THE INTERACTION OF TWO DUST PARTICLES IN PLASMAS

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The process of charging and shielding of two dust particles is studied with a molecular dynamic method and Monte Carlo method for describing of elementary processes, such as elastic, excitation, ionization, charge exchange processes.The three-dimensional P3M molecular dynamics method [1] is applied as the most complete description of plasma particles motion and interaction with macroscopic dust grain. The interaction between plasma particles and neutral gas was simulated using MCC method. The two spherical conductive dust particles were located in nondisturbed low pressure low temperature plasma at different values of the neutral gas density. The spatial distribution of plasma particles around dust grains obtained at different interparticle distances. The formation of the common ion cloud and the effect of ion shadowing were observed at the decreasing of the interparticle distance. The dependence of the electrostatic and ion drag forces on the interparticle distance was investigated.

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1. INTRODUCTION

The problem of the charging of dust particles in plasmas is one of the main tasks to be studied. In plasma dust particles acquire a charge, interact with each other. Since the electrostatic energy of interacting particles strongly exceeds their thermal energy, the particle can form an ordered lattice. The charge of the dust grains is of great interest to understand the behaviour of particulates in processing plasmas used for thin-film production, in processes of growing particles in the gas phase by nucleation and aggregation [2] as well as for the study of space plasmas [3]. The traditional method used to determine the interaction of dust particles with plasmas is by means of the Orbital Motion Limited (OML) theory. In some articles it was shown that this theory is not accurate in case of high gas pressure, at a strong interaction between particles and when a relative drift is added [2,3]. Various numerical methods can be employed to solve this problem. Among them, direct integration of the equation of motion of plasma particles represents a numerical experiment with significance approaching experiments in laboratory.

2. MODEL

The three-dimensional P3M molecular dynamics method is applied as the most complete description of plasma particles motion and interaction with macroscopic dust grain. The interaction with neutral gas was simulated using MCC method. The pressure of the neutral gas varies from 0 to 1.5 Torr. To reduce computational time the mass of the neutral gas atoms and ions was equal to hydrogen, but the elementary cross-sections was equal to argon. Two spherical conductive particles with radius $r_d = 1.2\,\mu m$ was located in nondisturbed plasma with initial ion and electron concentration $n = 1.8\cdot 10^{18} m^{-3}$, electron and ion temperatures $T_i = 0.025\,eV$ and $T_e = 1\,eV$ correspondingly. The length of the computational area cube is $L = 30\,\mu m$, that is much greater than electron Debye length $L_{De} = 5.5\,\mu m$. The simulation time is $t = 1.5\cdot 10^{-8}\,s$ that exceeds the ion plasma period $\tau_i = 3.6\cdot 10^{-9}\,s$.

3. RESULTS

Fig. 1 demonstrates spatial distributions of ion densities for two different distances between the grains at low pressure. We can see that at larger distances $R > 10\lambda_{Di}$ dust particles are isolated, i.e. areas of disturbed ion density near dust particles don't intersect. Ion density spatial distributions become nonisotropic at smaller distance (e.g. at $R < 10\lambda_{Di}$). The region of the higher ion density is formed between dust particles. The shielding distance of the dust is much greater than the ion Debye length and is comparable with electron Debye length, that corresponds to the results of numerous previous researches [4]. The concatenation of the ion clouds starts at the distances around $R = 10\lambda_{Di}$ that responds to the shielding length. The total charge that accumulates between grains can amount up to 10 percents of the dust charge that significantly modify the interaction between dust particles.

Fig. 2 demonstrates spatial distributions of ion densities for different values of the neutral gas pressure. The distributions show that taking into account the collisions not significantly affects on the shielding length, but greatly modify the form of the common ion cloud and the distance, when concatenation of the clouds begins. The velocity distribution of the ions between the dust grains greatly differs from the maxwellian. The increasing of the ion concentration between the dust particles bounds not only to the higher ionization rate but charge exchanging processes between ions and neutral atoms that result in trapping of the slow ions in the intergrain space. This leads to the stronger binding of the dust grains.

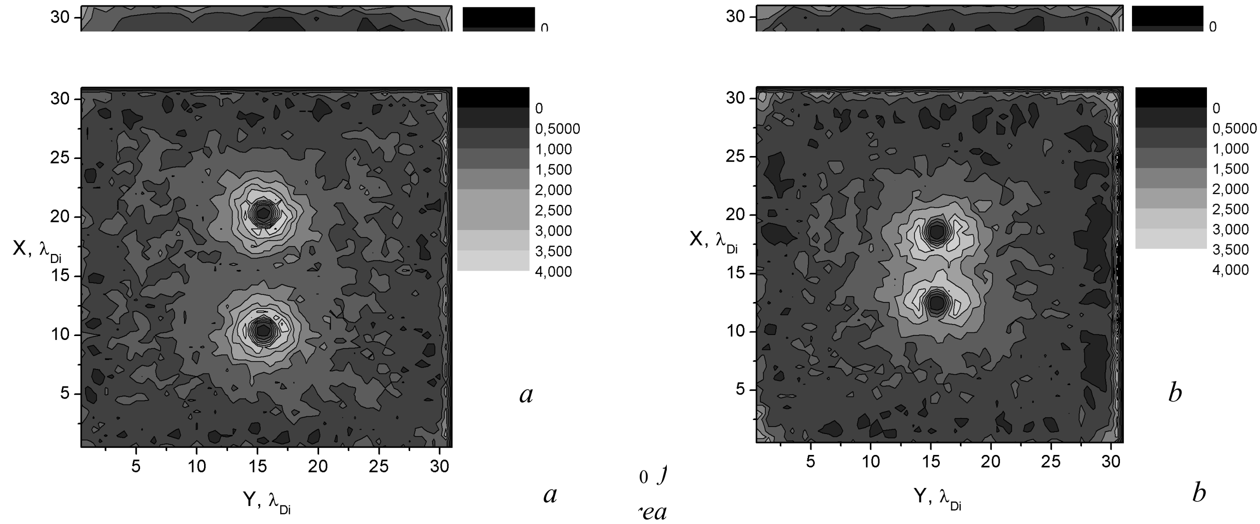

Fig.1 Spatial distribution of the ion density normalized to n_0 *for two intergrain distances: (a)* $L_1 = 10\lambda_{Di}$ *and (b)* $L_2 = 6\lambda_{Di}$*. Lighter areas corresponds to the higher densities*

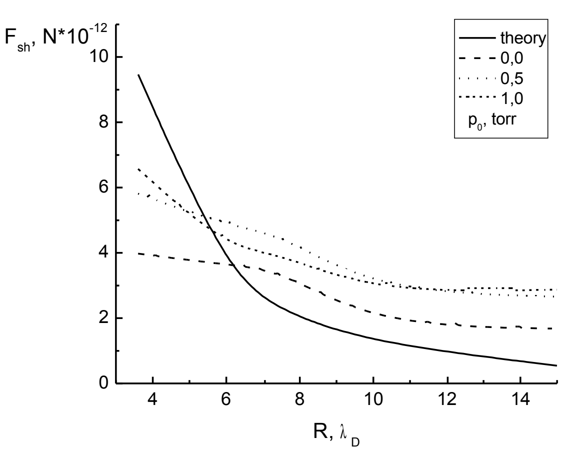

Fig. 3. The dependence of the ion shadowing force F_{sh} *on intergrain distance* R *for different values of the neutral gas pressure* $p_0 = 0.0 - 1.0$ *Torr. Solid curve responds to the theoretical dependence in collisionless case [5]*

Fig. 3 shows the dependence of the ion shadowing force F_{sh} on intergrain distance *R* for different values of neutral gas pressure. The effect of the ion shadow for collisionless case with maxwellian distributions of the plasma particles was previously investigated in [5]. It was shown that shadowing force can be described with Eq. (1)

$$F_{sh} = -\frac{3}{8}\frac{a^2}{\lambda_{Di}}\frac{Z^2e^2}{R^2}, \qquad (1)$$

where *a* is dust particle radius and Z is dimensionless dust charge. Black curve on Fig. 3 corresponds to this analytical dependence. Computated dependences show that even in collisionless case Eq. (1) cannot describe the force when intergrain distance is relatively small (more precisely when the concatenation of the ion clouds begins). From the other side, Eq. (1) coinsides with computated dependence on distances more than ten ion debye length accurate within the constant.

With higher values of the neutral gas pressure ion shadowing force increases that correspond to stronger binding between particles mentioned above. Increasing of the force on far distances conditioned to the greater ion flows due to the more intensive ionization rates. In case of higher pressure more ions accumulates between dust grains due to the ion-neutral charge exchange collisions that leads to the ion shadowing force growth at close interparticle distances.

4. CONCLUSIONS

The self-consistent hybrid molecular dynamics with MCC method simulation had been carried out to investigate nonlinear charging and shielding of two dust particles in plasmas. We have demonstrated that the concatenation of the ion shielding clouds between dust grains significantly grows with neutral gas pressure growing. The depending of the ion shadowing force on neutral gas pressure was investigated. It was shown that higher ion concentration due to ionization and charge exchange processes results in growing of the shadowing force in several times of magnitude. Also, it was demonstrated that the dependence of the shadowing force at close intergrain distances greatly differs from analytical one.

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ВЗАИМОДЕЙСТВИЕ ДВУХ ПЫЛЕВЫХ ЧАСТИЦ В ПЛАЗМЕ

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Представлены результаты компьютерного моделирования зарядки и экранирования двух пылевых частиц в плазме при помощи метода молекулярной динамики. Для учета элементарных процессов в плазме, таких как упругие столкновения частиц, возбуждение и ионизация нейтральных атомов, процессы перезарядки, был использован метод Монте-Карло. Для наиболее точного расчета динамики частиц плазмы и их взаимодействия с макроскопическими пылевыми частицами был выбран трехмерный метод P3M. При моделировании рассматривалось взаимодействие двух сферических проводящих частиц, помещенных в изначально невозмущенную низкотемпературную плазму низкого давления при разных давлениях нейтрального газа. Были получены равновесные пространственные распределения ионов и электронов вокруг пылевых частиц для разных расстояний между частицами. При уменьшении расстояния наблюдалось формирование общего для частиц ионного облака. Рассмотрена зависимость силы притяжения между частицами, обусловленная эффектом теневого экранирования.

ВЗАЄМОДІЯ ДВОХ ПИЛОВИХ ЧАСТИНОК В ПЛАЗМІ

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Представлено результати комп’ютерного моделювання заряджання та екранування пилових частинок в плазмі за допомогою методу молекулярної динаміки. Для врахування елементарних процесів в плазмі, таких як пружні зіткнення частинок, збудження та іонізація нейтральних атомів, процеси перезарядки, був використаний метод Монте-Карло. Для найбільш точного розрахунку динаміки плазмових частинок та їх взаємодії з макроскопічними пилинками був обраний тривимірний метод P3M. При моделюванні розглядалася взаємодія двох сферичних пилових частинок, що занурені у початково незбурену низькотемпературну плазму низького тиску при різних значеннях тиску нейтрального газу. Були отримані рівноважні просторові розподіли іонів та електронів навколо пилових частинок для різних відстаней між пилинками. При зменшенні відстані спостерігалося формування загальної для пилових частинок іонної хмари. Розглянуто залежність сили притягання між пилинками, що обумовлена ефектом тіньового екранування.