Dust grains as a Diagnostic Tool for RF-Discharge Plasma

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Abstract. Dust particles can be a useful plasma diagnostic tool. Sufficiently dust particles can be used as test grains for the visualization of the plasma potential distribution; larger dust particles can be used as specific probes to determine electron temperature. Here we report on diagnostic measurements carried out in a capacitively coupled planar rf discharge. The location of the sheath edge has been determined using test dust grains. Our diagnostic technique is based on measuring the equilibrium position of fine grains levitated above the powered electrode in an rf-discharge. Estimates show that for grains with radii less than 500 mm the grain equilibrium position and sheath edge location differ by less than 5 percent, and this difference continues to decrease with decreasing investigate grain radius. We use this technique to diagnose the sheath in an argon plasma which was generated at pressures in the range 20–100 mTorr by applying a 15 MHz signal to the power electrode. The shape of the potential well above the confining electrode was also visualized using even smaller dust grains that were generated in the discharge. The well shape was found to depend strongly on the confining potential.

INTRODUCTION

The possibility of using the dust grains as a diagnostic tool based on the fact that the grains in a discharge plasma acquire electric charge by collecting electrons and ions from the surrounding plasma. The charge on a grain can be extremely high (say 10^3 - 10^4 electron charges for a micron-sized particles) and depends on the ion and electron fluxes to the particle surface. The equilibrium position of such test grains is determined mainly by gravity and electrostatic forces in the sheath region. This means that the equilibrium position and motion of the grains is strongly dependent on plasma and sheath conditions. Analysis of grain behaviour can provide information on the spatial profile of electric field, ion density and velocity, and the sheath edge location.

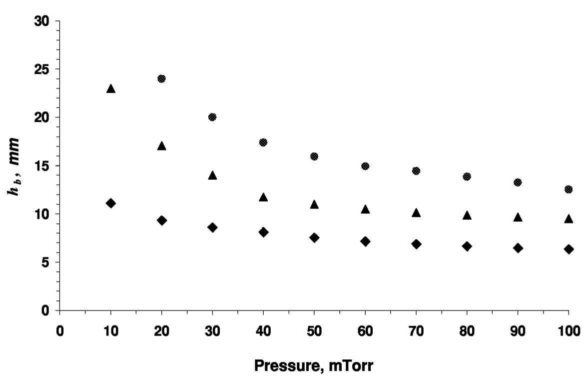

FIGURE 1. Position of sheath edge, h_b, as a function of pressure for different rf-input powers: squares – 100W, triangles – 60W, circles – 35W.

The location of the sheath edge in a planar rf-discharge has been determined using test dust grains. The diagnostic technique is based on measurement of the equilibrium position of fine dust grains levitated above the powered electrode in an rf-discharge. Estimates show that for grains with radii less than 500 nm the grain equilibrium position and sheath edge location differ by less than 5 percent, and this difference continues to decrease with grain radius. We have used this technique to diagnose the sheath in an argon plasma which was generated at pressures in the range 20 – 100 mTorr by applying a 15 MHz signal to the power electrode [1,2].

The test grains are generated in the discharge by electrode sputtering under high power (up to 200W) and high pressure (up to 1 Torr) conditions. The dust grains are illuminated using a Helium-Neon laser, which enters the discharge chamber through a 40-mm diameter window. Windows mounted on a side port and on the top of the chamber provide a view of the light scattered at different angles by the suspended dust particles. The size of the growing grains was estimated from analysis of the scattered light using techniques proposed in [3]. In our experiments grains grown to 300 – 500 nm. To obtain a vertical cross-section of the dust grain layer and provide a

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sheath dimension measurement, the laser beam was expanded in the vertical directions into a sheet of light by a system of cylindrical lenses. Images of the illuminated dust layer are obtained using a charged-coupled device (CCD) camera with a micro lens. The video signals are stored on a videotape recorder or are transferred to a computer. The resulting images allow direct measurement of test grain equilibrium position and therefore a determination of the sheath edge location. The variation of sheath thickness with pressure for different rf-input powers is shown in Figure 1.

The radial potential profile was measured using a transient motion technique (TMT) in which a dust particle levitated in the sheath was displaced from its equilibrium position by applying a negative voltage to a two pin electrode. When the voltage is switched off the particle returns to its original position due to the action of the radial electrostatic force $F_{el}=Z_d E_r$. By tracking the particle motion it is possible measure instantaneous velocity and acceleration. Then, using the equation of motion the potential difference between two points can be found as follows:

$$\Delta\varphi = \frac{ma\Delta s + F(v_1)\Delta s_1 + F(v_2)\Delta s_2}{Z_d}$$

Where $F = 4/3\delta m n_n v_{T_n} \pi a^2 v$ is the neutral drag force. The potential variation obtained in this way was normalised to the plasma potential at $r = 0$, as measured by the Langmuir probe.

The value of Z_d, the particle charge was obtained by the vertical resonance method [4]. As the particle motion is in the horizontal plane we can assume that the charge is constant. The resulting profile is shown on the Figure 2. The profile obtained using a rf-compensated single Langmuir probe is also shown. The two results show good agreement.

The radial electric field, calculated from the potential data, is shown in Figure 3. The high degree of scatter among the points is due to the use of simple numerical differentiation. The result, along with linear fits to the data, is shown, however, to indicate the possibilities of the technique. By fitting functions to the potential variation it would be possible to obtain more reliable estimates of radial electric field. The TMT itself could also be improved by using

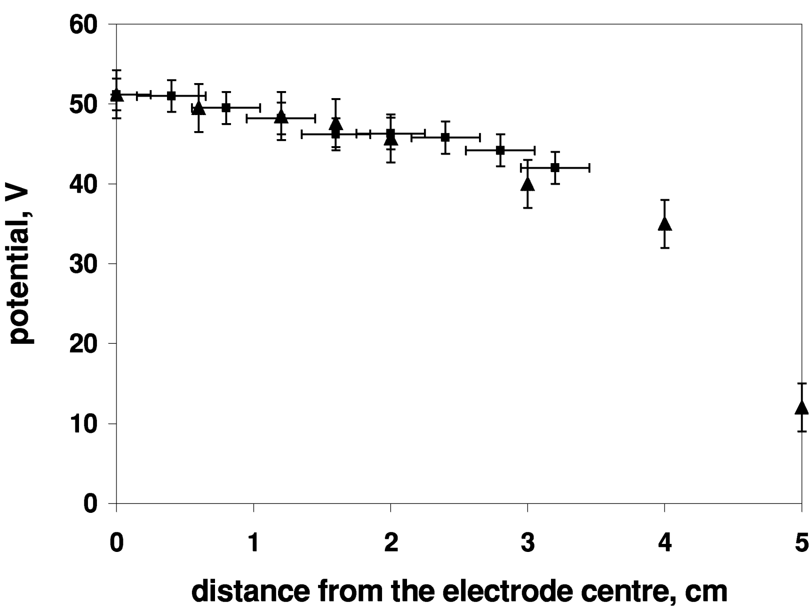

FIGURE 2. Radial potential profile: - Langmuir probe technique, Δ-transient motion technique

a laser, instead of a pin electrode, to displace the particle, causing minimal disturbance to the plasma.

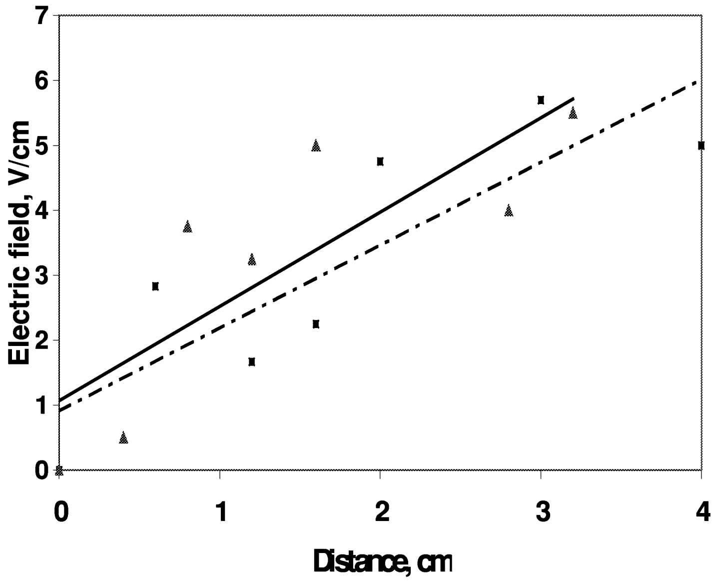

FIGURE 3. Electric field dependence versus distance from the electrode centre. - Langmuir probe technique, Δ-transient motion technique. The solid lane is trend for TMT data; the dashed line is mean square fit for probe data.

Even smaller particles than those used above find no equilibrium position in the sheath. Instead, they fill the plasma volume leaving, the sheath as a dust void. The shape of the potential well above the confining electrode in a radio-frequency (rf) discharge with a printed-circuit board electrode system [5] was visualised using fine dust grains that were generated in the discharge. The well shape was found to depend strongly on the confining potential.

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