CHARGING OF SMALL SOLID BODIES: LABORATORY SIMULATION

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Abstract

The present paper deals with the charging of glass particles of micron sizes by the monoenergetic electron beam with the energy in the range from 300 eV to 5 keV with motivation to investigate the properties of these particles which are significant in dusty plasmas. Our study is devoted to the measurement of the equilibrium surface potential of the spherical glass particles, and to the estimation of the influence of various currents on the charging/discharging process. Our experiments have shown that the electrons emitted from the surfaces inside the vacuum chamber can significantly influence the measured quantities. The sampling of the electron beam, which has been introduced, decreases this influence to that degree that the method used for the measurements allows us to determine the energy spectrum of secondary electrons which play a major role in the surface potential setting.

1. Introduction

Particulate matter (dust) is apparently the most common component of the space environment. A number of phenomena connected with dust particles within the solar system can be explained by their electric charging. The most important charging processes in the solar system are: photoemission caused by the solar UV radiation, attachment of the charged particles from the surrounding plasma, and secondary electron emission induced by high energy electrons or ions. While the plasma parameters in the solar system are relatively well known, the important properties (coefficient of photoemission, yield of the secondary emission, etc.) of dust particles are taken from measurements on large samples with planar surfaces and thus it is not clear if they can be used for micron sized particles [1].

Our study is devoted to the measurement of the equilibrium surface potentials as well as the dynamic investigation of charging/discharging processes of the spherical dust glass particles of diameters from 3-8 μm bombarded by the electron beam of various energies. Glass is chosen because of considerable similarity with the material of cosmic dust particles.

2. Experimental set-up

The main idea of the experimental arrangement is to investigate a single dust particle suspended in an electrodynamic trap (the quadrupole is used). The charging/discharging is carried out by an electron or ion gun. The quadrupole together with the dust reservoir are placed in an ultra-high vacuum chamber [2] (pressure less than 10^{-8} mbar). A trapped particle is irradiated by the He-Ne laser. The light scattered by the particle is magnified by a simple optical system and the co-ordinates of the amplified light spot are determined. The co-ordinate signals are used to control the motion of the particle by a damping system. The current Q/m ratio is calculated from the particle oscillation frequency f_z, the quadrupole supply voltage V_{ac}, and its frequency f_{ac} according to the following expression [3]:

$$\frac{Q}{m} \approx \pi^2 r_0 \frac{f_{ac} f_z}{V_{ac}},$$

where r_0 stands for the inner radius of the middle quadrupole electrode.

It should be noted that under our experimental conditions we can investigate only positively charged glass particles because in our beam energy (0.3-5 keV) the yield of the secondary emission is significantly higher than unity.

The ion bombardment is used for determination of particle's size by the observation of the discharge of a strongly positively charged particle by a low energetic ion beam. The ions cannot reach the particle surface due to the electrostatic repulsion. However, secondary electrons are produced on the quadrupole electrodes and cause the discharging of the particle. The particle's surface potential decreases and when it reaches a value at which the beam ions just come to the surface of the particle. The corresponding surface potential φ can be calculated with the knowledge of the ion energy $E_i = \varphi/e_0$ and hence the particle radius could be obtained according to the relation:

$$r = \sqrt{\frac{3\varepsilon_0\varphi}{\rho} \cdot \frac{m}{Q}} \,,$$

where e_0 means the elementary charge, ρ particle mass density, and ε_0 is the dielectric constant of vacuum.

In previous studies [4,5], the beam was emitted continuously and thus the AC electric field inside the quadrupole cause the defocusing and deflection of the electrons toward the quadrupole electrodes (the used quadrupole voltage is usually from 400 to 900 V in frequency range 0.3-3 kHz). It resulted in presence of the significant density of the secondary electrons with a broad energy spectrum. Moreover, the relative density and the energy spectrum of these electrons (background electrons) were an unknown function of the beam setting and energy. For this reason, the electron beam as well as the quadrupole power supply have been provided with a sampling electronics. Fig. 1 shows that the electron beam is switched on only inside the time window when the quadrupole voltage is pulled down to zero. According to our tests, switching off the (primarily sinusoidal) quadruple voltage up to 1/10 of a period does not change the frequency of particle oscillations and thus the calculated Q/m of the particle remains unchanged.
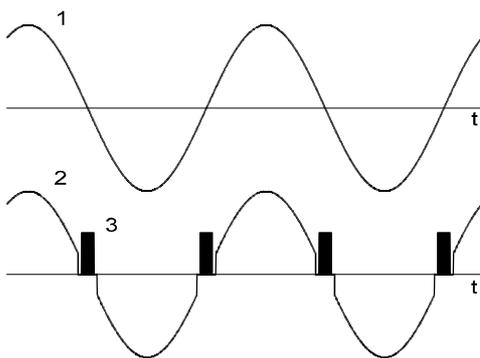
Fig. 1. The time diagram of beam sampling: 1- primary quadrupole voltage, 2 - sampled quadrupole voltage, 3 - electron beam current.
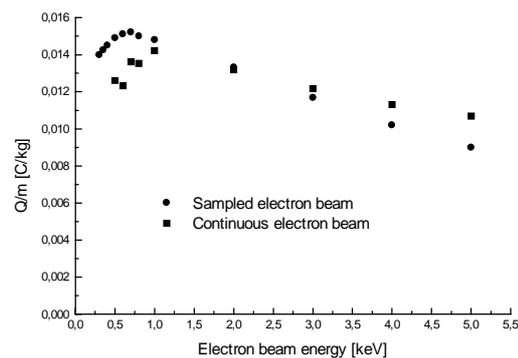
Fig. 2. An influence of beam sampling on measured Q/m ratio.

3. Results and discussion

Fig. 2 shows the equilibrium Q/m ratio as a function of beam energy for sampled and not sampled electron beam. The corresponding surface potentials are approximately 6-9 V [4].

Because the secondary emission is the only principal charging mechanism the correspondence between the yield of secondary emission and the Q/m ratio could be expected. Nevertheless, the difference between two curves in Fig. 2 suggests the influence of the secondary electrons emitted from the quadrupole electrodes. The curve measured with the sampled beam peaks at the energy ~700 eV which is in a good agreement with the expected value [6]. The decreasing of the Q/m ratio with the increasing energy is much steeper in the case of sampled electron beam. We explain this difference as a consequence of the additional secondary emission from the particle caused by the high energy (a few hundreds of eV) electrons which are not present when the beam is sampled. It is important to note that these electrons are emitted in the whole range of beam energies.

A dynamical investigation of the charging process allows us to determine all of charging/discharging currents from the volt-ampere (V-A) characteristics. In this method, the particle is firstly charged to a high surface potential by the ion gun and then discharged by electrons from the electron gun with the constant energy and current. The first derivative of the Q/m temporal changes yields the I/m ratio. The plot of this ratio as a function of Q/m ratio is called the V-A characteristics because Q/m ratio is proportional to the surface potential. To describe the obtained V-A characteristic it is necessary to consider the current of background electrons in addition to the principal current of the primary electron beam and secondary emission from the particle. If we assume the monoenergetic electron beam, the total current can be written:

$$I_{tot} = I_{beam} + I_{back} + I_{sec} = I_{beam}^0 \cdot \left(1 + \frac{e_0\varphi}{E_{beam}}\right) \cdot \alpha + I_{back}^0 \cdot \left(1 + \frac{e_0\varphi}{E_{back}}\right) \cdot \alpha - I_{beam} \cdot Y\left(E_{beam}, \varphi\right),$$

where α is a sticking coefficient (considered to be equal to one), E_{beam}, E_{back} are the energies of beam electrons and characteristic energy of background electrons, respectively, I_{beam}^0, I_{back}^0 are the beam and background currents for $\varphi = 0$, and $Y\left(E_{beam}, \varphi\right)$ is the yield of secondary emission.

The method described in [2] allows us to obtain the integral energy spectrum of secondary electrons from the particle. Figure 3 shows such spectra for a 1 keV discharging electrom beam in case of sampled and not sampled regime. The energy spectrum obtained for the not sampled beam exhibits a nonrealistic high-energy tail which extends up to 70 eV. The spectrum measured in sampled regime can be fitted by the integral Maxwellian distribution:

$$Y^M\left(\varphi\right) = Y_0 \cdot \left(1 + \frac{2}{\sqrt{\pi}} \cdot \sqrt{\frac{e_0\varphi}{2E_{SE}}} \cdot \exp\left(-\frac{e_0\varphi}{2E_{SE}}\right) - erf\left(\sqrt{\frac{e_0\varphi}{2E_{SE}}}\right)\right),$$

where Y_0 represents the maximum yield, and E_{SE} is the energy at which the energetic distribution of secondary electrons peaks. The obtained numerical values from the fit ($Y_0 = 2.5$ and $E_{SE} = 3.3$ eV) are in a good agreement with measured planar surfaces.
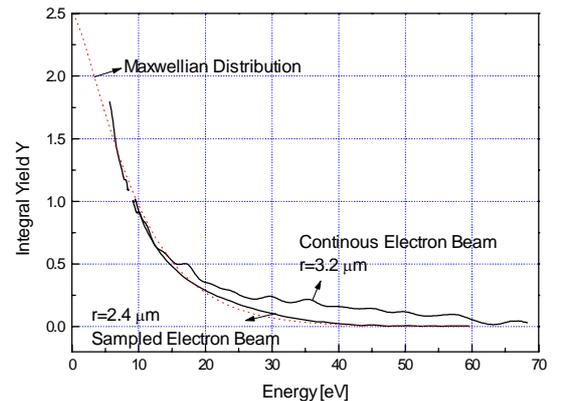
Fig. 3. The integral energy spectrum of secondary electrons emitted from the dust particles with sampled and not sampled electron beam (1 keV).

In Figure 4 the energetic spectra are shown for two different electron beam energies. The spectra were fitted and the corresponding values have been obtained: $Y_0 = 2.5, E_{SE} = 3.3$ eV for 1 keV and $Y_0 = 1.5, E_{SE} = 3.3$ eV for 3 keV primary beam.

Fig. 4. The energy spectrum of secondary electrons for two different particles measured with sampled electron beam at energies 1 keV and 3 keV.

4. Conclusion

The electrodynamic quadrupole is a widely applied instrument for the investigation of small particles. Our measurements have shown that a presence of the background particles should be taken into account in the whole range of beam energies. This background contains a portion of the high-energy electrons which can cause the secondary emission from the investigated particle. We have proposed a method which is based on the sampling of the electron beam in phase with the quadrupole voltage and swithing off this voltage during the beam emission. This method reduces significantly the high-energy portion of the background electrons and thus greatly contribute to an accuracy of the measurements.

The preliminary results show that

- the energy spectrum of the secondary electrons emitted from the small particle can be fitted by the Maxwellian distribution
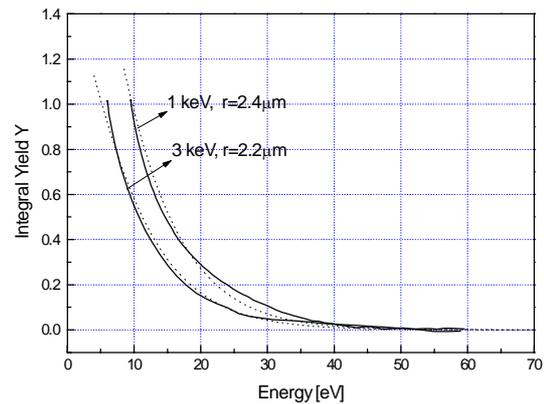- the parameters of the fit are similar to that obtained on planar surfaces.

We can conclude that for the particles of micron sizes the effect of the surface curvature is small and that this effect can be determined only by the systamatic measurements of properties of particles from an identical material but with different diameters. Such an experiment is under preparation.

Acknowledgements

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