

Experimental Investigation of Non-Isolated Dust Particles on the Plasma Characteristics in Direct Current System

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Abstract

This paper reviews the radial profile of plasma parameters in the present and absent of non-isolated dust particles at different positions from the cathode surface. The results of voltage and current discharge shown that the present of dust did not effect of the behavior of discharge voltage but it decreased the discharge current. However, the measurement of radial distribution of plasma parameters along the cathode at different distance (2 cm and 4 cm) from it shown that, all plasma parameters are non-homogenous distribution along the cathode in the cathode sheath and plasma bulk. Moreover, according to radial profile of plasma potential, the charge of copper dust particles is negative in the plasma sheath but it is charged postively in the plasma bulk.

Keywords: complex plasma, glow discharge, Langmuir probe, copper dust, plasma sheath.

Introduction

A dusty (complex) plasma is a multicomponent system consisting of electrons, ions, charged mesoscopic particles (dust grains), and neutral atoms or molecules. Interest in this 'unusual' state of matter stems from the ubiquity with which it is found in the laboratory, in space, and in astrophysics, such as: cometary tails, planetary rings, solar and planetary nebulae, the lower ionosphere (mesosphere), atmospheric lighting, and industrial plasma processing and nanomaterials fabrication devices [1-5]. The presence of dust particles causes a rich variety of phenomena in laboratory plasmas and plays an important role in plasma processing of semiconductors, planetary and space physics. The charge accumulated by the micron or submicron sized dust particles in plasma environment is one of the most important parameters of complex plasma [1]. Generally in laboratory plasma, the dust particles become negatively charged as a result of the higher flux of electrons to an uncharged surface as compared with ions. Due to the presence of energetic (primary) electrons, secondary electron emission may take place from the dust grain depending upon the secondary emission coefficients, which in turn reduces the dust charge [6].

The dust particles can have different shapes and sizes, and they can be either perfectly insulating or perfectly conducting. It

is found that in drifting plasmas, dust particles acquire an electric dipole moment. For insulating dust particles this moment is parallel to the ion drift, while for the conducting dust it is anti-parallel. For the conducting dust, the electric dipole moment is induced by the anisotropy in the potential distribution surrounding the particle and is smaller than the one for the insulating dust. In both cases, the electric dipole moment leads to a difference in the total charge on a dust particle in drifting plasmas as compared to general calculations by orbit theory for a model particle.

Experimental set up

In this work, the simplest and least expensive method of producing a dusty plasma is to use a dc. glow discharge. The chamber (which made of stainless steel) of this system is consists of two electrodes which were made from the Aluminum. A schematic of the chamber of such a device is shown in Fig.(1). The diameter of the both electrodes is 8cm and of 2cm thickness. The chamber which was pumped by two stage rotary pump to a base pressure of about 2×10^{-2} Torr. Copper (Cu) dust with particle size is equal to $3.75 \mu\text{m}$ is immersed in a plasma. The dust particle is dispersed (dropped) into a plasma column by mechanical device (see Fig.(1)). This device (i.e. duster) consisted from d.c. motor which is work by applied 3 d.c volt and a disc which used as a container of dust particle. The motor

was work by remote control system, this motor will give two motions to the disc rotation and vibration motions. The weight of copper dust particle which immereses into the plasma is equal 0.2 gm.



Fig.(1) Photograph of the chamber of the system.

The glow discharge is formed between an anode and a cathode when a d.c. constant voltage of about 2 kV is applied between two electrodes. As a results to this applied voltage, the electrical breakdown is formed in argon gas at relative pressures, of about $\approx 0.1-1$ Torr.

The radial profiles of plasma parameters were measured by cylindrical langmuir probes can get by putting three cylindrical langmuir probes at different radial positions along the cathode surface at working presure 0.8 Torr. The Langmuir probes, with a 3mm long, 0.3mm diameter tungsten probe tip, made mainly of a glass tube 5mm in diameter.

Figs. (2) and (3) show the photographs of plasma column discharge in the absence and present copper dust particles at different pressures.

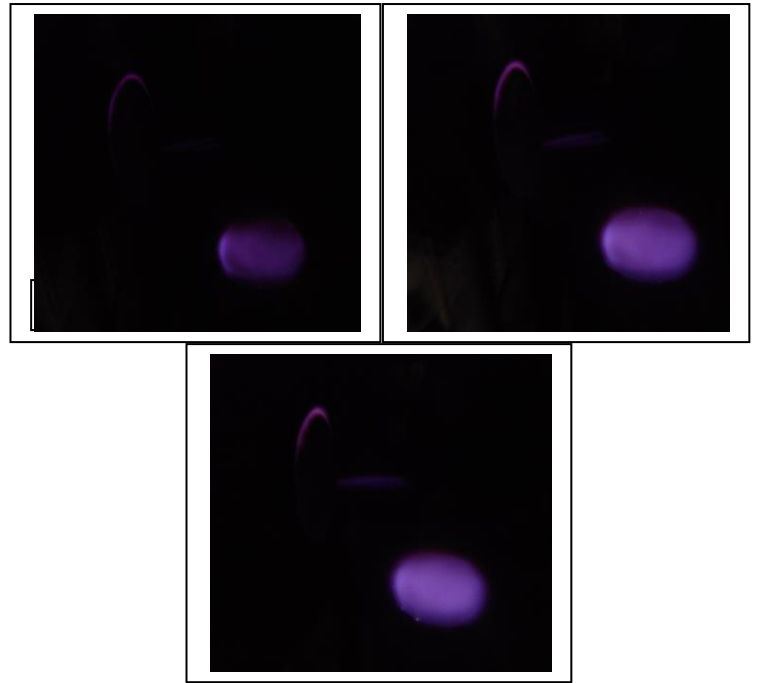


Fig.(2) Photographs of plasma discharge Without dust at different pressures.

Evaluation of plasma parameters

Ion Density

The ion current passing through an area A in the plasma were determined from the ion currents in the ion saturation region using the orbital motion limit (OML) probe theory. The advantage of using OML theory is that the ion density can be determined without the knowledge of the electron temperature. Here it is assumed that the plasma is isotropic, the electron temperature is much higher than the ion temperature ($T_e \gg T_i$) and the probe sheath is thick and non collisional. Assuming a maxwellian energy distribution in the unperturbed plasma, the following formula for a cylindrical probe is used to determine the ion current in the OML regime [7,8]:

$$I_i = A_p n_i e \left(\frac{-eV}{8M_i} \right)^{1/2} \dots\dots\dots (1)$$

where I_i , A_p , n_i and M_i are ion current, probe area, ion density, and the ion mass, respectively. By calculate the slope of the linear region (ion saturation region) of these I^2 vs V curves, we can obtain an expression for the ion density.

Electron temperature

When the probe potential is made less negative, probe collects both ions and electrons. As the potential (probe bias) is changed further in the positive direction, the ion and electron currents collected just cancel. This current varied exponentially with probe bias voltage. This current eventually saturates at the plasma space potential value (V_p) due to space charge limitation in current collection. In the transition region of the I-V curve, the electron current is given by [7,8]:

$$I_e = \frac{A_p \cdot n_e \cdot e \cdot v_{th}}{4} \cdot \exp \frac{-eV}{kT_e} \dots\dots\dots (2)$$

The electron temperature can therefore be calculated directly from the I-V characteristic of the probe. The slope yields the electron temperature:

$$Slope = \frac{-e}{kT_e}, \dots\dots\dots (3)$$

where T_e in K° .

$$Slope = \frac{1}{T_e (eV)} \dots\dots\dots (4)$$

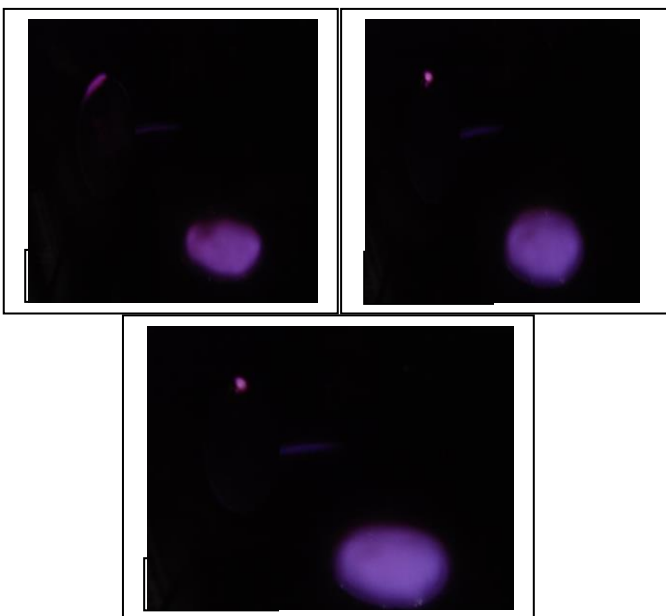


Fig.(3) Photographs plasma discharge in the present of copper dust at different pressures.

Methods of calculating the electron density described as following: for positively biased of probe, the probe collects all the electrons and repels all the ions. The electrons current collected is nearly constant. From this current, which is called the electron-saturation current I_{es} , the electron density can be calculated from the following relationship:

$$I_{es} = \frac{n_e e A_p}{4} \left(\frac{2kT_e}{m_e} \right)^{1/2} \dots\dots\dots (5)$$

where T_e is the electron temperature and the n_e is the electron number density.

Floating and plasma potentials

The floating potential (V_f) is the potential at which an unbiased probe would float in the plasma as a result of the developed sheath around it. V_f is define by $I_i (V_f) + I_e (V_f) = 0$, or $I_i = I_e$ where I_i and I_e are ion and electron current, respectively.

The plasma potential (V_p) corresponds to the bias voltage where the plasma and probe are at the same potential. The plasma potential defines the potential where the electron current changes from the electron repelling current to the electron saturation current. In the “electron saturation region” electrons experience an attracting potential whereas the probe delivers a repelling potential to the electrons in the “electron repelling region”. The potential at point of change is defined as plasma potential and can easily be obtained by looking at the rate of change of the current with respect to the applied voltage. The maximum of the first derivative dv/dI or the zero crossing of the second derivative d^2v/dI^2 of the probe current with respect to the voltage is the way to find the plasma potential. The floating potential can be calculated from the following equation, as the bias voltage at which $I_i + I_e = 0$.

Results and Discussions

Fig.(4) shows effect of dust particles on Paschen curve. The both curves in the figure illustrated that, the present of dust in the plasma media causes to slightly increase of the discharge voltage. The interaction between plasma particles (ions and electrons) with dust

grain causing this increasing in the discharge voltage.

Fig.(5) shows the current discharge as a function of pressure. It is clear from this figure that, with dust present, the discharge current is smaller than the current measured without dust. The attachment of electrons on dust particles of extremely low mobility causes the reduction of the current discharge [9].

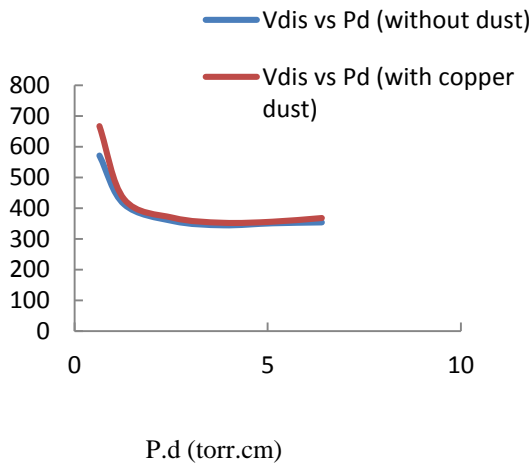


Fig.(4) Paschen curve in the present and absence of dust particles.

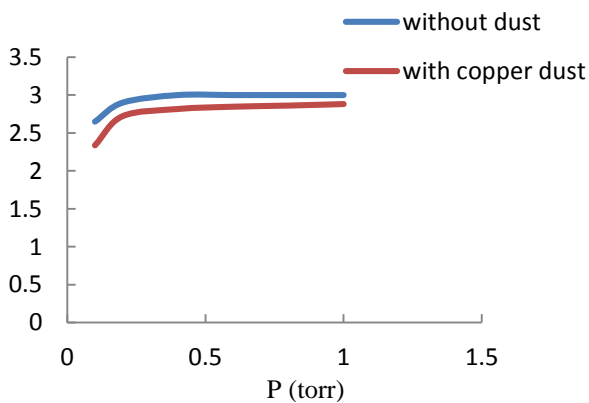


Fig.(5) Influence of copper dust particles on discharge current.

Radial Profile of Plasma Parameters in the Present of Dust Particles

The main diagnostic tool of the plasma characteristics consists of a Langmuir probes positioned at different point along the axis of cathode at a distances are 2 cm and 4 cm. Plasma parameters, namely ion density,

electron density, electron temperature ,plasma potential, floating potential are calculated at distances 2 cm and 4 cm from the cathode surface.

In dusty plasmas, the particles can levitate in the plasma bulk or in the plasma sheath, dependent on the gravitational conditions and on their size. Micrometer-sized particles immersed in typical laboratory plasmas get highly negatively charged. Unless in micro-gravity conditions, they are trapped in the plasma sheath [10]. The dust particles are trapped in the sheath where electric fields are present. The position of the particle is determined by the equilibrium of the upward electric and the downward gravitational forces. In addition, in the plasma sheath a dust particle is subject of other forces too: ion drag force, neutral drag force, thermophoresis, and radiation pressure. This makes their dynamics quite complicated and results in many interesting phenomena.

According to equation (1), the radial profile of the ion density along the cathode surface at distances 2cm and 4 cm is shown in Fig.(6). It is clear from this figure that, the ion density distrabution is non-unifrom with and without copper dust along the cathode surface in both distances. In addation, in the cathode sheath, the present of dust particles has influence on the ion density greater than in the plasma bulk.

According to equation (5), the radial profile of electron density with and without copper dust particle at different distances from the cathode surface were obtained in Fig.(7). One can obtained from this figure that, the electron density in both distance is non-uniform in the present and absent of copper dust particles. Moreover, the present of dust particles reduces the density of electrons in both positions.

According to equation (5), the radial profile of electron density with and without copper dust particle at different distances from the cathode surface were obtained in Fig.(7). One can obtained from this figure that, the electron density in both distance is non-uniform in the present and absent of copper dust particles. Moreover, the present of dust particles reduces the density of electrons in both positions.

Beside the above parameters, the radial profile of floating potential along the cathode surface at different positions were studied. Where V_f is easily measured being the potential at which no net current is drawn. Fig.(8) shows the variation of the radial profile of floating potential at different positions. It seems from this figure that, the radial profile of V_f is inhomogeneous along the cathode surface for both distance in the present and absence of copper dust. Since, the floating potential depends only on the electron temperature and the species of the ion invalid. Therefore, the floating potential become more negative when the electron temperature increases.

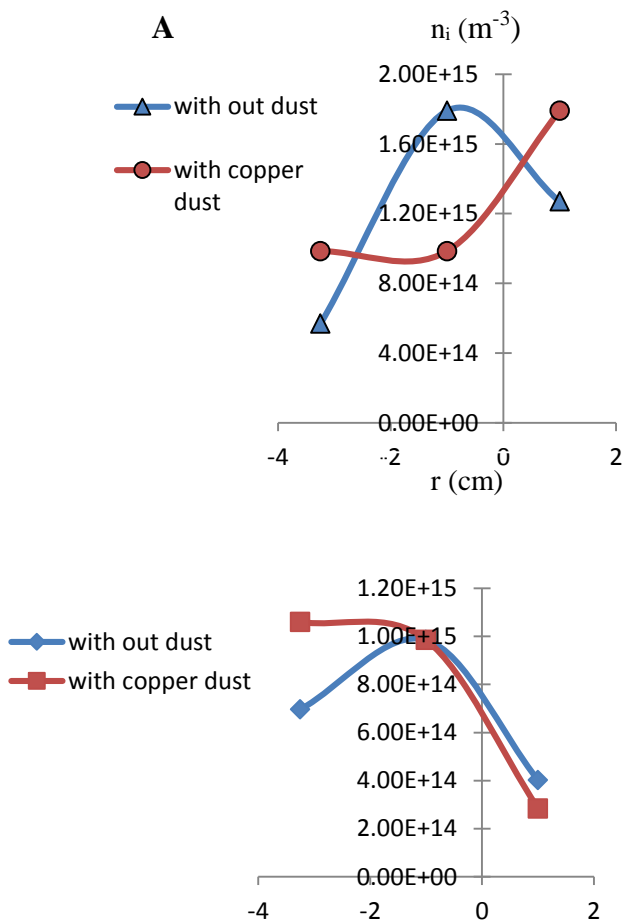


Fig.(6) Radial profile of ion density at pressure 0.8 Torr at different position from the cathode surface; A) 2 cm, and B) 4 cm.

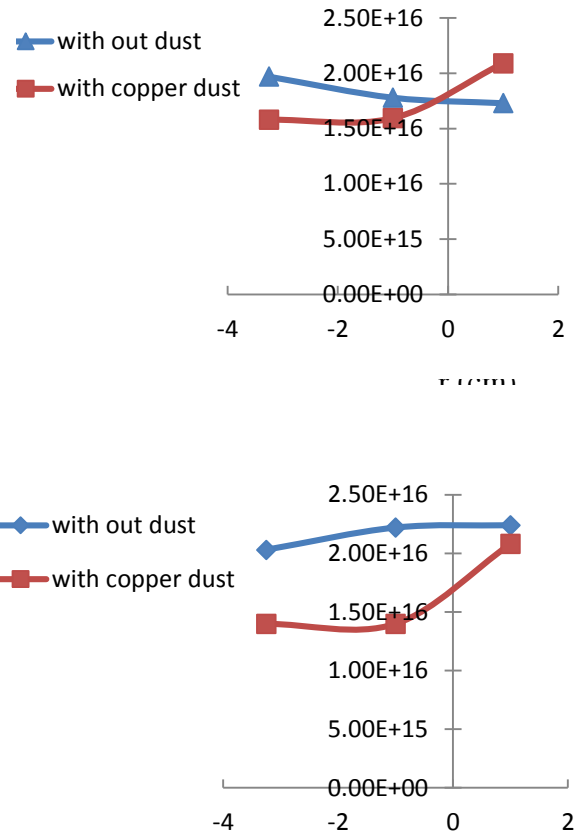


Fig.(7) Radial profile of electron density at pressure 0.8 Torr for different distance from the cathode surface; A) 2 cm, and B) 4 cm.

In addition to the above, the effect of dust particle on the radial profile of plasma potential at different distances from cathode surface was studied (see Fig.(9)). It should be observed from this figure that, the radial distribution of plasma potential for both distance is non- uniform in the present and absent of copper dust particles. This behavior of plasma potential.

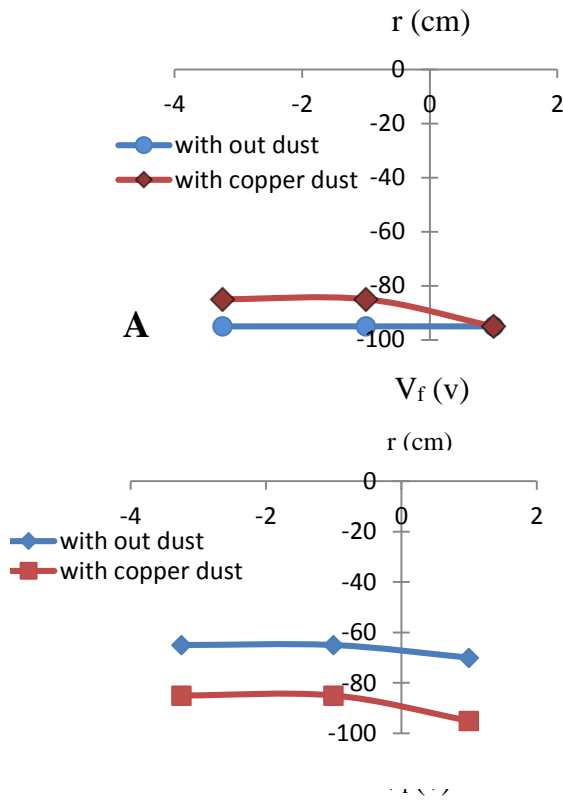


Fig.(8) Radial profile of floating potential at pressure 0.8 Torr for different positions from the cathode surface; A)2 cm, and B) 4 cm.

Distribution attributed to the non- uniform distribution of both electron and ion densities. As well as, the plasma potential has a negative value in the present and absence of copper dust for both distances. On the other hand, the present of dust particles near the cathode surface reduced the negatively of plasma potential while increases negatively of plasma potential far way from the cathode surface. This behavior give evidance of the fact that the dust particles are charged negatively near the cathode surface but it charged positively in the region of plasma (far way from the plasma sheath).

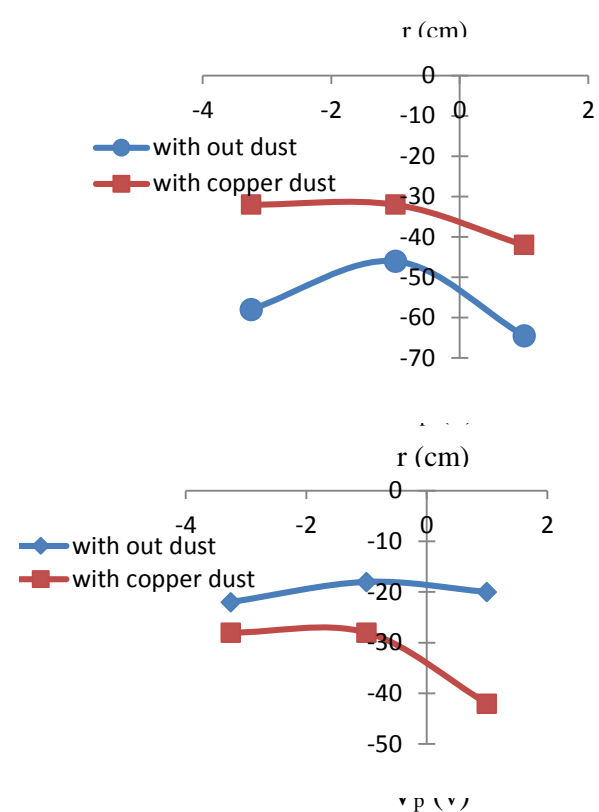


Fig.(9) Radial profile of plasma potential at pressure 0.8 Torr at different positions from the cathode surface; A) 2 cm and B) 4 cm.

Conclusions

In present paper, the radial profile of plasma characteristics for distances 2 cm and 4 cm from the cathode surface at constant pressure 0.8 torr are stuided. These characteristics illustrated that, the radial profiles are non- homogeneous along the cathode at both distances in the present and absent of copper dust particles. Moreover, the results of radial profile of plasma potential in the present of dust particles shows that (plasma negative) the dust particles are charged negatively in cathode sheath but it charged positively in the plasma bulk.

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الخلاصة

في هذا البحث تم استعراض التوزيع الاشعاعي لخصائص البلازما في حالة وجود وعدم وجود جسيمات الغبار الموصلة لمختلف المواقع عن سطح القطب السالب. لقد اوضحت نتائج تيار وفولطية التفريغ ان وجود الغبار ليس له تأثير على فولطية التفريغ ولكن وجود الغبار سوف يعمل على تقليل تيار التفريغ. على اية حال ان القياسات للتوزيع الاشعاعي لخصائص البلازما على طول القطب السالب لمختلف المواقع عن القطب السالب (2 سم و 4 سم) توضح بان توزيع الاشعاعي لكل خصائص البلازما يكون غير منظم على طول القطب السالب في منطقة القشرة القريبة من القطب السالب وجسم البلازما، وان جسيمات الغبار الداخلة في منطقة القشرة القريبة من القطب السالب سوف تشحن بشحنة سالبة اما في منطقة البلازما فسوف تشحن بشحنة موجبة.