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REPRINT

Contrib. Plasma Phys. **55**, No. 5, 407 – 412 (2015) / **DOI** 10.1002/ctpp.201400091

A Method of Separation of Polydisperse Particles in the Plasma of Radio-Frequency Discharge

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Received 30 October 2014, revised 24 January 2015, accepted 27 January 2015
Published online 17 February 2015

Key words Dusty plasma, separation, radio-frequency discharge, monodisperse particles, plasma crystal

A method of separation of polydisperse dust particles in the plasma of radio-frequency (RF) capacitive discharge is considered. Investigations of plasma equipotential field enabled us to determine conditions for separation of polydisperse dust particles. The simplicity of the technology made it possible to obtain small dispersed particles of different materials. Samples of small dispersed microparticles of silica and alumina were obtained. The size and chemical composition of samples were examined using a Quanta 3D 200i scanning electron microscope (SEM, FEI, USA). The average size of separated silica nanoparticles was 600 nm, that of silica and alumina microparticles was 5 µm. Two separation methods were developed: the first one used a special trap and shape of the bottom electrode of RF discharge (for separation of microparticles) and the second used an electrical trap (for separation of nanoparticles). The graphs of particle size distribution were constructed using graphical and mathematical calculations.

1 Introduction

It is well known that dusty plasma is an ordinary plasma with embedded small (nano- to micrometer sized) particles of solid matter. In strongly coupled plasma such particles form liquid or lattice structures that are called Coulomb crystals or "plasma crystals". Investigations of plasma crystals are still ongoing in many research groups. There are a lot of works devoted to studying properties of dusty plasmas using experimental, theoretical and simulation methods [1-6]. Dust is usually formed in the plasma as a result of two processes - outer injection and chemical reactions in the gas discharge. The second method is used to produce nanomaterials and to study their growth processes [7-11]. In some cases dust particles can play a negative role in nanotechnology and cause defects in microelectronic processing. However, scientists learned to control dust formation in semiconductor manufacturing [7-9] and reduce the number of defects. This is one of the most valuable achievements in studying plasma crystals. In addition, there is work studying dusty plasmas that gives further insights in plasma physics of thermonuclear fusion [12-13] (MAST, JET and ITER), understanding of inorganic living matter [14].

The method of dust formation by outer injection of dust particles into the plasma of gas discharge arouses interest because of the simplicity of formation and the resulting of dusty plasma, control of the size of dust particles (using monodisperse particles) for studying structural transition of plasma crystals [15-16]. However, in nature, the distribution of particle sizes is more randomized and can be polydisperse or monodisperse. A distinctive feature of these distributions is usually their dispersion, which obeys the normal law of the Gaussian distribution. At present there are many methods used to obtain monodisperse, nano-, submicro- and micropowders [17-19]. One of them is the method of separation of polydisperse particles. Depending on the medium of separation, there are wet and dry separation (separation with electric and magnetic fields [20]) and other methods. The main disadvantages of the existing methods of separation are large dispersion of separated particles and limited choice of materials. The present work considers a method of separation of polydisperse dust particles in the plasma of a radio-frequency discharge, where plasma parameters and a special type of electrodes are used as an instrument for separation. This method enables us to obtain mono- and small-dispersed dust particles from polydisperse dust particles without limitations on the choice of materials for separation.

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2 Experiment

Our investigations of the separation of polydisperse dust particles was conducted in an argon gas plasma formed via a radio-frequency capacitive discharge. The object of investigation in this paper is dust structures and extraction of dust particles by mass. The condition of formation of dusty plasma is described in detail in [21].

Studying dust formation in the plasma of radio-frequency capacitive discharge at different plasma parameters enabled us to develop a new method of separation of polydisperse dust particles. It was found that at different values of gas pressure and constant value of discharge power, the location of dust structures and their form was different. The pictures of dust structure for different plasma parameters are shown in Figure 1. Depending on the location of the dust structure inside the ring trap, two methods of separation of micro- and nanoparticles can be used.

The separation of polydisperse dust particles in the plasma of RF discharge is based on capture and control of the dust structure by modification of the equipotential surfaces in the RF plasma.

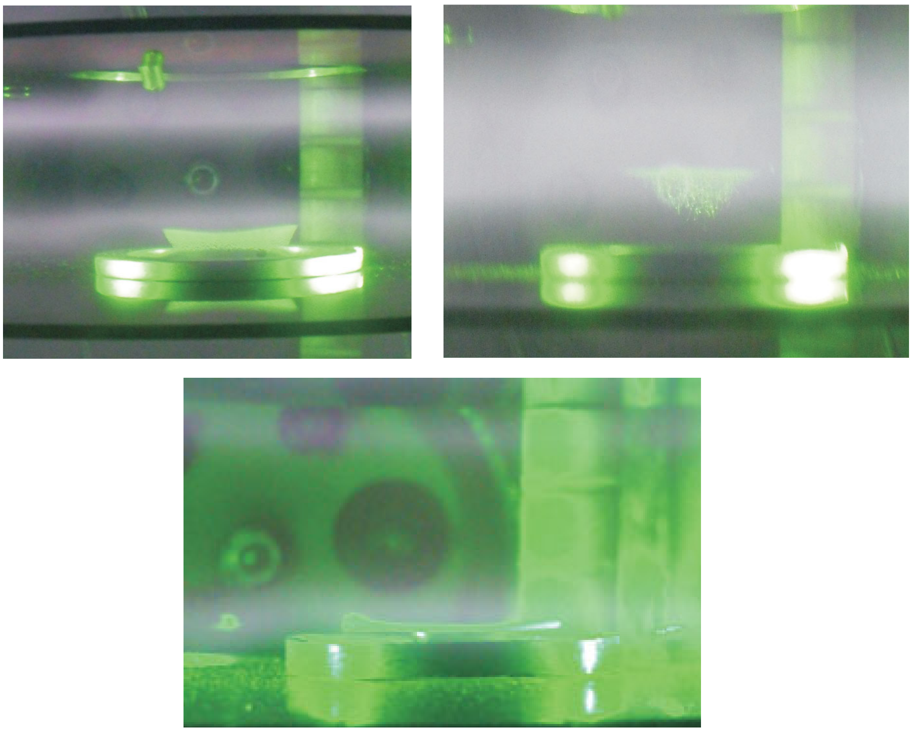

Fig. 1 Different locations of dust structures for different plasma parameters, discharge parameters (RF power and gas pressure) for each picture a) 4 W and 0,1 Torr, b) 15 W and 0,009 Torr, c) 5 W and 0,3 Torr.

The experimental setup for separation of polydisperse dust particles (silica and alumina powders of initial sizes of several hundred nanometers to 100 μm) consists of the working chamber (1), a pair of disk electrodes (2), side windows (3) for visualization of the separation process, a radio-frequency (RF) generator (4), a vibrating membrane (5) and a sonic generator, a ring (6) for dust trapping and a container (7) for collecting separated dust particles, the so-called "electrical trap" (8). The scheme of the setup is shown in Figure 2.

After RF plasma ignition, polydisperse alumina/silica particles were injected through the vibrating membrane to form a dust structure. An open ring was used for extraction of levitated microparticles from the dust structure to the container fixed under the lower electrode (Figure 2). Dust particles were re-injected through the vibrating membrane in order to replenish the concentration of dust particles inside the ring and to regulate the number of injected particles.

The so-called "electrical trap" consists of two coaxial cylindrical electrodes powered by DC power supply (voltage range is 0-600 V) to deflect the electric equipotential surfaces in the RF plasma. Using a closed ring and an "electrical trap" it is possible to attract the dust cloud into the collector container without attraction of microparticles. Why does in this case the separation occur? As it is known, the dust structure consist of a micro- and nanosized dust particles, but using of trap (closed ring) enable us to capture only a few submicro- and all microsized dust particles. Thus the nanosized and most of submicrosized dust particles could not be captured because of surface tension forces are beginning to play a more significant role than the force of gravity. Attraction of those particles into the collector container could be done with ”electrical trap” by modification of the equipotential surfaces in the RF plasma.

In the separation process the following values of plasma parameters were used: gas pressure 10^{-2} - 1 Torr, discharge power 0.5 - 30 W.

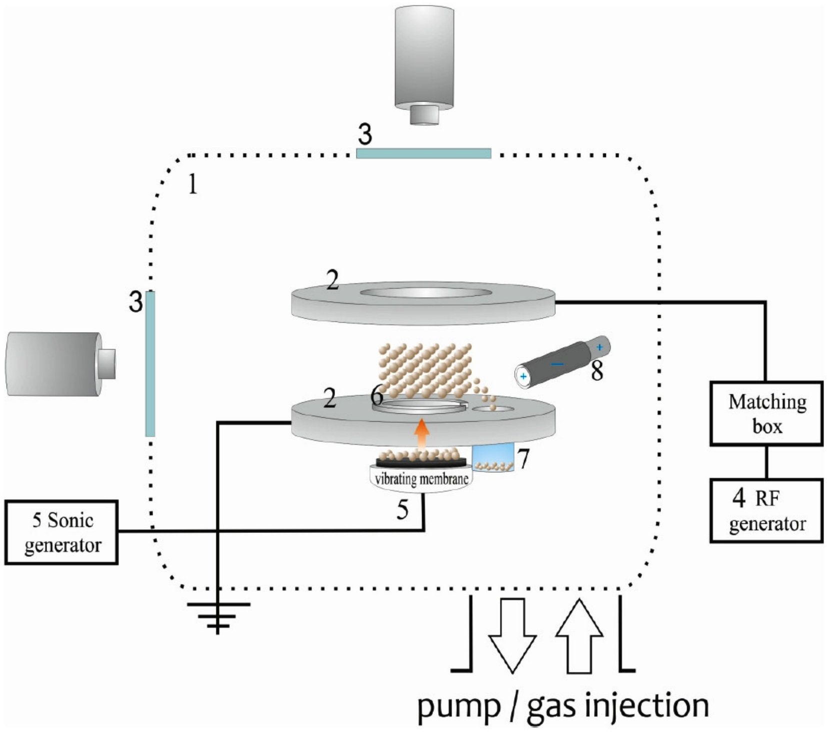

Fig. 2 Experimental setup. The description of the numbered components is contained in the main text.

3 Results

Separated silica and alumina mircoparticles were obtained using the above described separation method with the following plasma parameters: pressure for silica and alumina of 0.3 and 0.15 Torr, respectively, and discharge power of 1.5 W.

The particles obtained after separation were examined by a Quanta 3D 200i scanning electron microscope (FEI company, USA). SEM images of separated microparticles and their corresponding histograms are shown in Figures 3 and 4. After estimation of SEM images the average size of separated silica and alumina microparticles was 5 μm, whereas before the separation the sizes of particles in silica/alumina powders ranged from 1 μm to 100 μm.

The proposed method includes a stepwise separation of polydisperse particles by mass. The deviation of separated silica microparticles from the average size of 5 μm is smaller than the deviation of separated alumina microparticles, which can be explained as follows - silica microparticles have spherical shapes, whereas alumina microparticles are irregularly shaped, hence silica microparticles of the same diameter have the same mass (because of the density is fixed) and alumina microparticles of the same mass have different shapes - average diameters.

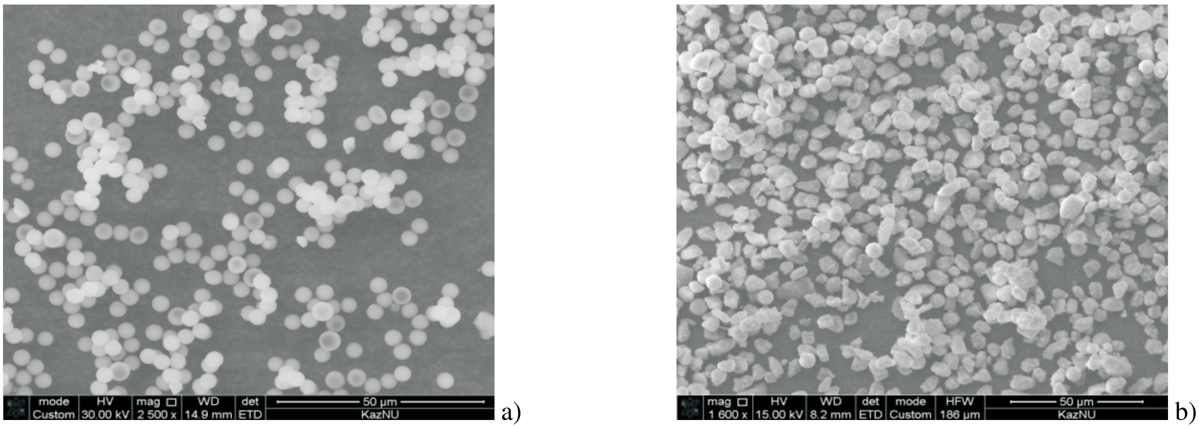

Fig. 3 SEM images of separated microparticles of SiO_2 a) and Al_2O_3 b).

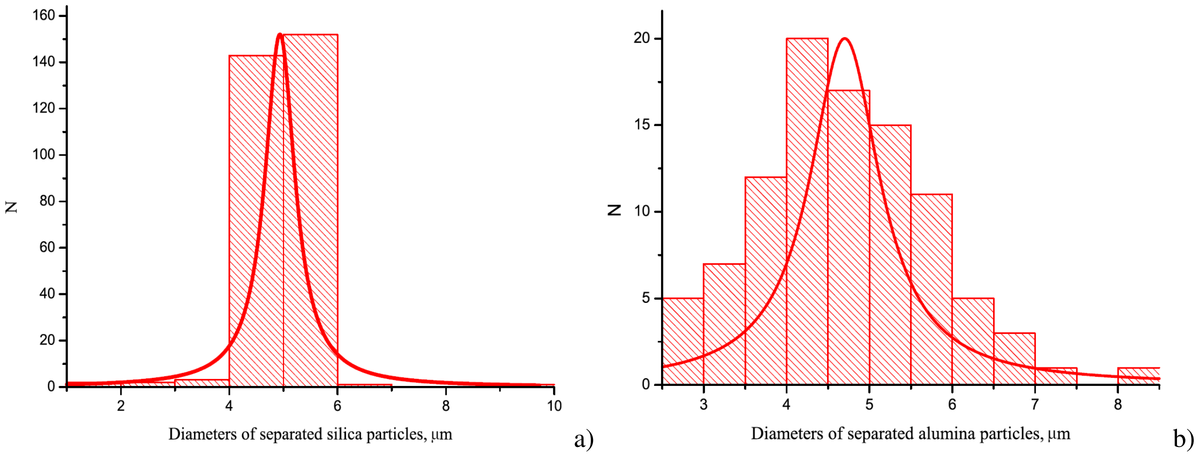

Fig. 4 Histograms of separated silica a) and alumina b) microparticles.

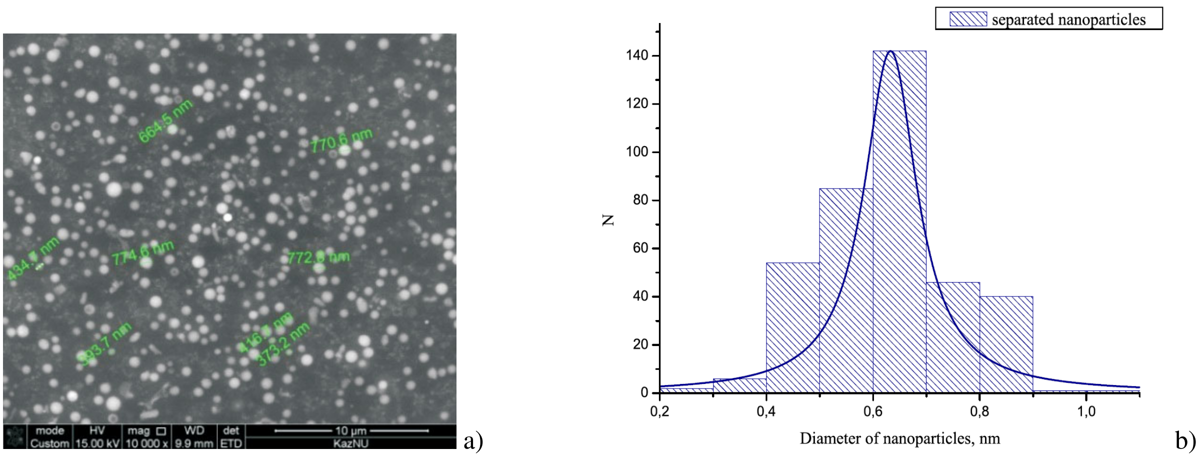

Fig. 5 SEM image of separated nanoparticles of SiO_2 and their histogram.

The samples of silica nanoparticles were obtained at RF discharge power of 0.5 W, argon gas pressure of $6 \cdot 10^{-2}$ Torr and DC voltage at "electrical trap" of 350 V (Figure 5).

Figure 5 shows that the average size of silica nanoparticles obtained after separation is 600 nm with wide deviations, which is explained by the difficulties of controlling and capturing of nanoparticles (dust cloud) from plasma dust structure of polydisperse particles.

Figure 6 shows the chemical composition of samples of SiO_2 nanoparticles obtained after separation. Undoubtedly, the obtained spectra of separated nanoparticles correspond to the chemical composition of injected silica particles and not of products of electrode corrosion. Thus, the impurities of the final products of separation are excluded.

Figure 7 shows the final graph of particle size distribution before and after separation. A wide peak corresponds to particle sizes before separation and a narrow peak corresponds to particle sizes after separation, therefore according to the criteria of monodispersity, silica and alumina particles obtained after separation can be classified as monodispersed particles.

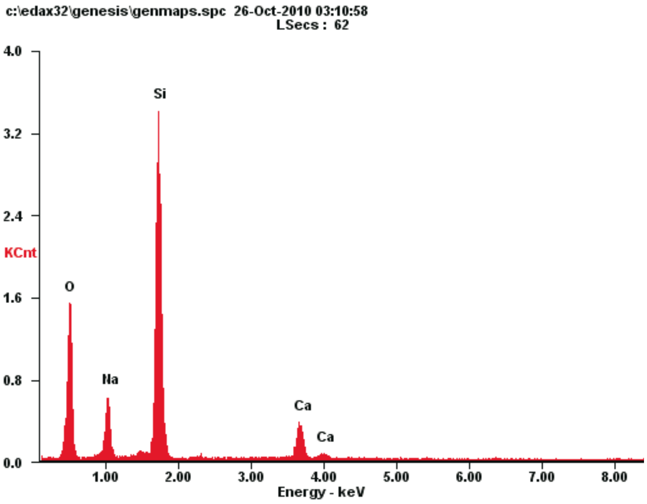

Fig. 6 The spectra of chemical composition of silica nanoparticles.

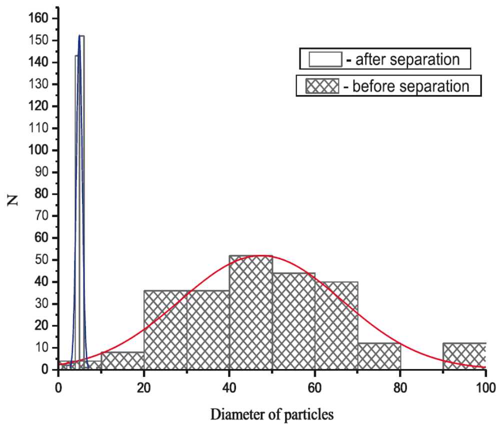

Fig. 7 Final particles size distribution before and after separations.

4 Conclusion

Using the proposed method of separation, monodisperse microparticles of silica and alumina of an average size of 5 µm and silica nanoparticles of an average size of 600 nm were obtained. The morphology, chemical composition and sizes of separated particles were examined by the scanning electron microscope (SEM, FEI, USA). The advantages of the proposed method are the simplicity of technology and small dispersion of obtained particles after separation as compared with existing analogues. The range of separation is 600 nm - 50 µm. The impurities of the final products of separation are excluded.

Acknowledgements This work has been supported by the grant 1081/GF of the Ministry of Education and Science of RK.

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