

Ordered structures in nuclear induced dusty plasma

L.V. Deputatova, V.E. Fortov, A.V. Khudyakov*, A.P. Nefedov, V.A. Rykov*,
V.I. Vladimirov,

*Institute for High Energy Densities, Russian Academy of Sciences, Izhorskaya ul. 13/19,
Moscow, 125412 Russia, dlv@ihed.ras.ru*

**Leipunskii State Research Center "Institute of Physics and Power Engineering", pl.
Bondarenko 1, Obninsk, Kaluzhskaya oblast, 249020 Russia, rykov@ippe.obninsk.ru*

The present work aims at experimental investigating the behavior of dust particles of various diameters in a nuclear-excited plasma in the presence of electric fields with a varying spatial configuration. The nuclear induced dust plasma is created by ionizing particles appearing in nuclear reactions during nuclear fission as well as during the α - and β -decay [1]. A typical feature of such a plasma is its space-time non-uniformity associated with its track structure [2] The accumulation of charge by particles in this type of plasma is stochastic [3] and the time of charge variation is determined by the intensity of decays in a radioactive source and by the distance to the source. A dust particle in a nuclear induced plasma in an external electric field experiences the action of bunches of electrons and ions drifting towards different electrodes and having (in the case of a uniform field) a shape close to a cylindrical one with a symmetry axis parallel to the trajectory of the ionizing particle. As a result of diffusion bunches of electrons and ions spread in the radial direction. The difference in the diffusion coefficients results in a considerable increase in the radii of electron bunches. These formations encounter dust particles more frequently and transfer a negative charge to them.

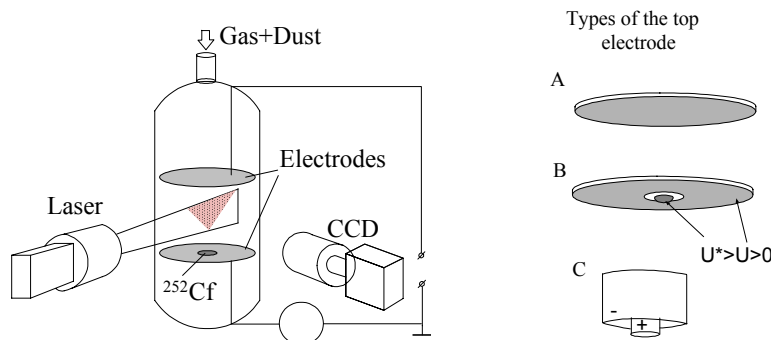


Fig.1 Experimental setup

The less frequent action of ion bunches effectively discharges dust particles. Alternating action of electron and ion bunches leads to strong fluctuations of the electric charge of a dust particle [3]. In an external electric field under a considerable gas pressure, the drift of elec-

trons and ions to the electrodes causes a momentum transfer to neutral components of the medium. In view of the large velocity and a short time of the electron drift to the anode, the momentum transferred by electrons to neutral particles is negligibly small and the momentum transfer by ions plays the decisive role. As a result, the gas performs a motion whose type depends not only on the geometry of the volume occupied by the gas, but also on the concentration of dust particles, their mass and charge. Such a movement complicates the formation of stationary dust structures and leads to the evolution of vortices, streamlined clouds, and jets of dust particles.

As a source of ionizing radiation, we used a thin layer of ^{252}Cf whose nuclei experience alpha-decay and spontaneous fission in a ratio approximately equal to 16 : 1. The intensity of the source was $4 \cdot 10^6$ fissions per second. For such an intensity of the radioactive source, the concentration of neon ions near its surface is $N_i \sim 3 \cdot 10^9 \text{ cm}^{-3}$. The source was mounted on an grounded metallic electrode (Fig.1) made in form of a disk of diameter 44mm. A high-voltage electrode of the same diameter was arranged at a distance of 3.5 cm from the source. In the vicinity of this electrode, the ion concentration was $N_i \sim 10^8 \text{ cm}^{-3}$. Additional electrodes were mounted on the planar high-voltage electrode to create a nonuniform field.

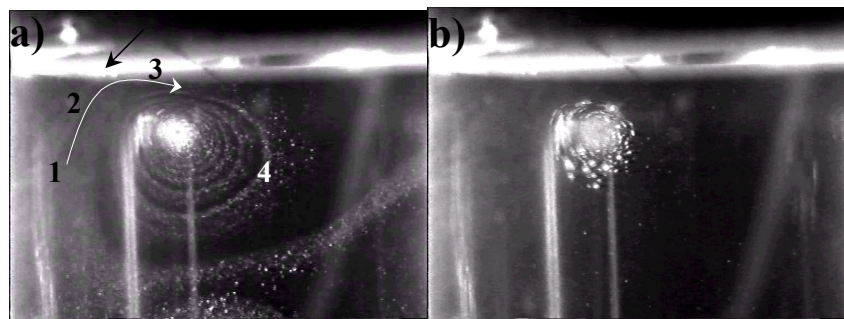


Fig.2. Vortex flow of Zn dust particles for $U=187 \text{ V}$, $U^*=442 \text{ V}$, and neon pressure $0.4 \cdot 10^5 \text{ Pa}$; frame size $3.2 \times 2.4 \text{ cm}^2$; (a) 1.5 min, (b) 4.5 min after the injection of the gas-dust mixture.

A gas-dust mixture was produced by a pulsed action of a neon flow supplied from a dispenser with a fixed volume. This flow was directed to a container with a netlike bottom containing the particles under investigation, and the formed gas-dust mixture uniformly filled the entire volume of the glass cell. The gas pressure was varied from 10^4 to 10^5 Pa . We used Zn particles with a mean radius of 1.2 μm . The concentration of particles varied from 10^5 to 10^6 cm^{-3} . The cell was exposed to a 2D laser sheet. In order to analyze the effect of a nonuniform electric field on the motion of dust particles, we used a plate electrode with

auxiliary high-voltage electrodes. The potential U of the main electrode as well as the potentials U^* of the auxiliary electrodes had positive values with $U^* > U$. The particles were gradually accumulated into a rotational dust structure (Fig. 2a) whose center was located under an auxiliary electrode and was displaced towards the center of the cell. In a few minutes, the majority of the particles were concentrated at the center of the structure, while the remaining volume was free of particles almost completely. With the passage of time, agglomeration of small particles into coarse-grained fragments could be seen, the finer fraction remaining in the central part (Fig. 2b). After the restoration, the vortex motion at this stage may continue for a long time under constant external conditions.

The radii of Zn particles constituting a rotating structure varied from 5.5-6.2 μm . The fivefold increase in the radius points towards a coagulation of the particles in the rotating structure. In the case when potentials U and U^* are identical and electrode B (Fig.1.) is used, Zn dust particles after the injection of the gas-dust mixture coagulate during a few minutes into a cloud with well-defined boundaries (Fig. 3a,b). The cloud has the shape of a truncated cone with the base lying in the plane of the upper electrode and the top near the radioactive source. The entire volume of the experimental cell can be divided into five regions in which the particles behave in different manners. The value of the electric charge q of particles was calculated from the condition of equilibrium and varied from 400 to 1000 e . The average interparticle distance is $190 \pm 30 \mu\text{m}$ and the dust concentration is $3 \div 4 \cdot 10^4 \text{ cm}^{-3}$. A pair distribution function for dust particles has a clearly manifested peak typical of liquid structures. Under a constant pressure and for constant potentials of electrodes, the cloud forms in a few minutes the streamlined upper part close to spherical (Fig. 3b). Then it gradually changes the contour of its boundaries and smoothly falls on the lower electrode.

The clouds described above are formed under pressures from $0.1 \cdot 10^5 \text{ Pa}$ to 10^5 Pa and their behavior is always the same. In the absence of an electric field or a radioactive source, no clouds are formed, and the particles injected into the volume gradually fall down. If the potential of the upper electrode is increased after the formation of a dust particle structure, dust particles rush towards it with a velocity proportional to the potential. It is interesting to note that the entire structure does not move upwards. One or a few jets of moving particles are formed in its upper part. In front of the electrode, the velocity of particles in a jet decreases and the jet expands to form a funnel. The jet may change its shape; the location of its bases may also change (Fig. 4a). In the regions of space outside the structure and jets, the number density of dust particles is close to zero. The use of an auxiliary electrode having a

hemispherical shape and insulated from the main electrode by a dielectric makes it possible to remove dust particles from the cloud (Fig. 4b). In this case, a single dust jet directed to this electrode is formed.

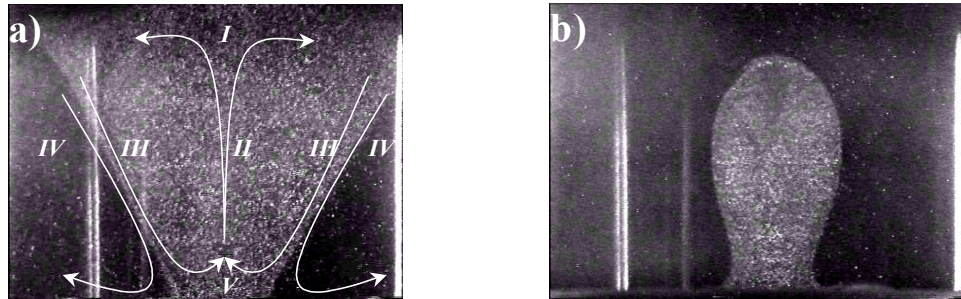


Fig.3. Evolution of the dust cloud formed by Zn particles: a) 2 min, b) 4 min 45 s after the injection of the dust component. The upper electrode has the shape A (fig.1). Its potential is 52 V, distance between the upper and lower electrodes is 3.5 cm, the neon pressure is $0.76 \cdot 10^5$ Pa; frame size is 4.2×3.1 cm²

If we form the electric field by two thin-walled tubes of diameters 3mm and 5mm having potentials different in sign than we can achieve such field configuration when the negatively charged dust particles attract into the internal tube having the positive potential about 150 V relatively to ground. Fig. 4c. The external tube had a negative potential -200 V.

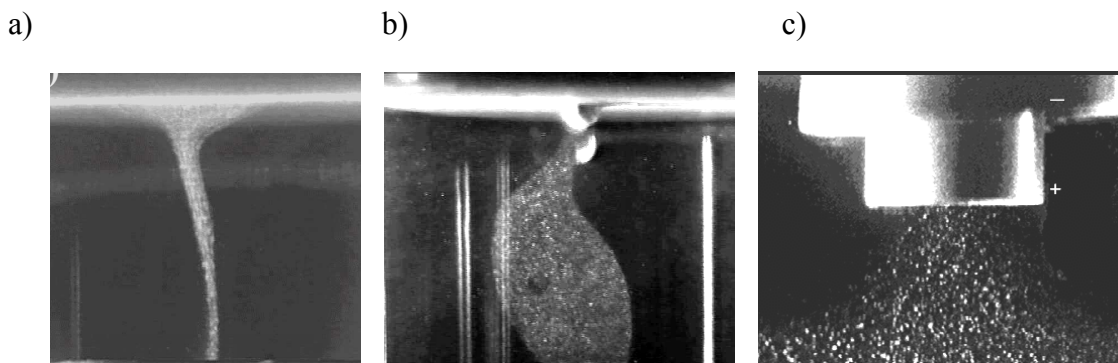


Fig.4. Control and removal of dust particles clouds by A, B and C electrodes presented on Fig.1

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