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VISUALIZATION OF ION AND NEUTRAL DRAG IN COMPLEX (DUSTY) PLASMAS

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Introduction

The spatial distribution and motion of micro-particles in plasmas is a consequence of several forces acting on them. In order to determine separately the effects of ion drag and neutral drag, respectively, the interaction of an external ion beam source with dust grains levitated in the plasma sheath in front of an rf-electrode has been experimentally studied.

The superposition of electrostatic field force F_{el} in front of the powered electrode, gravitational force F_g of the particles, neutral drag F_n due to a gradient in the gas pressure, and ion drag F_{ion} of the extracted ion beam results in a characteristic particle arrangement [1]. The profile of the gas flux along the electrode as well as the profile of the ion beam can be impressively visualized by the interaction of these currents with the microscopic probe particles. The contributions of F_n and F_{ion} to the net force can be calculated.

Experimental

In order to observe the interaction of confined powder particles with the surrounding plasma and the external ion beam an asymmetric, capacitively coupled rf-discharge was employed. The experiments have been performed in the reactor *PULVA II*, which is schematically drawn in Fig.1. The plasma glow is located in the region between the planar aluminium rf-electrode (*D=130 mm*) and the upper part of the cylindrically shaped reactor vessel (*D=400 mm*), which serves as grounded electrode, see Fig. 1. A copper ring was placed on the electrode to confine the injected dust particles (SiO_2, *0,8µm*) by a parabolic potential trap. The different forces onto the grains could be qualitatively varied by variation of the gas pressure (*0,1 … 10Pa*), the power of the ion source (*500 … 800W*), the beam voltage (*400…1400V*), and the particle size (*0,5…10µm*). Depending on the gas pressure the rf-plasma induced a self-bias of *60 … 300V* at the bottom electrode. For the determination of the plasma parameters the experiments were carried out both with and without dust particles as well as with and without ion beam operation. The injected powder particles are negatively charged and confined in the rf-plasma near the sheath edge (~ *10mm*) where they can be observed by light scattering of an illuminating laser fan (*532nm*).

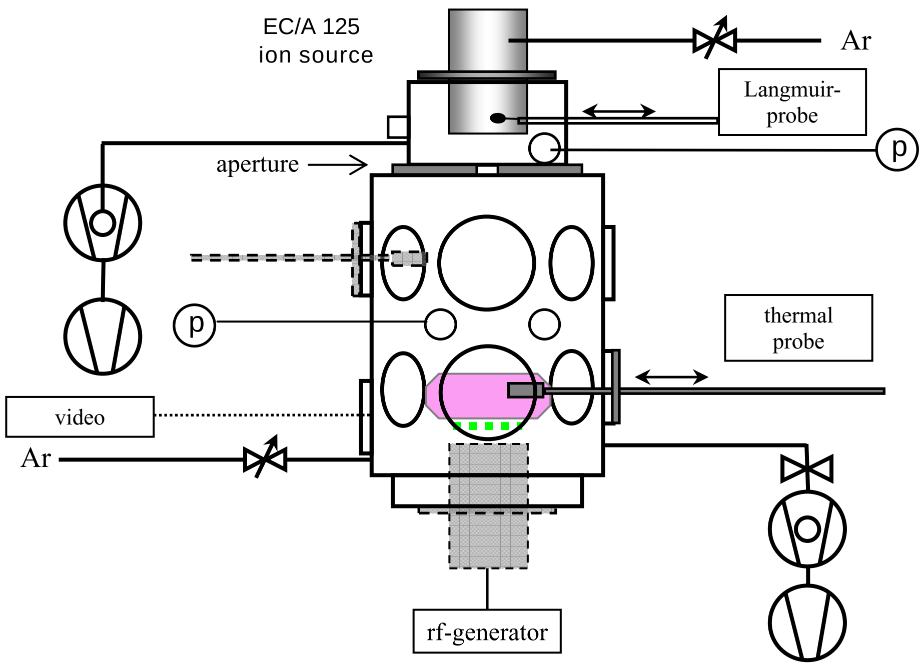

Fig.1: Schematic of the experimental set-up PULVA II

The ion beam source (EC/A 125, IOM Leipzig) is mounted on top of the vessel opposite to the rf-electrode (Fig.1). The generated ions are extracted by a molybdenum grid system (diameter: *125mm*) and accelerated by the beam voltage which was varied between *400* and *1400V*. The distance of the levitated particle cloud to the extraction grid system of the ion source was about *640mm*. In order to get a good separation of the ion beam source and the region of plasma-particle interaction in front of the rf-electrode, a tube of *75mm* diameter has been used. At the bottom of the "beam tube" is a hole (*D=5mm*) where the ions leave the tube for interaction with the confined probe particles. By this method, thermalization of the ions on their way from the extraction grid to the particles has been minimized.

Results and Discussion

If the hole of the beam tube is closed by a shutter (Fig.2a), a common situation of complex plasma is realized. The particles are levitated due to the force balance between gravity F_g and electrostatic force F_{el} by the electric field in front of the rf-electrode. If the shutter is removed and, thus, the hole is open there exist a strong pressure gradient between the rf-plasma region (*3Pa*) and the beam region inside the tube (*0.1Pa*). The result is a neutral drag F_n by the gas flow which changes the shape of the originally flat dust cloud into a dome-like structure, see Fig.2b. This structure can be explained by the flow patterns which can easily be simulated. Finally, if the ion beam is switched on the dome is distorted again by the pushing ion drag force F_{ion} (Fig.2c).

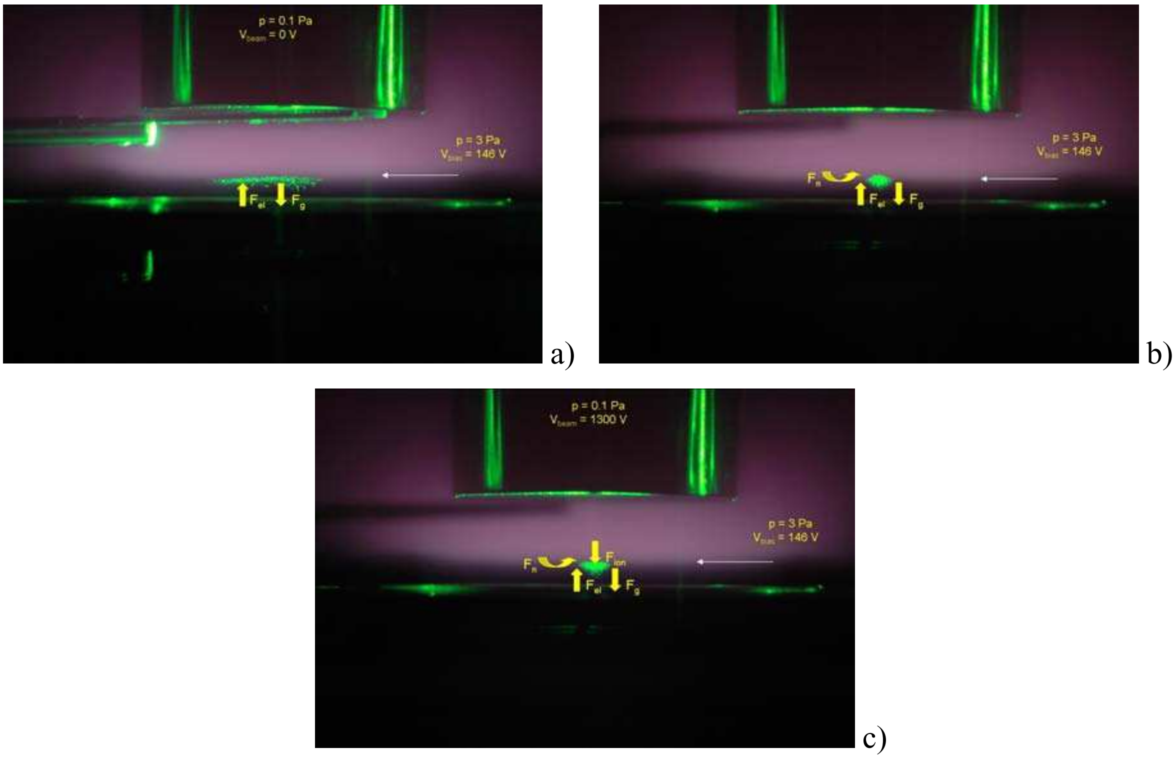

Fig. 2: Particle interaction with the plasma and the ion beam at p=3Pa and V_{bias}=146V.
a) hole closed, b) hole open, c) ion beam (V_{beam}=1300V) on.

For levitated particles of mass m_d and charge Q_d in steady state the force balance in vertical *z*-direction can be written as:

$$F(z) = F_{el}(z) + F_n(z) - F_g - F_{ion}(z) \approx Q_d(z)E(z) + F_n(z) - m_d g - F_{ion}(z) = 0 \qquad (1)$$

Due to the pressure difference between the discharge region (~*3Pa*) and the ion beam tube (~*0.1Pa*) the flowing Ar gas atoms result in a typical flow pattern (Fig.3). The neutral drag F_n is proportional to the square of the velocity of the Ar atoms [2]:

$$F_n \approx n_n m_n v_n^2 \pi r_d^2 \qquad (2)$$

The pressure gradient influences the amount of the velocity in the flow pattern. For typical experimental conditions and depending on position of the dust cloud the neutral drag has been estimated to be in the order of 1 …3 10^{-15}N.

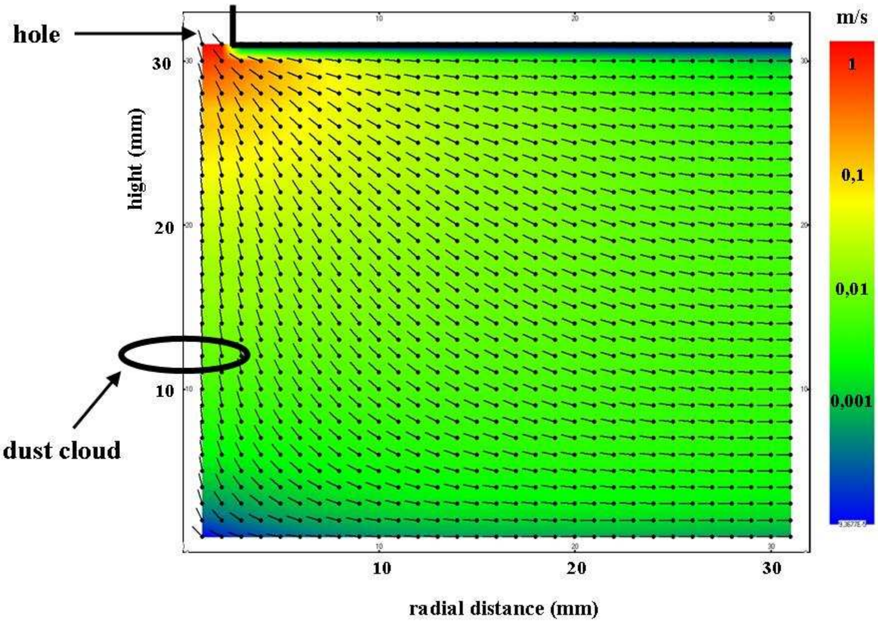

Fig. 3: Simulation of gas flow pattern due to the pressure difference between plasma region of particle confinement and ion beam tube.

The ion drag force F_{ion} consists of two components: the orbital force and the collection force [2]. The orbital force corresponds to the momentum transfer due to Coulomb scattering and the collection force is a consequence of direct collisions between the beam ions and the particle. Since the directed kinetic energy of the supersonic ions is much larger than the potential of the dust particles the particle cross section πr_d^2 can be regarded as collection impact parameter. Then the ion drag force becomes

$$F_{ion} = n_i m_i v_i^2 \pi r_d^2 = \pi r_d^2 j_i \sqrt{\frac{2m_i}{e_0}} \sqrt{V_{beam}} \tag{3}$$

where n_i is the density of the ions of mass m_i and directed velocity v_i which can also be written in terms of the ion flux density j_i and the beam voltage V_{beam}. For typical experimental conditions as given above the ion drag force is in the order of $1 \ldots 5\ 10^{-14}\ N$ depending on the beam voltage. The ion drag induced by the external beam source is about 10 times larger than the neutral drag. Both forces are about 10% of the confining forces F_g and F_{el} [1].

References

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