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Experimental study of laminar flow in dusty plasma liquid

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Abstract

It is for the first time shear viscosity of dusty plasma liquid defined by the screened Coulomb interaction of dust particles is estimated on the basis of experimental data. The results of the experimental studies of the laminar viscous dusty plasma flow are presented in the Letter.

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1. Introduction

The dusty plasma of gas discharges is a partly ionized gas, which contains negatively charged dust particles of micron size. Micron-sized dust particles in gas-discharge plasma assume a significant negative charge ($\sim 10^3$–$10^5 e$) and may form quasi-stationary plasma-dust structures similar to a liquid or a solid [1–6].

Quite unusual dynamics of dusty plasma under external effects have been demonstrated recently in a number of studies, such as various flows in plasma-dust structures [7,8] and shock waves. However, the main characteristics of the medium being treated, which enable one to change over from a descriptive study of the observed phenomena to their detailed analysis, have hardly been studied. Such characteristics include, first of all, the dust plasma viscosity defined by the screened Coulomb interaction of dust particles. Attempts at theoretical calculation of shear viscosity run into the need of using a not quite well-defined approximation of interparticle interaction by the Debye potential [9,10]. Therefore, it is of significant interest to experimentally estimate the dusty plasma viscosity.

2. Experiment

This Letter deals with experimental studies into the shear viscosity when treating laminar flows in a

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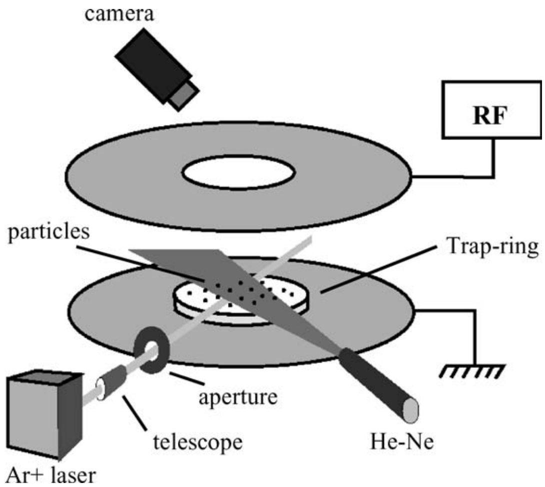

Fig. 1. Schematic of the experimental setup.

dusty plasma liquid. An experimental setup, whose schematic is given in Fig. 1, was developed for the investigation of the shear viscosity of a dusty plasma liquid. The laser radiation was used to develop a laminar flow in the medium being studied; it was the treatment of this flow that enabled one to draw inferences about the shear viscosity.

Two flat electrodes were placed in a vacuum chamber. The lower, grounded, electrode was a metal disk of a diameter $d = 19$ cm. The upper electrode located at a height $H = 5$ cm from the lower electrode had a ring shape with an outside diameter $d_{\text{out}} = 19$ cm and inside diameter $d_{\text{in}} = 5$ cm. The vacuum chamber was filled with argon to a pressure $P = 50$ Pa, and the voltage from a radio-frequency generator with a carrier frequency of 13.56 MHz was applied to the electrodes. This resulted in the emergence of a glow discharge between the electrodes in the argon atmosphere. Dust particles from a special container were introduced into this discharge via an opening in the upper electrode. Macroparticles were transparent plastic spheres 1.9 µm in diameter. After getting into the discharge and being negatively charged [3], these dust particles levitated in the electrode layer. In order to contain the dust cloud and preclude the departure of the particles, a ring 5 cm in diameter and 0.2 cm high was mounted on the lower electrode. For visualization, the resultant structure was illuminated by a plane beam of a He–Ne laser. The beam was 2.5 cm wide, with the characteristic thickness of 200 µm in the waist region. The

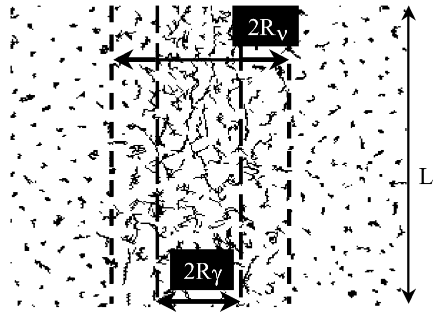

Fig. 2. Typical trajectories of dust particles under the effect of laser radiation. The characteristic dimension of the flow channel is $2R_\nu = 7$ mm, while the width of the region within which the dusty plasma system was affected by laser radiation is $2R_\gamma = 3$ mm.

flow within the plasma-dust structure being investigated was initiated by the radiation of an argon laser with a wavelength of 514 nm. The laser beam was pre-expanded by a telescope, and then the central part was cut out from the beam using a diaphragm of diameter $d = 3$ mm. The motion of dust particles was recorded using a CCD-camera (Fig. 2).

3. Analysis and result

On analyzing the video images obtained during the experiment, one can construct the binary correlation function and draw inferences about the concentration of macroparticles for an unperturbed dusty plasma liquid, as well as estimate the coupling parameter Γ in this medium [11]. These data are given in Fig. 3. One can see from the graph of the correlation function that the short-range order of arrangement of macroparticles is present in the system and no long-range order is observed. Therefore, we deal with the liquid state of a dust structure. We trace in time the paths of individual particles to obtain the distribution of their drift velocity inside and outside the flow channel (Fig. 4(a)).

Note that, for correct estimation of the correlation between the geometric dimensions of a channel within which one observes a directed motion of macroparticles levitating in the electrode layer of the discharge and the width the beam region within which the radiated power density of the laser proves to be sufficient to cause the directed motion of macroparticles, one must know the distribution of the radiated power of the laser along the laser beam radius. In the course of