BALLISTIC MODELS OF DUST PARTICLE GROWTH AND DUST STRUCTURE FORMATION

M.V. Shatalina(1), **E.A. Mareev**(2)

(1) Institute of Applied Physics, Russian Academy of Science,
46 Ulyanov st., Nizhny Novgorod, 603950 Russia.
E-mail: aries@appl.sci-nnov.ru

(2)As (1) above, but E-mail: mareev@appl.sci-nnov.ru

ABSTRACT

It is known from the experiments that small growing dust particles in plasma usually form rather complicated resembling fractal clusters. We present a generalized ballistic model of structure formation in dusty plasmas. We develop a numerical model of the growth of a dust grain in plasma and examined its characteristics. The process of dust cloud formation has been investigated as well. In the modelling we took into account different laws of interaction between dust particles. Numerical simulations provide the growth rate of dust particles close to experimental values.[1]

INTRODUCTION

Nowadays dusty plasma is a popular object of theoretical and experimental investigations. Under usual circumstances the dust grains accumulate a negative electrical of the order of 10^2 to 10^4 times the charge of an electron, due to the high mobility of the electrons as compared to ions. Sometimes the presence of dust can essentially influence characteristics of plasma that contains dust particles [1]. It is known from the experiments that small dust particles in plasma occasionally form the fractal structure in the shape of cauliflower when growing [2]. The state of the numerical and theoretical modelling of these dusty plasma phenomena is less developed than the state of experiment up to now, and recently has attracted great attention including particle simulation code development [3].

MODEL

In our modelling we have generalized the common ballistic a growing model of the Brownian cluster for of structure formation in dusty plasmas. Dust structure is characterized by its radius R, charge Q and N – the number of particles in a structure. The charge of structure Q can be estimated as $Q \cong C\varphi$, where $C = 2R$ - structure capacity [4], $\varphi \cong T_e / e$ - thermal potential of the structure.

Dust structure fractal dimension D can be approximated by the following equation:

$$D = \frac{\ln N}{\ln(R/a)}, \tag{1}$$

where a – radius of a small dust particle [5].

In the modelling we took into account different laws of interaction between dust particles. Absorbing surface of dust particle leads to non-Debye potential [6]:

$$\varphi = \varphi_0 \left[\frac{1}{2} \frac{T_e}{T_e + T_i} \left(1 + \frac{T_i}{2e|\varphi_0|} \right) \frac{a^2}{r^2} + \frac{a}{r} \exp\left(-\frac{r}{r_D} \right) \right]. \tag{2}$$

Also we have taken into account another mechanism of dust particle interaction – effective attraction. This effect may occur due to dust grain adsorption of the plasma particles therefore the resulting interaction force is repulsive at short distance and attracting at remote distance [7].

[1] This work is supported by the Russian Foundation for Basic Research (project N. 00--02--17758).

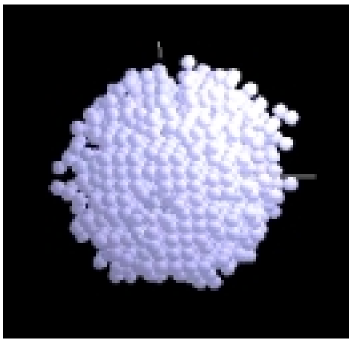

Fig.1. 3-D view of dust grain simulation.

We assumed that if the particle reaches the structure it will join the structure under the influence of intermolecular forces and occupies a place near the closest point of the structure. The distance between particles in the structure $L = 2a$, $a = 1 \div 10$ nm. Also we take into consideration that adhesion probability of a particle is less than 1. The penetration of small dust particles with high kinetic energy to the growing structure has been specified to characterize various types of dust materials.

For the numerical calculation the time of growth can be estimated as:

$$T_{str} \cong N_{total} \nu_d^{-1}, \qquad (3)$$

where $\nu_d = n_d \sigma_{str} V_{Td}$ – dust frequency of collision (V_{Td} and n_d - thermal velocity and concentration of dust particles, $\sigma_{str} \cong \pi R^2$ - absorption cross-section of the structure), N_{total} - total number of algorithm steps. Since the adhesion probability is less than 1 we have $N<N_{total}$. From the other hand we can estimate the growth time using simple theoretical approach. Let the rate of particle increasing in the structure is

$$dN/dt = \nu_d. \qquad (4)$$

From (1) and (4) we have $R \propto t^{1/(D+2)}$.

NUMERICAL SIMULATION RESULTS

Using the following parameters of dusty plasma: T_e = 2 eV, $T_i \approx T_d$ =0.1 eV, $n_e = n_i = 10^9$ sm^{-3}, $n_d = 10^8 \div 10^{10}$ sm^{-3} we have found the fractal dimension of the dust structures D = 2.88±0.06, which characterizes sufficiently dense packing of the cluster. 3-D view of a spherical dust grain in our model is presented on Fig.1. In this model a temporal growth of a particle radius turned out to be approximated by the logarithmic curve. We can approximate the curve for the large N by a power law (Fig.2.):

$$R \propto t^{0.1854}. \qquad (5)$$

Substituting the measured value of fractal dimension to (4) we have: $R \propto t^{0.21}$.

Also we have investigated the process of dust cloud formation. The distance between particles in the structure L =3.62a [6], $a = 1 \div 10$ μm. . Fractal dimension of the cloud does not exceed 2.5.We have used a similar model for modelling of the dust cloud with another particle size (1 µm). We found the fractal dimension of a dust cloud (D = 2.43±0.05) that is

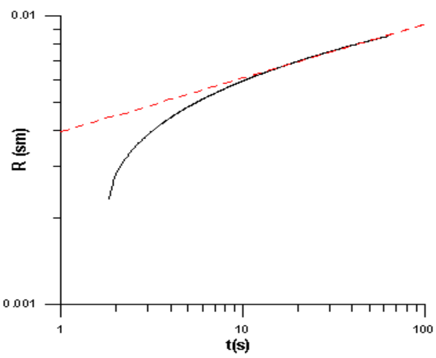

Fig.2. Numerical simulation of dusty structure radius (-) and its power approximation (- -)

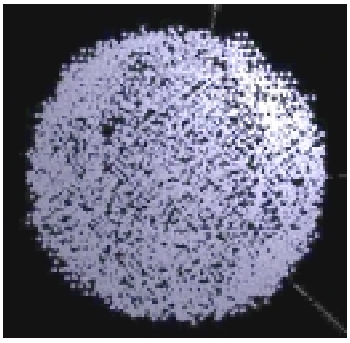

Fig.3. 3-D view of dust cloud simulation.

close to the fractal dimension of a simple Brownian cluster. 3-D view of a spherical dust cloud in our model is presented on Fig.3.

CONCLUSION

We have presented a model of structure formation in dusty plasmas as a generalized ballistic model of the Brownian cluster. In particular, we built a numerical model of the growth of a dust grain in plasma and examined its characteristics. Also we have investigated the process of dust cloud formation. In the modelling we took into account different laws of interaction between dust particles. The penetration of small dust particles with high kinetic energy to the growing structure has been specified to characterize various types of dust materials. As a result of numerical simulations we found that simultaneous account for both of these effects gave us the growth rate (from 1 nm to 100 nm) close to experimental values.

REFERENCES

[1] V.N. Tsytovich, "Dust plasma crystals, drops and clouds", *Uspekhi Physicheskikh Nauk*, vol.167, N 1, 1997. P.57-99.

[2] L. Boufendi and A. Bouchoule, "Particle nucleation and growth in a low-pressure argon-silane discharge". *Plasma Sources Sci. Technol*. 3, 1994. P.262-267.

[3] G. Joyce, M. Lampe, and G. Ganguli, "Particle Simulation of Dust Structures in Plasmas", *IEEE Transactions on Plasma Science*, vol. 29, N 2, April 2001. P.238-246.

[4] Ya.L. Alpert, A.V. Gurevich, L.P. Pitaevsky *Artificial satellites in the rare plasmas*. M. Nauka, 298 c, 1964.

[5] B.M. Smirnov. *Physics of fractal clusters*. M. Nauka, 1991.

[6] Ya. K. Khodataev, R. Bingham, V.P. Tarakanov, V.N. Tsytovich. "Interaction mechanisms of dust particles in plasmas". *Phizika plasmy*, vol. 22, N11, p.1028-1038, 1996

[7] A.M. Ignatov "Simple model of dust-plasma clouds". *Phizika plasmy*. vol.24, N8, p. 731-737, 1998.