MACROPARTICLE MOVEMENT VELOCITY IN DUSTY STRUCTURES OF VARIOUS COMPOSITIONS

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The results of experimental investigations of the movement velocity of a macroparticle in the dusty structures of various physical-chemical compositions formed in a stratified column of a dc glow discharge, are presented. The macroparticle substances are alumina ($r = 10 - 35$ μm), polydisperse Zn ($r = 1 - 20$ μm) and Zn$'$ ($r = 20 - 35$ μm). Plasma-forming gases are inert gases (Ne, Ar). The inverse relation between the velocity and the gas pressure (in the range 40–400 Pa) is found and, for the same material of macroparticles in different gas plasmas, is confirmed by theory and does not contradict observations. But, to explain a difference of quantitative data for macroparticles made from different materials in Ar plasma, the additional research is required.

Complex plasma is a widespread state of matter in the nature and technological operations. The problem of particles' kinetics in complex plasma arises, because the appearance of macroparticles in plasma modifies plasma properties and gives rise to various processes: an interaction between macroparticles and ions and electrons gives rise to the charging of macroparticles, power from plasma to macroparticles transfers through plasma oscillations, macroparticles lose energy because of neutral impacts, negative charge of macroparticles gives rise to forming the particle flows in plasma, *etc.* The investigation of these and many other processes has a high significance for power machines (tokamaks, lasers, rocket engines, *etc.*), plasma technologies of material processing and producing, astrophysics, for the physical modeling of condensed matter, microcosmic objects, and astrophysical objects inaccessible for experiments.

The plasma-dust structures in complex plasma represent an unusual state of matter. We may expect that a variation of the physical-chemical characteristics of a plasma-forming gas and a macroparticle material will result in quantitative changes of the characteristics of a structure, as well as in a macroparticle motion [1, 2] under similar conditions.

It is known from the previous experiments that the macroparticles embedded into plasma acquire a kinetic temperature much more than the temperature of ambient gas, i.e., the interaction between charged macroparticles and ambient plasma in ordered structures results in the essential heating of macroparticles [3]. In work [4], the theoretical justification of the heating of macroparticles due to a fluctuating electric field of plasma is proposed. An important result of that work is the expression for the kinetic temperature of macroparticles which is propotional to the electron temperature T_e. However, no quantitative experimental data, which would confirm it for the complex plasma of a dc glow discharge, are available.

In present work, we study the influence of the physical-chemical composition and some parameters of complex plasma on the velocity of macroparticles. In experiments, we use the complex plasma of a dc glow discharge at low currents and pressures. The ordered structures (Fig. 1) are formed from macroparticles levitating in strata of a positive column.

A vertically oriented gas discharge tube (the internal diameter $2R = 30$ mm) is employed [1, 5]. The shape of electrodes is a cylinder with a diameter of 25 mm. A narrowing (diameter 2.5 mm) is placed within the tube. The narrowing is necessary to the generation of stable standing striations in a wide range of parameters. Macroparticles are injected in plasma from a container which is placed at the top of the tube. The macroparticle materials are Al_2O_3 (r = 10–35 μm, $\langle r\rangle = 23$ μm), polydisperse Zn (r = 1–20 μm, $\langle r\rangle = 8$ μm), and Zn' (r = 20–35 μm, $\langle r\rangle = 28$ μm). Plasma-forming gases are inert gases (Ne, Ar).

Powder is injected into plasma by shaking a container. Macroparticles fall through the grid bottom and are trapped in strata. The glass tube is evacuated by a diffusion pump, and the base vacuum is about 10^{-5}–10^{-4} Torr. The pressure of a plasma-forming gas p is varied in the interval 0.3–3 Torr, the discharge current I is 0.4–1.2 mA (the electron density n_e in dust-free plasma is about

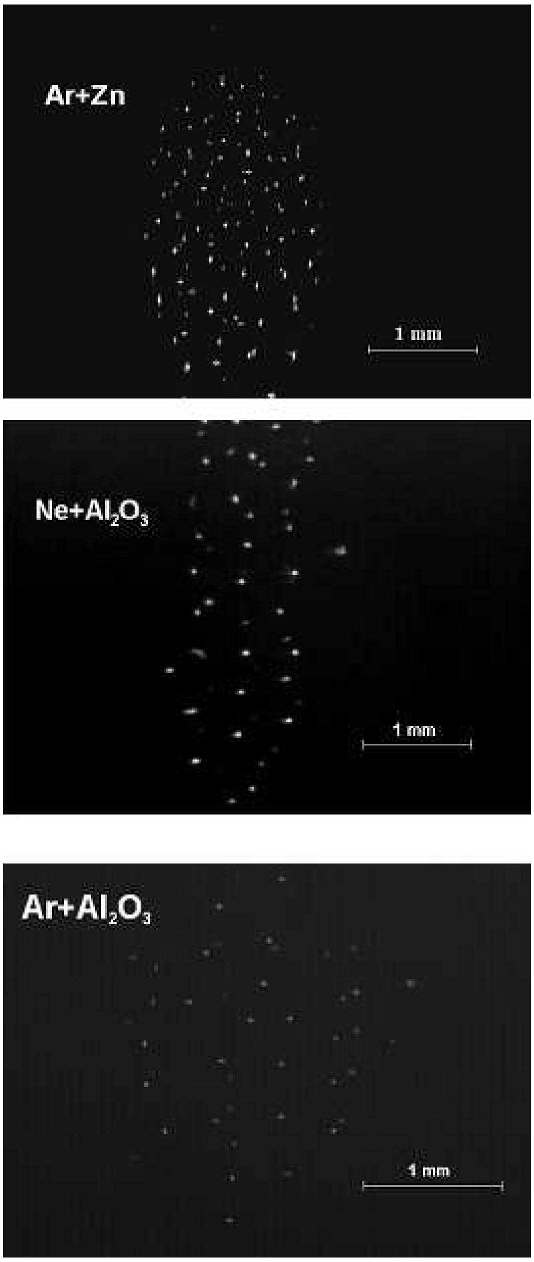

Fig. 1. Structures of macroparticles in a stratum glow discharge (a gas pressure of 0.6 Torr, a discharge current of 1 mA)

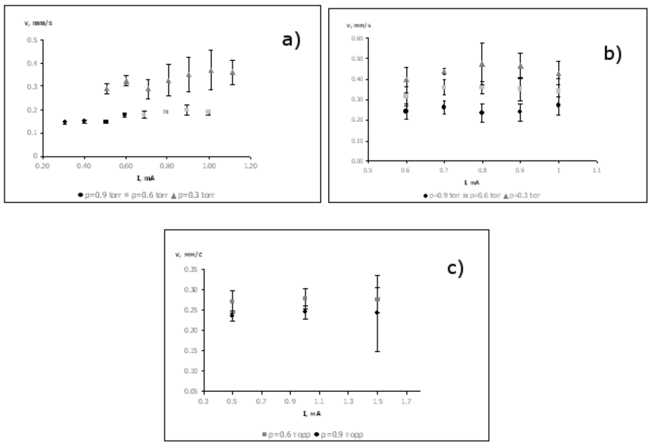

Fig. 2. Experimental dependence of the average velocity of motion of macroparticles on the discharge current: *a*)Ar+Al_2O_3 [2], *b*) Ne+Al_2O_3 [2], *c*) Ar+Zn

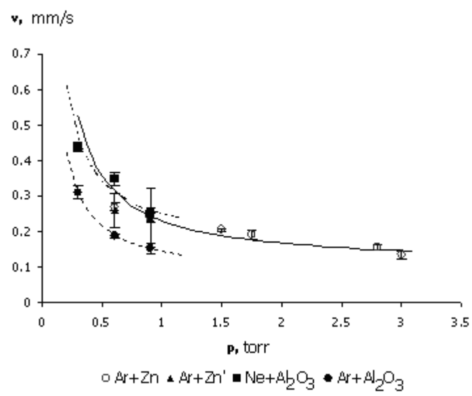

Fig. 3. Macroparticle velocity versus the gas pressure (figures – experiment, lines – approximation by the inverse relation) at room temperature

10^8 cm^{-3}, the electron temperature is about several eV). The probe measurements under similar conditions can be found in [6].

Macroparticles in a cross-section of the macroparticle structure were observed by a CCD-camera for 4 s (a picture frequency of 25 Hz). 100 displacements was done by every macroparticle for this time. Every displacement ds_i occurs for 1/25 s at a velocity v_i. The macroparticle mean velocity of a displacement for 4 s and the dispersion were calculated for 100 v_i. Then the ensemble averaging for N macroparticles (visible in a cross-section) was made taking into account the dispersion of velocity values. Errors were estimated, by basing on 3 measurements for each point in Fig. 2 and Fig. 3.

The slight influence of the electron density on the macroparticle velocity is evident from the dependence of the mean macroparticle velocity on the discharge current (Fig. 2). The discharge current $I \approx en_e v_e R^2$, where v_e is the electron drift velocity.

An inverse relation between the macroparticle velocity and the gas pressure (Fig. 3) was found for ordered dusty structures of various compositions. A decrease of the velocity (Fig. 3) is caused by both the friction on neutrals and a decrease of the electron temperature. The trend to curves $v(p)$ for similar macroparticles (Al_2O_3) in Ar and Ne plasma correlates with curves $T_e(p)$ for the same gas plasma [7]. These experimental data are in agreement with the theory [4]. The influence of the electron temperature on the macroparticle motion was observed, for example, in experiments with a high-energy electron beam (tens of eV) under similar discharge conditions [8], but without quantitative measurements.

The conducted researches give us an experimental evidence that the macroparticle material also influences, in particular, the kinetic temperature of macroparticles in ordered dusty plasma structures. This result is not follow from [4] and cannot be also explained by the friction on neutrals, because the macroparticles have approximately identical size (Al_2O_3 and Zn'). To explain a difference of quantitative data for different materials of macroparticles in Ar plasma, the additional research is required.

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ШВИДКІСТЬ ПЕРЕМІЩЕННЯ МАКРОЧАСТИНОК У ПИЛОВИХ СТРУКТУРАХ РІЗНОГО КОМПОНЕНТНОГО СКЛАДУ

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Р е з ю м е

Наведено результати експериментальних досліджень швидкості переміщення мікрочастинок у пилових структурах різного фізико-хімічного складу. Плазмово-пилові структури формувались у стратах позитивного стовпа жевріючого розряду. У ролі пилової компоненти використовували частинки оксиду алюмінію (r = 10–35 мкм) і цинку (r = 1–20 мкм і r = 20–35 мкм). Газовими наповнювачами виступали інертні гази (Ne, Ar). Було отримано зворотні залежності швидкості переміщення мікрочастинок від тиску газу (в діапазоні 40–400 Па). При цьому для мікрочастинок із однакового матеріалу, але у плазмі різних газів дані узгоджуються з теоретичними передбаченнями і не суперечать спостереженням. Але, щоб пояснити розбіжність у швидкостях макрочастинок різного матеріалу в аргоновій плазмі, потрібні додаткові дослідження.