is changed. This effect causes a variation in the sheath (width and shape) and, thus, a variation in the particles force balance. Another effect of the additional ion supply is an enhanced charge carrier recombination at the surface of the floating dust grains. It can be expected that the net charge is decreased by the recombination. Certainly, also the ion drag force by the ions of the beam influences the force balance of the confined grains. The importance of this effect has often been discussed in respect to the void formation in plasma crystals.

In order to examine the influence of additional electric fields on the shape of a particle cloud, a second perpendicular field has been superposed. The glass wall, which extends into the plasma and which is on floating potential, might cause a force on the particles in the direction of the glass surface. As a result, the surrounding sheath shows some kind of "wetting behaviour". This comparison with fluids springs into mind when looking at Fig.3 under this point of view.

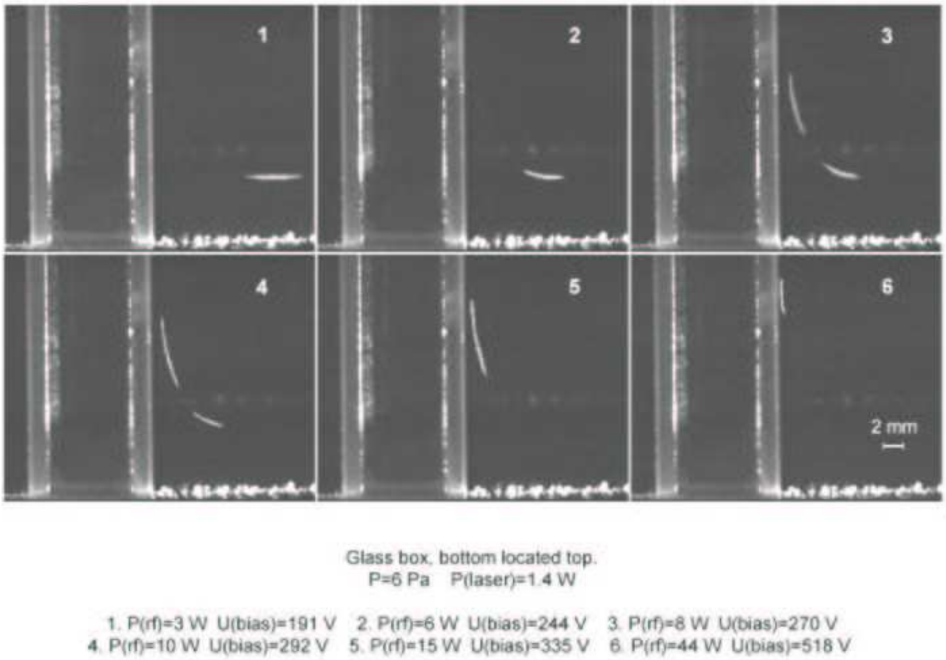

Fig.3: Wetting of a glass wall by particles due to superposition fields.

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