Stable structures of microparticles in the electrodynamic trap created by the corona discharge

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Abstract. For the first time the stable structures of microparticles in a dynamic linear trap with corona electrodes have been obtained. The possibility for capturing and confining of microparticles in a linear electrodynamic trap with corona electrodes at atmospheric pressure has been studied experimentally. The corona discharge on the electrodes of the trap was generated by an alternating electric field.

1. Introduction
Coulomb structures are the ensembles of charged particles interacting with each other by forces of electrical nature. Strongly correlated Coulomb systems demonstrate such phenomena as phase transitions, waves and instabilities of various nature [1]. In the case of atmospheric pressure, there were attempts to obtain structures of charged dusty particles in the thermal plasma of a gas burner and in the corona discharge. The corona discharge is applied particles separating, powder coloring and in electrostatic precipitators for removing dust particles from air flows. Therefore, the mechanisms of particles charging and their motion in the corona discharge have been explored [2]. Nevertheless, stable dusty structures in the corona discharge have not been obtained yet. Thus, to obtain stable dusty structures in the corona discharge one need to use some additional trap.

Since Coulomb systems consisted only of aerosol particles with charges of the same sign is unstable in principle, the stable ordered structure could be obtained in the potential trap. Such traps can be formed in low pressure electrical discharges [1, 3]. The weight of the charged particles was balanced by the longitudinal electrical field in the axial direction, in the case of a discharge with cylindrical symmetry. The radial electric field confining charged particles in the radial direction appears due to the ambipolar diffusion of electrons and ions to the walls. The sizes of the confined particles were in a rather narrow range from 1 to 25 µm. This range is determined by the particle charge and electrical discharge fields that provide its levitation. At atmospheric pressure in air, there were attempts to obtain structures of charged particles in the thermal plasma and in the electrodynamic traps. In the thermal plasma, stable structure of particles have not been obtained [3] due to the strong gas flows and high temperature gradients. The capturing and confining of charged particles at atmospheric pressure in air can be realized in the quadrupole linear electrodynamic trap [4]. Quadrupole linear traps allow to create the ordered structures of charged dust particles in air at atmospheric pressure [4,5]. The structures
can consist of positively or negatively charged particles. The particle size ranges from 1 to 150 µm. In this case, the ordered structures of the charged particles can be used to study Coulomb systems without neutralizing plasma background and the action of ion and electron flows, which are always present in non-homogeneous plasma.

The aim of this work is to study the possibility of capturing and confining of microparticles in a linear electrodynamic trap with corona electrodes at atmospheric pressure.

2. Experimental setup
In the paper the electrodynamic trap with the electrodes, which created the corona discharge was used. Neutral dust particles were injected in the trap, where they were charged in the plasma of the corona discharge. As a result, the trap confined the charged particles with plasma cloud. The electrodynamic trap consisted of four wire horizontally oriented electrodes. The electrode length was equal to 10 cm and the electrodes diameter was equal to 300 µm. The distance between the electrodes was equal to 10 mm. The photo of the electrodynamic trap is shown in figure 1. Corona discharge on the electrodes was ignited at a voltage of 5 kV. The ac voltage frequency was equal to 50 Hz. In our experiments, we used polydisperse Al₂O₃ powder. Figure 2 shows the particle-size distribution of the powder. The uncharged particles were injected into the trap from the top side. To observe the particle dynamics they were illuminated by a laser with a wavelength of 532 nm and a maximum power of 150 mW. Particle imaging was done by a digital camera HiSpec 1 with a maximum resolution of 1280 × 1024 pixels. The camera allowed us to record video frames with a maximum resolution up to 506 frames/s.

3. Experimental results
The uncharged particles were injected into the trap from the top side. The particles were charged in an electric field of the corona discharge during downward motion and the trap captured some of them. For particles with a diameter, more than 1 µm the main charging mechanism is a
field charging. In this case, the charge of the particle $q$ can be estimated by the Pauthenier formula [6]:

$$q = 3\varepsilon_0 Ed^2 \left( 1 + 2\frac{\varepsilon - 1}{\varepsilon + 2} \right),$$

where $E$ is the electric field intensity, $\varepsilon_0$ is the dielectric constant, $d$ is the size of the particle and $\varepsilon$ is the relative permittivity of the particle. The electric field intensity essentially depends on the particle position in the trap. For example a $10 \mu$m particle located near electrode can be charged up to 40000 units of electron charge. The captured particles formed a stable structure near the axis of the trap. The presence of the electric wind arising due to the direct movement of ions complicates the particle confinement in a trap with the corona discharge in comparison with the classical electrodynamic trap. The photo of stable structure of aluminium oxide particles in a linear electrodynamic trap with corona electrodes is shown in figure 3. The amplitude of ac voltage was equal to 7 kV and current was equal to 80 $\mu$A. In this paper, we did not measure the size of the trapped particles. However, based on past experiments, it can be assumed that the particle size was from 10 to 40 $\mu$m. The dimensions of the structure were $1.4 \times 0.2 \times 0.15$ cm. The structure consisted of approximately 55 particles. The average interparticle distance was equal to 0.8 mm.

![Figure 2. The particle-size distribution of Al₂O₃ powder.](image)
Figure 3. Stable structure of aluminium oxide particles in the linear dynamic trap with the corona electrodes.

4. Conclusion
For the first time the stable Coulomb structures in the corona discharge at the atmospheric pressure were obtained. It was found than the electrodynamic trap with the corona electrodes could capture and confine uncharged dust particles.

Acknowledgments
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