Dust Motion in rf-Discharge Plasma

Alex. A. Samarian and Brian. W. James
School of Physics, University of Sydney, NSW 2006, Australia

Sheath edge location
The charge of dust particles in sheath region
Sheath model

- Different features of the sheath and plasma areas

- Sheath edge location is one of the most important parameters in many sheath models
Charging of dust particle

\[ \frac{dQ}{dt} = I_i - I_e \]

\[ I_e = \sqrt{8\pi R^2} N_e \nu_{Te} \exp(e\phi_s / T_e) \]

\[ I_i = \sqrt{8\pi R^2} N_i \nu_{Ti} (1 - e\phi_s / T_i) \]

\[ \phi_s = Q_d / R_d \quad dQ/dt = 0 \]

\[ \phi_s = \phi^f \]

\[ Q_d \]

\[ \sqrt{\frac{T_i}{m_i}} \left[ 1 - \left( \frac{eU(r)}{kT_i} + \frac{e^2}{R_d kT_i} Q_d \right) \right] = \sqrt{\frac{T_e}{m_e}} \left[ \exp \left( \frac{eU(r)}{kT_e} + \frac{e^2}{R_d kT_e} Q_d \right) \right] \]

Q_d up to \(10^6 e\) and Q_d = F(t,r)
Equilibrium of dust particles

\[ F_{ei} - F_g + F_{th} - F_i = 0 \]

\[ m_{pg} + 2\pi^2 m_i n_s v_s^2 [\chi_1 + \chi_2] = eZ_d E + \frac{32}{15} \sqrt{\frac{\pi m}{8T}} a^2 \kappa \frac{\partial T}{\partial z} \]

Where
\[ \chi_1 = 1 - \frac{2Z_de^2}{m_i v_s^2 a} \]
\[ \chi_2 = 2 \left( \frac{Z_de^2}{m_i v_s^2 a} \right)^2 \ln \left[ \frac{\left( \lambda_d / a \right)^2 + \left( \frac{Z_de^2}{m_i v_s^2 a} \right)^2}{1 - \frac{Z_de^2}{m_i v_s^2 a}} \right] \]

and \( \lambda_d \) is the screening length.

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Normalised difference between grain equilibrium position & sheath edge position as a function of grain radius for different values of ion plasma frequency $\omega_i$

$$\omega_i = \sqrt{4\pi n_i e^2 / m_i}$$

*for $\omega_i = 10^7$ s$^{-1}$

* for $\omega_i = 5 \times 10^6$ s$^{-1}$

* for $\omega_i = 10^6$ s$^{-1}$

$$F_i = \pi a^2 n_i m_i v_i^2 \left(1 - \frac{eZ_d}{amv_i^2}\right)^2$$

$\frac{(h_b - h_{eq})}{h_b}$

Dust radius, $\mu$m

E(z)

$\varphi(z)$

Z$_b$

Z$_c$

Plasma

Sheath

Electrode
Experimental setup
Experimental setup
Experimental Setup

The test grains are generated in the discharge (power up to 200W, pressure up to 1 torr) by electrode sputtering.

Experimental chamber and image of test dust particles levitated above the electrode.
Main parameters

- RF discharge 15 MHz
- Pressure from 10 to 400 mTorr
- Input power from 15 to 200 W
- Self-bias voltage from 5 to 180 V
- Carbon (C) particles’ diameter $\sim 1 \ \mu m$
- Melamine formaldehyde - 2.79 $\mu m \pm 0.06 \ \mu m$
- Melamine formaldehyde - 6.13 $\mu m \pm 0.10 \ \mu m$
- Argon plasma $T_e \sim 2 \ eV$, $V_p = 50 \ V$ & $n_e \sim 10^9 \ cm^{-3}$
Measured electron temperature $T_e$ (points with error bars) and discharge emission $I$ (solid line) for $P = 90$ m Torr, $W = 80$ W. The dashed line shows the equilibrium position ($h_{eq} = 10.8$ mm) of test grains ($a \sim 350$ nm).
Result of Measurements

Position of sheath edge ($h_b$) vs pressure at different rf-input powers

- 35W
- 60W
- 100W
Result of Measurements

Estimation of dust charge from vertical equilibrium

\[ V(h) = h^2 V_b / h_b^2 + V_p - V_b \]
\[ E = 2(V_p - V_b)(h_b - h_{eq}) / h_b^2 \]
\[ Z_d = 2\pi \rho \frac{a^3 h_b^2}{3e} (V_p - V_b)(h_b - h_{eq}) \]

Dust particle radius, (µm) | Charge on dust particle (e)
---|---
0.95 | 5.3x10^3 | 3.6x10^3
1.39 | 1.1x10^4 | 5.8x10^3
3.07 | 4.2x10^4 | 1.2x10^4
Summary

Spatial location of sheath edge in planar rf-discharge has been determined using test dust grains.

The diagnostic technique is based on measurement of the equilibrium position of fine (<500nm) dust grains levitated above the powered electrode of the rf-discharge.

Using the resulting value of sheath dimension the charge on dust particles in the sheath region has been estimated.