OBTAINING OF STABLE PLASMA-DUST STRUCTURES IN THE STRIATION OF A GLOW DISCHARGE IN A MAGNETIC FIELD UP TO 15000 G

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INTRODUCTION

The first research of dusty plasmas in magnetic field [1] was carried out in DC discharge. One of the tasks to be solved, which was set by the authors, was to control the volume dust structures with the help of the influence of the longitudinal magnetic field. When the magnetic induction range was extended to the value on the order of 10000 G, there was the problem of the stable discharge and probably of the stability of the dust structures in the dust traps. In [2,3], the DC discharge was replaced by the RF discharge but the discharge chambers were similar (could be used for two types of discharge). Perhaps, authors of [4] also faced the problem of obtaining dusty plasmas in the glow discharge in the strong magnetic field more than 1000 G.

The large number of new researches of dusty plasmas in magnetic field which appeared in the last 10 years [5-10] uses only RF discharge in which dusty plasmas is formed in the shape of the monolayers placed perpendicular to the vector of magnetic induction. However, in the RF discharge in the magnetic field, the dust layers lose stability and uniformity too. So, the effect of discharge filamentation breaks the uniform dust disk into fragments (patterns), the size of which is several millimeters which is comparable to the width of the volume dust structures in the glow discharge [5].

In most recent works [11-13] we created the stable traps in stratified glow discharge in the strong magnetic field. In this communication we want to discuss some technical problems and conditions of the experiment, under which it was possible to create the stable dust trap, as well as to compare conditions with literary data from the works of the 1960s in which the properties of the glow discharge in the magnetic field were studied intensively.

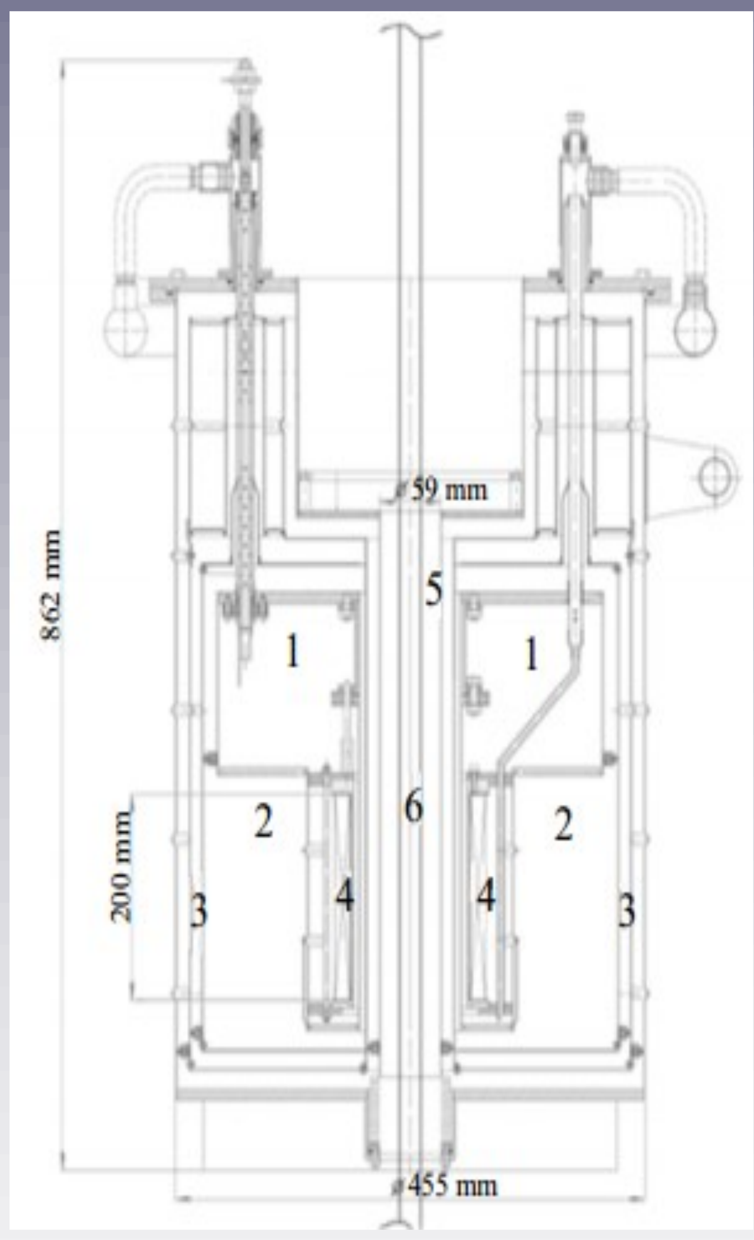

Fig. 1. Scheme of the cryomagnet with the discharge tube. (1) 20 L container with liquid helium; (2) 15 L tank with liquid nitrogen; (3) vacuum chamber; (4) superconducting solenoid; (5) warm channel (bore); and (6) discharge tube.

EXPERIMENT

Magnetic field with induction of up to 20000 G was created by cryomagnet, detailed in Fig.1.The cryomagnet is a helium cryostat with a superconducting solenoid inside. The maximum magnetic field created in the center of the solenoid reaches 2.7* 10^4 G at the current of 55 A. The homogeneity of the magnetic field in this area is 0.1% in cm^3. The vector of magnetic induction is directed vertically. Liquid helium is necessary to provide a superconducting phase transition of the solenoid. The liquid helium container in turn is placed inside a liquid nitrogen tank, designed to reduce the loss of liquid helium. All these are placed in a chamber, pumped to a high vacuum up to 10^{-5} Torr, which is necessary to reduce a flow of liquid nitrogen. Inside the cryomagnet there is a cylindrical channel (warm bore) with diameter 59 mm isolated from low temperatures. An object of experiment is placed here in homogeneous magnetic field. The temperature inside the warm bore during operation of the cryomagnet was 281 K.

A discharge tube with inner diameter 22 mm and 1.5 meters length was located coaxially to the warm bore inside the cryostat. The tube was able to shift along the cryostat so that an observed dusty structure was always in the central part of the solenoid (inhomogeneous magnetic field). Both electrodes were placed outside the cryomagnet and did not enter a magnetic field region; the cathode was located at the bottom. An injection of particles was carried out by a container with a fine mesh at its bottom. It was fixed in the side appendix of the discharge tube at 1 m distance or more from the superconducting solenoid. The injection was managed by shaking of the container with dust by outside magnet. To ensure stable stratification, a dielectric current narrowing insert was placed inside the discharge tube. Observations were carried out in the first striation from the insert in the direction of the anode.

The observations of dust structures formed from polydisperse quartz powder were made. Three types of inert gas were used: helium, neon and argon in a magnetic field of up to 10000 G. As the stable dust structure we considered one which has regular rotation in the magnetic field. The dust structure could be trapped in the striation in the strong magnetic field, but be distorted or displaced from the discharge axis and lose rotation. After passing the region of the instability in magnetic induction, the dust structure either restores the rotation or falls out of the trap; this we call "breakdown". The following figures give an idea about the obtained stable structures and breakdowns, Fig.2 - Fig.4.

DISCUSSION

The conditions that allowed for the first time to produce dust plasma in the glow discharge in the strong magnetic field of up to 10000 G were selected in the experiment. In the significant number of cryomagnet launches, the dusty plasmas in the strata experienced breakdowns, even if the discharge continued to burn and the discharge current was not interrupted. We tried to compare our experimental observations with the available literary data about uniform (not stratified) glow discharge in the magnetic field and to conclude the general recommendations for obtaining the stable dusty plasmas.

First, the longitudinal magnetic field reduces radial diffusion, as a consequence, radial energy release (proportional to electron density). The thermal gradient (hence the force of the thermophoresis), pushes the dust structure toward the wall, often giving it an annular shape. Probably, the authors [4] faced this problem. To prevent it, we minimized the discharge current and did not use (in neon) high gas pressures as far as possible.

Second, in the glow discharge in the longitudinal magnetic field there is current-convective instability [14-16]. The parameters of instability can be estimated from literary data. Despite the fact that we have stratified discharge, the area of this instability is present, Fig.4 (2500 – 3500 G). In addition, in a number of launches there were two areas of instability; the second one was in the magnetic field 6000 – 11000 G under the same conditions (neon, p = 0.7 Torr). It was partially possible to avoid these instabilities if the cathode was located outside the magnetic field and the diameter of the discharge tube was reduced (from 2 cm to 1.5 cm).

In addition, at reduced pressures (up to 0.2 Torr and less) the breakdown of the structure occurs more likely, Fig.3. Due to the breakdowns, it was not possible to make observations in helium even at higher pressures, Fig.2. We also suppose that the breakdown is triggered by the deflection of the tube axis from the direction of the longitudinal magnetic field, as well as by the substantially narrow diaphragm (less than 4 mm) in the strata-forming insert.

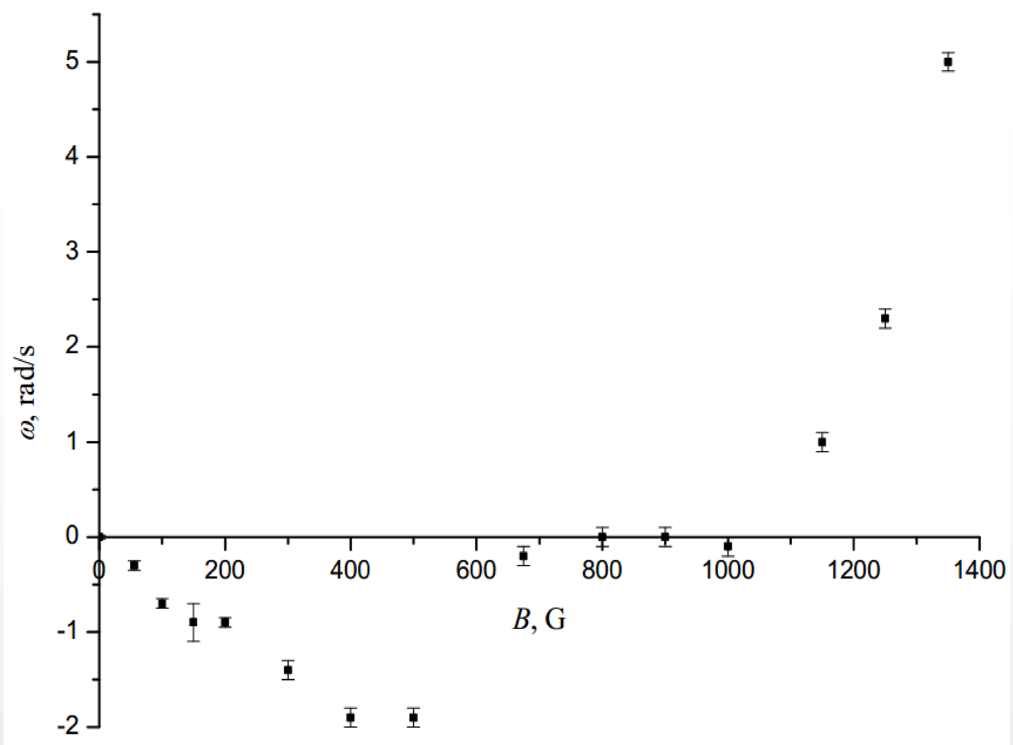

Fig.2. The dependence of angular velocity of horizontal cross section of dusty plasma structure formed in the striation trap of glow discharge on the induction of magnetic. Conditions: plasmaforming gas is helium, discharge current is 1 mA, gas pressure is 2.4 Torr. In the magnetic field 0.14 T there was the breakdown of the dust structure in the trap.

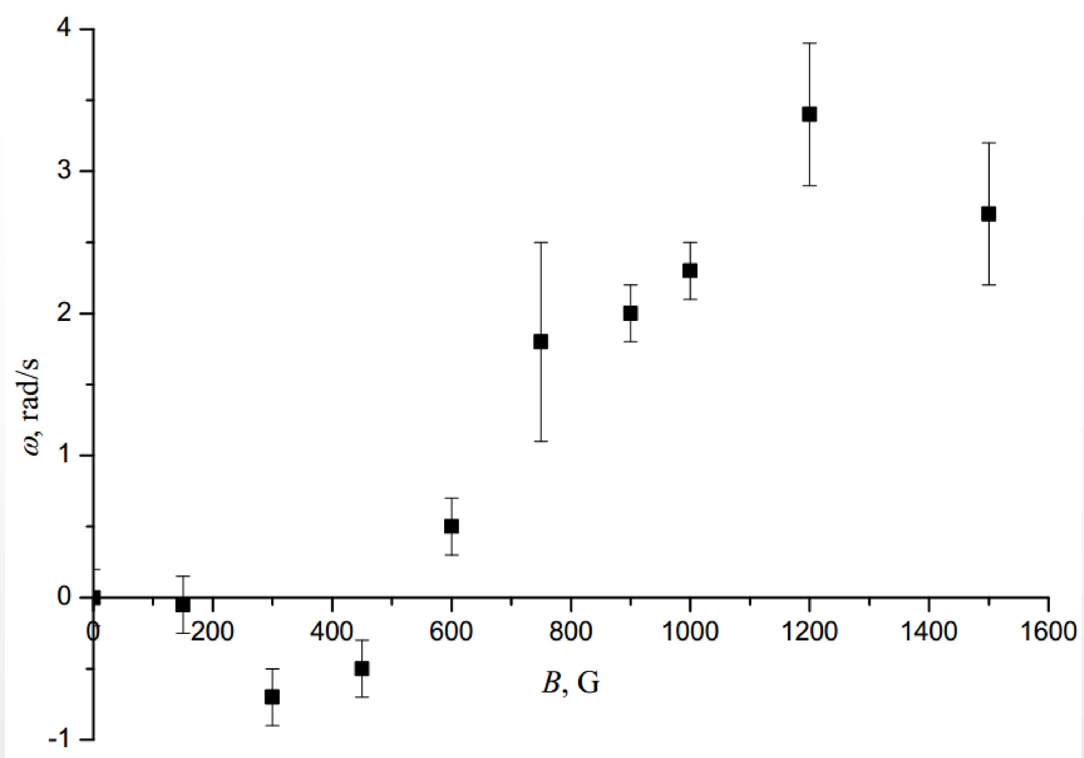

Fig.3. The dependence of angular velocity of horizontal cross section of dusty plasma structure formed in the striation trap of glow discharge on the induction of magnetic field obtained at minimal pressure and current. Conditions: plasmaforming gas is neon, discharge current is 1 mA, gas pressure is 0.2 Torr. In the magnetic field 0.15 T there was the breakdown of the dust structure in the trap.

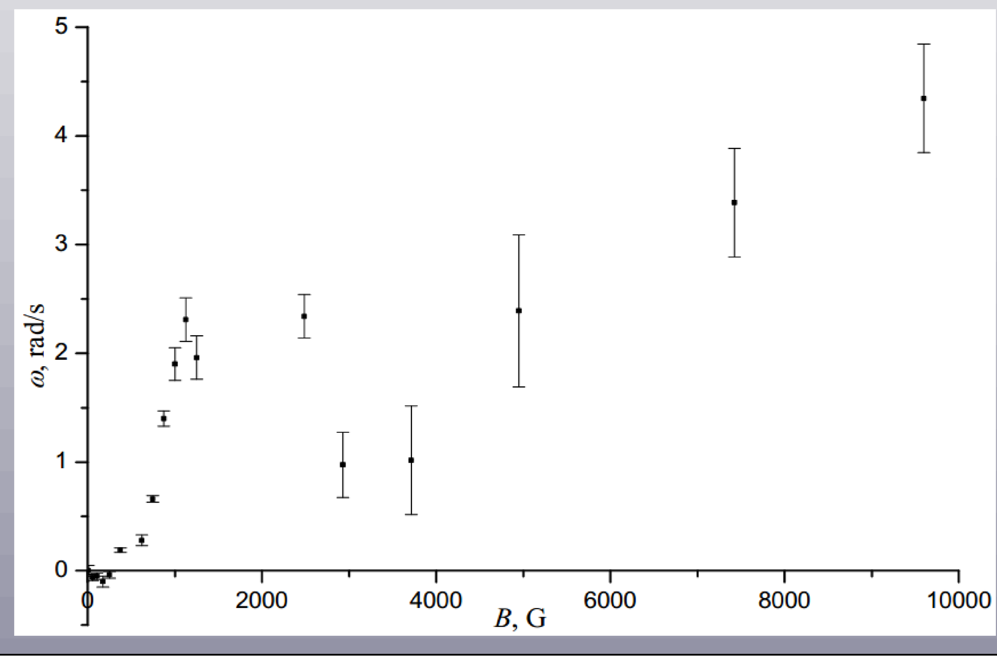

Fig.4. The dependence of angular velocity of horizontal cross section of dusty plasma structure formed in the striation trap of glow discharge on the induction of magnetic field. Conditions: plasmaforming gas is neon, discharge current is 1.4 mA, gas pressure is 0.6 Torr, polydisperse quartz particles with main size 5-6 µm. In the area from 3000 to 4000 G there is instability, but there is no complete breakdown of the dust structure.

CONCLUSIONS

Varying the following parameters: a sort of the gas and its pressure, discharge current, diameter of tube and the location of its cathode in magnetic field, alignment of discharge and field, particle size (dispersion), for the first time it was possible in experiment to create stable dust plasma in stratified glow discharge in strong magnetic field.

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