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EVALUATION OF DIFFUSION CONSTANT AS KINETIC PARAMETER OF DUSTY PLASMA STRUCTURES*

This paper is concerned with diffusion processes in dusty plasmas. The video registration method and the correlation spectroscopy method are described and their applicability is tested. These methods are applied for diffusion constant value calculation. A good agreement between values of diffusion constants calculated by the video registration method and the correlation spectroscopy method are shown.

Key words: Dusty plasma, correlation spectroscopy, diffusion constant, self-organization

INTRODUCTION

Dusty plasma is an ionized gas containing microsized particles of solid matter [3]. Charged particles form self-organized, dissipative, ordered crystal-like structures in plasma, so-called plasma crystals. At the same time, dusty plasma structures could be in different physical state: solid, fluid or gas-like state. Definition of the phase transitions processes in dusty plasma is one of the main purposes of studying dynamic and kinetic processes in dusty plasma physics. For instance, melting transition is observed when the gas pressure in the discharge is reduced [4], [5].

Nowadays, investigation is aimed at developing and testing new methods for measuring and computing kinetic characteristics of dusty plasma. One of the parameters that characterizes stability of a dusty plasma crystal is a diffusion constant. While studying kinetic processes in dusty plasma it is important to know the oscillation characteristics of structure particles. The diffusion constant is an order parameter of plasma crystal, and this constant determines the value of particle oscillations. If the value of the diffusion constant is known, it is possible to investigate the processes in the dusty structure at the kinetic level.

The causes of dust particles self-diffusion in the structures are described in [6]. Diffusion in dusty plasma differs from diffusion of gases, liquids and solid states. In this case diffusion is a random motion of charged dust particles, due to fluctuations of the charged particles with time. The self-diffusion depends on changes in the field of a charged particle, on plasma parameters, and particle interaction. When transition from a solid state to a liquid state and further to a gas-like state occurs, more intensive movement of particles can be observed. Therefore, the value of the diffusion constant is directly associated with the physical state of a dust cloud.

Much attention to the definition of diffusion in the dust structures is paid in [7], [8], [9], [10]. Results of diffusion constants calculations were obtained by the video registration method.

Diffusion of microparticles is a primary means of mass transport, which determines the energy loss in the dust systems and their energy characteristics [9]. The mass transfer in a dusty plasma by particle's diffusion is described in [8], [11]. The diffusion constant shows a qualitative change in the dynamic state of the structure. The results of numerical simulation of mass transfer processes are presented in [11].

Currently there are no materials related to the application of the correlation spectroscopy method to study dusty plasma, to conduct simultaneous experiments by video registration and correlation spectroscopy methods, and to compare the values obtained.

EXPERIMENTAL SETUP AND METHOD DESCRIPTION

The experiments were conducted in a setup for studying the physics of dusty plasma structures. A discharge tube is evacuated to 10^{-4}–10^{-5} torr. and filled with gas. A dust-plasma crystal is formed in glow-discharge plasma that is induced in the discharge tube. A metal container with particles (e. g. Al_2O_3, Zn, CuO or other polydisperse powder) is used to inject particles in the experiment. The dusty structure was visualized by a semiconductor laser DTL-316 and a set of lenses, forming a "laser knife". It is possible to observe the object in the scattered light. The plasma crystal is detected by the CCD camera. The signal (picture) is processed by the software, and the diffusion constant is calculated by the video registration method. A correlation spectroscopy unit consists of a photomultiplier tube (PMT), which is used as a detector of scattered radiation, a correlator, and a program that implements data acquisition in real time, processes and saves data.

As a result of the experiment we obtained diffusion coefficients calculated by the video detection method and correlation spectroscopy method.

Video registration method

The software recognizes the signal received from the video camera and determines position of each particle in a section of the structure. Structure observations for the several seconds t helps to determine trajectory of each particle. Picture frequency is 25 fps, and spatial resolution is 6 μm per pixel [1].

Diffusion constant equation:

$$D(t) = \frac{<< r(t) - r(0) >_M{}^2 >_t}{4 \cdot t}, \quad (1)$$

where $<<r(t)\text{-}r(0) > M^2 > t$ is a square displacement, *r(0)* – position of a particle at the initial time, i. e. at the beginning of shooting, *r(t)* – the position of a particle through time *t*, *M* – number of particles in the ensemble.

Correlation spectroscopy method

The diffusion constant is calculated on the basis of the signal autocorrelation function obtained by detecting the dust structure scattered radiation. Autocorrelation function:

$$g_2(\tau) = \overline{I_1(t) \times I_2(t+\tau)}, \quad (2)$$

where I_1 and I_2 – is the value of the signal intensity at different periods of time. If the particles are in a like viscous fluid, the autocorrelation function can be represented as:

$$\gamma(\tau) = e^{-(q^2 D\tau)}, \quad (3)$$

where $q = 2*k*\sin(½\Theta)$, $k = 2\pi/\lambda$ – wave-vector, Θ – scattering angle.

Using (2) и (3) it is possible to calculate a diffusion constant.

RESULTS

To estimate reliability of diffusion values experiments were conducted in which simultaneous registration of a dusty plasma structure by correlation spectroscopy and video registration methods was performed. The diffusion constant was computed by both methods simultaneously.

The table shows that both methods give equal value of the diffusion constant, within experimental accuracy. The value of the coefficient, measured by direct detection may be underestimated due to the fact that measurements are made in “laser knife” and only horizontal and radial movements of particles are detected, while diagonal or other movements are neglected.

The results of experiments (pressure = 80 Pa)[10], [11]

Methods	Current, mA	Gas	Particle material	$D/10^6$, cm^2/s	$\Delta/10^6$, cm^2/s
Correlation spectroscopy method	0,6–0,8	Ar	Al_2O_3	0,70–1,3	0,5
Video registration method	0,6–0,8	Ar	Al_2O_3	0,51–1,3	1,1
Correlation spectroscopy method	1,0–1,2	N_2	Zn	0,90–1,51	0,5
Video registration method	1,0–1,5	N_2	Zn	1–1,4	1,1

In addition, obtained experimental data could be compared with the calculations made in [9].

As a result, the order of constant values obtained in our experiment and in [9] is comparable, which invalids our data. Some discrepancy in experimental data can be explained by differences in experimental conditions.

CONCLUSION

In conclusion, we can say that that the correlation spectroscopy method can be used to study kinetic processes and to calculate dusty structures diffusion constants. This conclusion is made on the basis of conducted experiments on simultaneous recording of the diffusion constants by the video registration and correlation spectroscopy methods. The results obtained are within experimental accuracy, indicating reliability of the values recorded by the correlation spectroscopy method.

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