Measurement of Sheath Potential in Radio-Frequency Discharges

Sameer Ismail Farahat
The Islamic University of Gaza, P. O. Box 108, Gaza-Strip, Palestine

Abstract

In radio-frequency (RF) discharge the sheath potential is defined as the difference between the plasma potential and the direct-current (DC) bias voltage, $V_{sheath} = V_p - V_{dc-bias}$. It is found that sheath potential is a constant potential. In radio-frequency discharge the plasma was produced by a 13.56 Mhz radio-frequency wave. The energy of this wave is the steady voltage known as root-mean-square voltage multiplied by the elementary charge e. That is, the energy of the wave is given by eV_{rms}. It is found that the energy of the secondary electron is almost equal to the energy of radio-frequency wave, $E_s = eV_{sheath} = eV_{rms}$. This led to the establishment of the driven electrode basic principle, which states that: "In RF discharge, electrons emitted from the driven electrode biased below the plasma potential during the RF cycle are lost to the plasma while electrons emitted from the driven electrode biased above the plasma potential during the RF cycle are reflected back to the driven electrode, if space charge effects can be ignored".

1 Introduction

The observation that material removed from the walls of a glass tube, if it is subjected to a high frequency discharge, excited through external electrodes appears to have been made by Robertson and Clapp [1]. In the following up investigation of their work, Hay recognized that the removal of material was due to sputtering and that it occurred only if the frequency used was sufficiently high, although the reason for this was not understood [2]. Lodge and Stewart provided further evidence that the material was removed through sputtering and later associated it with the appearance of a negative charge on the surface of the insulator underneath the high frequency electrode [3]. Levitskii made probe and ion energy measurements as well as limited sputtering studies in a high frequency discharge containing metal electrodes [4]. Anderson *et al*, pursuing an earlier suggestion by Wehner, showed how the application of RF voltage to the outside glass wall of a thermionically supported sputtering system could be used to effect cleaning of the inside of the tube and suggest that the method could be used for the deposition of insulating films [5, 6]. This general approach was subsequently developed by Davidse and Maissel into a practical method for the deposition of insulating films at reasonable rates over substantial areas [7, 8]. The beam plasma mechanism of the discharge is explained by Bohm and Gross [9-12].

With the application of DC voltage on a glass tube having two electrodes of equal areas facing one another a reasonable distance apart a discharge strikes and a dark space, called the sheath, is seen at the cathode. The voltage difference between cathode and anode is dropped almost entirely across the sheath, leaving the glow space nearly field free. If, instead of DC, a low frequency alternating voltage is applied to this tube it is observed that the system behaves as if it had two cathodes, since a sheath is seen at both electrodes. In fact, this system is really a succession of short-lived DC discharges of alternating polarity since, at these low frequencies, there is ample time for a discharge to become fully established within each cycle.

In the following sections the measured DC bias voltage with respect to the ground, the measured sheath potential, the emission of the secondary electron from the driven electrode, and the driven electrode basic principle of the RF discharge are going to be discussed.

2 Experimental Determination of Sheath potential

2.1 Measurement of DC Bias Voltage

In practice in capacitively coupled radio frequency discharges all systems are asymmetric. The asymmetry may exist even if the electrodes are of the same size, due to the presence of an earthed metal chamber or pumping table. The applied voltage is alternating but DC potentials are automatically set up to ensure that the average electron current to an electrode is equal to the average ion current.

The asymmetry of the system leads to the establishment of a DC bias voltage across the device. An equal and opposite voltage, must of course, be developed across the blocking capacitor. The current flowing to an electrode must be equal to the current leaving the other electrode at all times. Each current is the sum of the ion current, the electron current and the displacement current; the last of these averages out to zero over a complete cycle [13].

The experimental work was performed in the apparatus which consisted of a glass vessel, probes, radio-frequency electrostatic probe circuit and a PlasmaProbe system hardware for acquisition-obtaining a plasma characteristic [14].

The DC bias voltage with respect to the ground, $V_{dc-bias}$, was measured by a DC voltmeter across a coil of 220 μ-H connected between the driven electrode and the ground.

2.2 Biasing the Plasma by Gridded Probe

During these experiments there are always two probes in the plasma. One probe for biasing the plasma by a DC voltage while the other is used to measure the I-V characteristics. A gridded probe, one grid only, of area $= 10.3 \times 10^{-6}$ m^2, a planar probe of area $= 10.2\times10^{-6}$ m^2, and a cylindrical probe of area $= 3.9\times10^{-6}$ m^2 were used to characterise an RF plasma generated between two electrodes. The two electrodes either have equal area $= 7.85 \times 10^{-3}$ m^2, or one electrode shape and area is different from the other. In the course of these experiments the chamber was filled with argon at different pressures, the electrode separation fixed at 6 cm and the driven electrode excited at 13.56 MHz while the other electrode was grounded.

In Figures 1, 2 and 3 the plasma was DC biased by a gridded probe, the grid and the collector together were biased by a DC voltage, and the I-V characteristics were measured by a planar probe. The planar probe was RF driven by maximizing the floating potential of the probe. From the knees of the probe traces, the crossing from positive to negative of the second derivative, the plasma potentials, V_p, were measured for different gridded probe bias voltages.

Definition 1 : *The sheath potential is defined by*

$$V_{sheath} = V_p - V_{dc-bias}. \tag{1}$$

In these experiments a relation between the grid bias voltage, plasma potential, the DC bias voltage with respect to the ground and sheath potential is shown in the following figures.

In Figure 1 the pressure was fixed at 5 Pascal. The area of the two electrodes are equal, $A_g = A_d$, where A_g is the area of the grounded electrode and A_d is the area of the driven electrode. When the gridded probe bias voltage was between -30 V and 10 V the DC bias voltage with respect to the ground was fluctuating between -57 V and -59.4 V while the plasma potential was fluctuating between 40.3 V and 38.6 V. That is, sheath potential was fluctuating between 97.3 V and 98 V. When the gridded probe was between 20 V and 60 V the DC bias voltage with respect to the ground was exponentially increasing from -57.1 V to -33 V and the plasma potential was also exponentially increasing from 39.6 V to 59.5 V. That is, sheath potential was fluctuating between 96.7 V and 92.8 V. If the plasma was biased by more voltage then sparks appeared every where on the electrodes and the probe trace was useless to measure the plasma potential. From this result we conclude that sheath potential was fluctuating with mean value at 95.6 V and standard error of 0.6 V. That is, sheath potential can be written as $V_{sheath} = 95.6 \pm 0.6$ V with an error of 0.8%. From this result we conclude that sheath potential did not change by perturbing the plasma.

The RF voltage V_{rf} on the driven electrode was kept constant at $V_{rf} = 300$ V$_{pp}$ while the RF voltage on the probe was fluctuating with mean value at 12.5 V$_{pp}$ and standard error of 0.1 V$_{pp}$. That is, the percentage error was

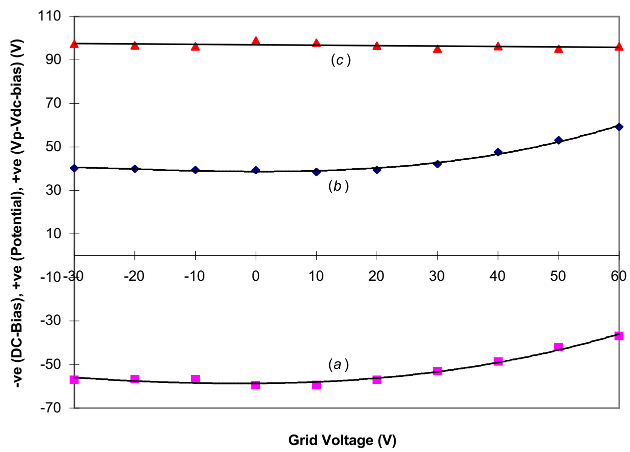

Figure 1: The pressure was at 5 Pa, the driven electrode was held at $V_{rf} = 300$ V$_{pp}$, and $A_g = A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured from the planar probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 95.6 \pm 0.6$ V with an error of 0.8%.

0.8%. This means that the total RF in the plasma has a root mean square value of $V_{\text{rms}} = 100.6$ V.

In Figure 2 the pressure was fixed at 1 Pascal. The area of the two electrodes are equal, $A_g = A_d$. When the gridded probe bias voltage was between 0 V and 30 V the DC bias voltage with respect to the ground was fluctuating between -75.3 V and -74.8 V while the plasma potential was increasing from 49.7 V to 51 V. That is, sheath potential was flactuating between 124.9 V and 125.8 V. When the gridded probe was between 30 V and 60 V the DC bias voltage with respect to the ground was increasing from -74.8 V to -65.9 V and the plasma potential was increasing from 51.0 V to 60.0 V. That is, sheath potential was fluctuating between 125.8 V and 125.9 V. If the plasma was biased by more voltage then sparks appeared every where on the electrodes and the probe trace was useless to measure the plasma potential. It is found that sheath potential can be written as

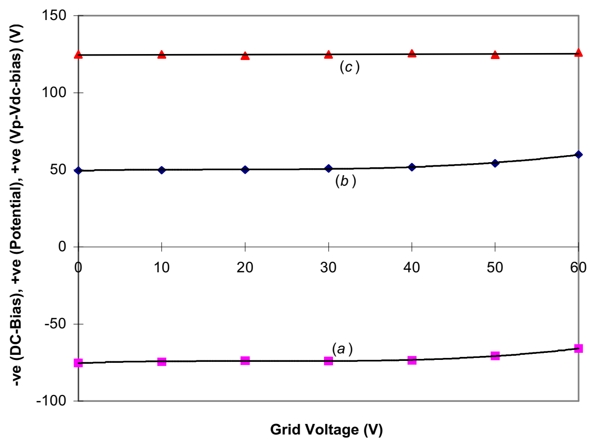

Figure 2: The pressure was at 1 Pa, the driven electrode was held at $V_{rf} =$ 400 V_{pp}, $A_g = A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured from the planar probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 125.0 \pm 0.31$ V with an error of 0.3%.

$V_{sheath} = 125.0 \pm 0.31$ V with an error of 0.3%.

The RF voltage on the driven electrode was kept constant at $V_{rf} = 400$ V_{pp} while the RF voltage on the probe can be written as 9.8 ± 0.17 V_{pp} with a percentage error of 1.7%. That is, the total RF voltage in the plasma has the root mean square value of $V_{\rm rms} = 136.6$ V.

In Figure 3 the pressure was kept fixed at 5 Pascal. The area of the grounded electrode, $A_g = 33.78 \times 10^{-3}$ m^2, is larger than the area of the driven electrode, $A_d = 7.85 \times 10^{-3}$ m^2, and the area of the ground inside the chamber was increased. When the gridded probe bias voltage was between 10 V and 60 V the DC bias voltage with respect to the ground was linearly increasing from -26 V to -21.2 V and the plasma potential was linearly increasing from 68.9 V to 72.1 V. That is, sheath potential was fluctuating between 94.9 V and 93.3 V. When the gridded probe was between 60 V and 90 V the DC bias voltage with respect to the ground was linearly increasing from -21.2 V

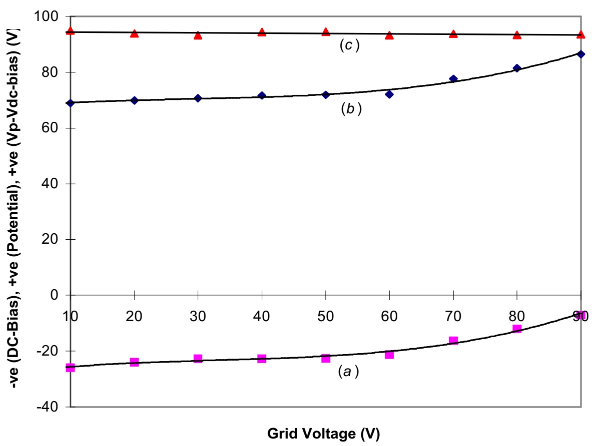

Figure 3: The pressure was at 5 Pa, the driven electrode was held at $V_{rf} = 300$ V$_{pp}$ and $A_g > A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured by a cylindrical probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 94.0 \pm 0.3$ V with an error of 0.3%.

to -7 V and the plasma potential was linearly increasing from 72.1 V to 86.5 V. That is, sheath potential is fluctuating between -93.3 V and -93.5 V. If the plasma was biased by more voltage then sparks appeared every where on the electrodes and the probe trace was useless to measure the plasma potential. From this result we conclude that sheath potential can be written as $V_{sheath} = 94.0 \pm 0.3$ V and did not change by perturbing the plasma, since the percentage error is 0.3%.

The RF voltage on the driven electrode was kept constant at $V_{rf} = 300$ V$_{pp}$ while the RF voltage on the probe was fluctuating with mean value of 10.8 V$_{pp}$ and standard error of 1.2 V$_{pp}$. That is, an error of 11%. This means that the total RF in the plasma has a root mean square value which is given by $V_{\rm rms} = 101.2$ V.

2.3 Biasing the Plasma by Planar Probe

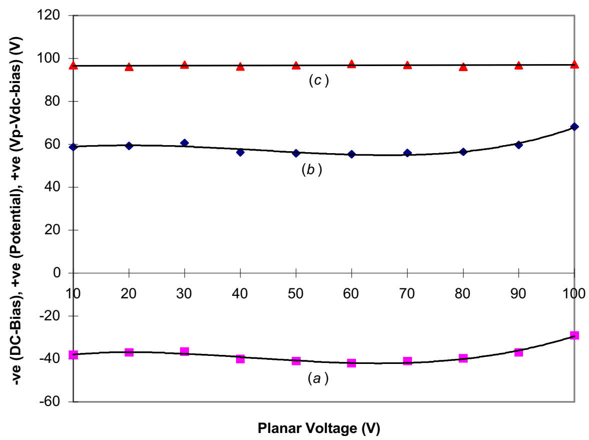

Figure 4: The pressure was at 5 Pa, the RF voltage on the driven electrode, $V_{rf} = 300$ V$_{pp}$ and $A_g > A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured by a cylindrical probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 96.8 \pm 0.15$ V with an error of 0.2%.

In Figure 4 the plasma was perturbed by a planar probe. The I-V characteristics were measured by a cylindrical probe. From the knees of the probe traces, the plasma potentials were calculated for different probe bias voltage. During the experiment the pressure was fixed at 5 pascal. The area of the grounded electrode which has a cup shape, $A_g = 33.78 \times 10^{-3}$ m^2, is larger than the area of the driven electrode which is a flat disc, $A_d = 7.85 \times 10^{-3}$ m^2. The figure shows if the planar probe bias voltage was between 10 V and 50 V the DC bias voltage with respect to the ground was linearly decreasing from -38.0 V to -41.0 V and the plasma potential was linearly decreasing from 58.8 V to 55.7 V. Also, it is found that sheath potential is fluctuating between 96.8 V and 96.3 V. When the planar probe bias voltage was between 50 V and 80 V the DC bias voltage with respect to the ground increased from -41.0 V to -39.7 V and the plasma potential increased from 55.7 V to 56.4

V. When the planar probe bias voltage was between 80 V and 100 V the DC bias voltage with respect to the ground was linearly increasing from -39.7 V to -29 V and the plasma potential was linearly increasing from 56.4 V to 68.2 V. If the plasma was biased by more voltage then sparks appeared everywhere on the electrodes and the probe trace was useless to measure the plasma potential. That is, sheath potential was kept at $V_{sheath} = 96.8 \pm 0.15$ V with an error of 0.2%.

The RF voltage on the driven electrode was kept constant at $V_{rf} = 300$ V_{pp} and the RF voltage on the probe was fluctuating with mean value of 12.4 V_{pp}, standard error or 1.05 V_{pp}, and an error of 8.5%. That is, the total RF in the plasma has a root mean square value of $V_{\text{rms}} = 101.7$ V.

2.4 Biasing the Plasma by Cylindrical Probe

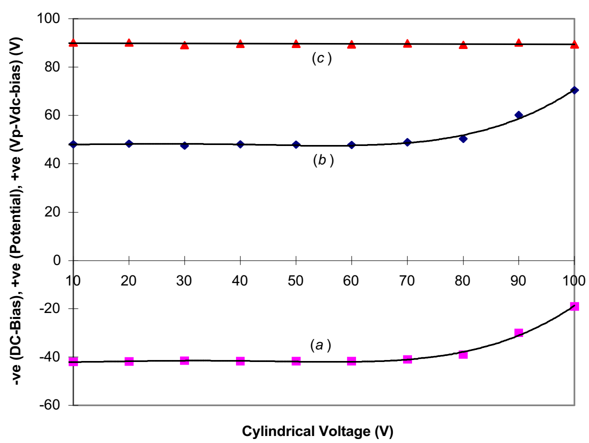

Figure 5: The pressure was at 5 Pa, the driven electrode was held at $V_{rf} = 300$ V_{pp} and $A_g > A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured by a planar probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 89.7 \pm 0.11$ V with an error of 0.1%.

In Figure 5 the plasma was perturbed by a cylindrical probe. The I-V characteristics were measured by a planar probe. From the knees of the probe traces the plasma potentials were calculated for different probe bias voltage. During the experiment the driven electrode was held at $V_{rf} = 300$ V_{pp} and the pressure was fixed at 5 pascal. The grounded electrode has a cup shape and its area, $A_g = 33.78 \times 10^{-3}$ m^2, is higher than the area of the driven electrode, $A_d = 7.85 \times 10^{-3}$ m^2, which is a flat disc. For each measurement of the planar probe trace the DC bias voltage was recorded. When the cylindrical probe bias voltage was between 10 V and 70 V the DC bias voltage with respect to the ground was fluctuating between -42 V and -41 V while the plasma potential was fluctuating between 48.1 V and 48.9 V. That is, sheath potential was fluctuating between -90.1 V and -89.9 V. When the cylindrical probe was between 70 V and 100 V the DC bias voltage with respect to the ground was exponentially increasing from -41 V to -19.0 V and the plasma potential was exponentially increasing from 48.9 V to 70.4 V. That is, sheath potential was fluctuating between 89.9 V and 89.4 V. If the plasma was biased by more voltage then sparks appeared everywhere on the electrodes and the probe trace was useless to measure the plasma potential. This means that sheath potential can be written as $V_{sheath} = 89.7 \pm 0.11$ V with an error of 0.1%.

The RF voltage on the probe was 12.4 ± 0.49 V_{pp} with an error of 4%. That is, the total RF in the plasma has the root mean square of $V_{\rm rms} = 101.7$ V.

3 Plasma potential Measurement by Gridded Probe

In the following experiments only a gridded probe, with one grid, is used to characterise RF plasma. The plasma was DC biased by the grid and the I-V characteristic was measured by the collector of the gridded probe. From the knees of the probe traces the plasma potentials were measured for different grid bias voltages. In the course of these experiments the chamber was filled with argon at a pressure of 1 Pascal, the electrode separation was fixed at 6 cm and RF voltage on the driven electrode was at 300 V_{pp}.

A relation between the grid bias, the plasma potential and the DC bias voltage with respect to the ground and the plasma is shown in Figure 6. The two electrodes have equal areas of $A_d = A_g$.

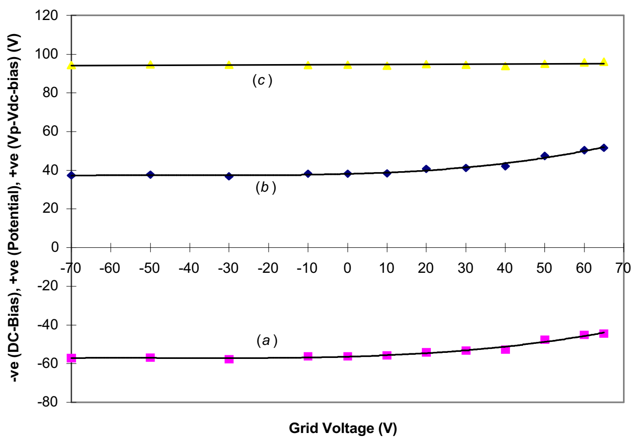

Figure 6: The pressure was at 1 Pa, the driven electrode was held at $V_{rf} = 300$ V$_{pp}$, and $A_g = A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured by the collector of the gridded probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 94.7 \pm 0.18$ V with an error of 0.2%.

When the grid bias voltage was between -70 V and 30 V the DC bias voltage with respect to the ground was linearly increasing from -57.1 V to -53.3 V and the plasma potential was linearly increasing from 37.3 V to 41.2 V. That is, sheath potential is fluctuating between 94.0 V and 94.9 V. When the grid bias voltage was between 30 V and 65 V the DC bias voltage with respect to the ground was increasing linearly from -53.3 V to -44.5 V and the plasma potential was increasing linearly from 41.2 V to 51.5 V. This means that, sheath potential was fluctuating between -93.8 V and 96.0 V. If the plasma was biased by more voltage then sparks appeared every where on the electrodes and the probe trace was useless to measure the plasma potential. Therefore, sheath potential was kept constant and can be written as $V_{sheath} = 94.7 \pm 0.16$ V with an error of 0.2%.

The RF voltage on the probe was fluctuating between 12.5 V$_{pp}$ and 11 V$_{pp}$. That is, the RF voltage on the probe can be written as 12.0$\pm$0.2 V$_{pp}$

with an error of 1.8%. Therefore, the total RF voltage in the plasma has the root mean square value of $V_{\rm rms} = 100.8$ V.

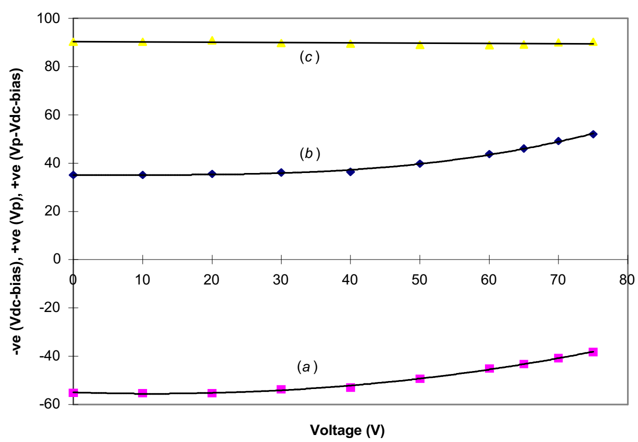

Figure 7: The pressure was at 1 Pa, the driven electrode was held at $V_{rf} = 300$ V$_{pp}$, and $A_g > A_d$. (a) The DC Bias voltages with respect to the ground. (b) Plasma potentials measured by the collector of the gridded probe traces. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 89.9 \pm 0.36$ V with an error of 0.4%.

The area of the driven electrode, $A_d = 7.85 \times 10^{-3}$ m^2, is less than that of the grounded electrode which has a cup shape, $A_g = 33.78 \times 10^{-3}$ m^2, Figure 7.

When the grid bias voltage was between 0 V and 40 V the DC bias voltage with respect to the ground was linearly increasing from -55.2 V to -52.0 V and the plasma potential was linearly increasing from 35.1 V to 36.5 V. That is,sheath potential is fluctuating between 91.4 V and 88.5 V. When the grid bias voltage was between 40 V and 75 V the DC bias voltage with respect to the ground was increasing linearly from -52.0 V to -39.3 V and the plasma potential was increasing linearly from 36.5 V to 52.0 V. Then, sheath potential was fluctuating between 88.1 V and 91.3 V. If the plasma was biased by more voltage then sparks appeared everywhere on the electrodes and the probe trace was useless to measure the plasma potential. That is sheath potential was kept constant and can be written as $V_{sheath} = 89.9 \pm 0.36$ V with an error of 0.4%.

The RF voltage on the probe was kept constant at 12.5 V_{pp}. That is, the total RF in the plasma was $300 - 12.5 = 287.5$ V_{pp}. This means that the root mean square value is given by $V_{\text{rms}} = 100.6$ V.

4 Fixing the DC Bias Voltage at -50 V

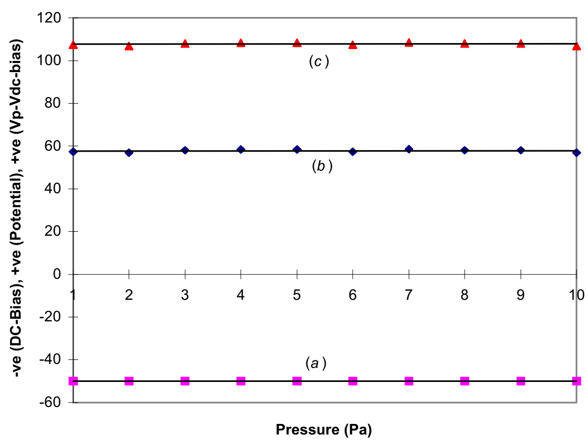

Figure 8: Variation of pressure with potential and the DC bias voltage. (a) The DC bias voltage with respect to the ground fixed at -50 V. (b) Plasma potential measured by a cylindrical probe. (c) Sheath potential. That is, $V_{sheath} = V_p - V_{dc-bias} = 107.8 \pm 0.18$ V with an error of 0.2%.

During this experiment the RF voltage on the driven electrode, V_{rf}, was adjusted to keep the DC bias voltage with respect to the ground at -50 V. The pressure was varied between 1 Pa and 10 Pa. The I-V characteristics were measured by a cylindrical probe. From the knees of the probe traces, plasma potentials were measured and plotted as shown in Figure 8. It is evident that the plasma potentials were fluctuating between 57.4 V and 58.5

V. From this result sheath potential can be written as $V_{sheath} = 107.8 \pm 0.18$ V with an error of 0.2%.

The RF voltage on the driven electrode, V_{rf}, was fluctuating between 300 V_{pp} and 350 V_{pp}. That is, the RF on the driven electrode can be written as $V_{rf} = 327.1 \pm 5.4$ V_{pp} with an error of 1.6%. Also, the RF voltage on the probe was fluctuating between 8 V_{pp} and 17.5 V_{pp}, which can be written as 13.3 ± 1.2 V_{pp} with an error of 8.8%. This means that the root mean square value of RF voltage in the plasma is given by $V_{\mathrm{rms}} = 110.9$ V.

5 Discussion

From the above results it is concluded that sheath potential does not change if the DC bias voltage with respect to the ground has been changed by biasing the plasma with a DC voltage through a probe. Also, sheath potential does not change if the DC bias voltage with respect to the ground is fixed, and the RF voltage on the driven electrode and the pressure are changed.

Since the DC bias voltage is negative, i.e., the driven electrode is charged negative, then the driven electrode is emitting electrons to the plasma. One mechanism of producing these electrons is the bombardment of energetic ions accelerated across the sheath towards the driven electrode causing the emission of these energetic electrons.

Definition 2 : *Since the plasma is positive at the plasma potential, then the driven electrode plays a role as a virtual cathode and the plasma as a virtual anode. Therefore, the driven electrode is emitting electrons called secondary electrons and their energy, E_s, is given by the multiplication of sheath potential by the electron charge. That is,*

$$E_s = eV_{sheath}. \tag{2}$$

The above equation is exactly similar to the equation of the energy of the primary electron emitted from the emissive probe where the emissive probe plays a role as a cathode and the plasma as a virtual anode [15].

In RF discharge the plasma was produced by a 13.56 MHz RF wave. The energy of this wave is the steady voltage known as the root-mean-square voltage multiplied by the elementary charge e [16]. That is, the energy of the wave is given by eV_{rms}.

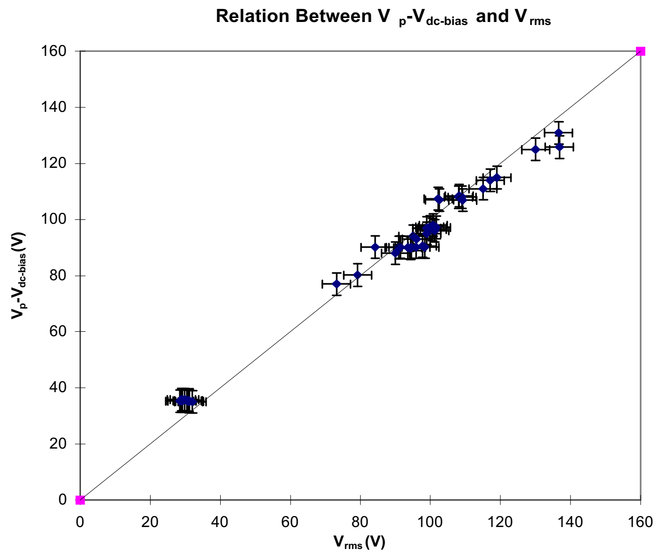

Figure 9: Relation between $V_p - V_{dc-bias}$ voltage and V_{rms} of the RF voltage across the driven electrode sheath. The crosses is the experimental points with 4% error fitting to the straight line $V_p - V_{dc-bias} = V_{rms}$.

Figure 9 shows the relation between the voltage of the secondary electrons emitted from the driven electrode and accelerated across the sheath and the root-mean-square voltage across the driven electrode sheath. This result shows that the relation between the energy of the secondary electron is almost equal to the energy of the RF wave with a percentage error of 4%. That is,

$$E_s = eV_{rms}. \tag{3}$$

The above conclusion leads us to the RF driven electrode basic principle which states that: “In RF discharge, electrons emitted from the driven electrode biased below the plasma potential during the RF cycle are lost to the plasma while electrons emitted from the driven electrode biased above the plasma potential during the RF cycle are reflected back to the driven electrode, if space charge effects can be ignored” [17].

Argon plasma was produced by energetic secondary electrons emitted from the driven electrode. The plasma forms a virtual anode concentric with the driven electrode so that the energy of the secondary electron is

$$E_s = eV_{sheath} = e\left(V_p - V_{dc-bias}\right). \tag{4}$$

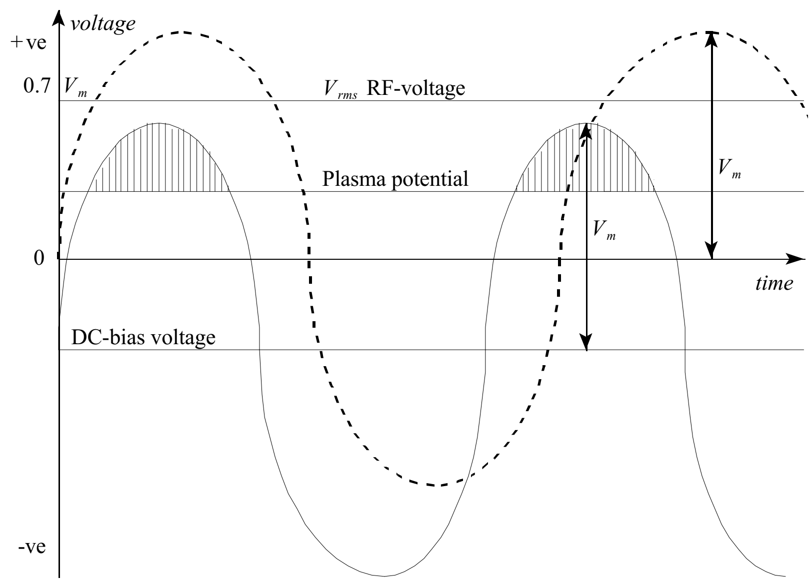

Figure 10: The dashed curve is the RF-sin wave with V_p its amplitude, the peak value, and the $V_{rms} = 0.7\ V_p$. The solid curve is the RF-sin wave introduced on the driven electrode with a DC-bias voltage.

This principle can be explained as shown in Figure 10. The RF-sin wave has a peak value V_m known as the amplitude, and a steady voltage known as the root mean square voltage $V_{rms} = 0.707\ V_m$. When the RF-sine wave is applied on the driven electrode with a DC bias voltage, the wave will be modulated in phase and the DC bias voltage will become its zero voltage axis. Also, the plasma potential will become the new V_{rms} value of the wave. The value of $V_{sheath} = V_p - V_{dc-bias}$ is the voltage of the secondary electrons emitted from the driven electrode and accelerated across the sheath. This voltage is lower than the plasma potential during an RF cycle. However, any electron emitted during the RF cycle above the shaded area of the sine wave

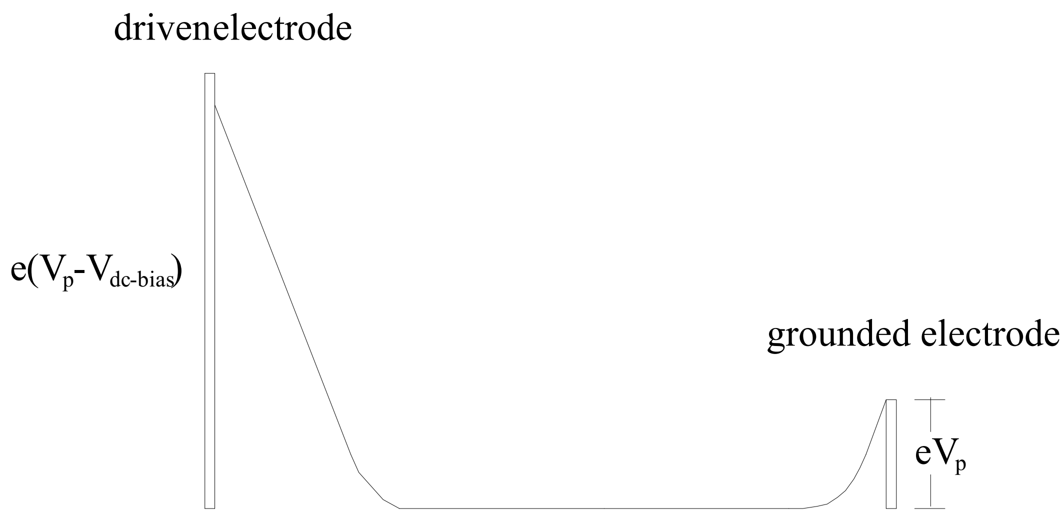

Figure 11: Electron energy diagram for the RF discharge, where V_p is the plasma potential with respect to the ground and $V_{dc-bias}$ is the D.C. bias voltage with respect to the ground.

will return back to the driven electrode because its energy is higher than the plasma potential; the plasma potential is negative with respect to this area.

In an RF discharge the electrons emitted from the driven electrode during the RF cycle must have the energy of $eV_{sheath} = e\left(V_p - V_{dc-bias}\right)$, and the electrons emitted from the grounded electrode have the energy of eV_p. The electron energy diagram is shown in Figure 11. From the diagram it is clear that thermal electrons of temperature k_BT_e are trapped between the two barriers, since $k_BT_e < eV_p$. That is, thermal electrons are going to oscillate locally around the ions, each electron is suspended by one ion, between the two sheaths with the electron plasma frequency $\omega_p = \left(n_0e^2/m_e\epsilon_0\right)^{1/2}$ with n_0 is the electron density [18].

6 Conclusion

A cylindrical, planar, and a gridded probes are used to measure plasma potential for RF plasma. The DC bias voltage with respect to the ground is measured by DC voltmeter. It is found that sheath potential, which is defined as the difference between plasma potential and DC bias voltage $V_{sheath} = V_p - V_{dc-bias}$, is constant and does not change by biasing the plasma by DC voltage. This means that across the sheath there are two voltages. One of them is RF voltage while the other is DC voltage. This led to the establishment of the driven electrode basic principle which explains how secondary electrons emitted from the driven electrode during RF cycle. Also, it is found that the energy of the secondary electrons is equal to the energy of the RF wave, $E_s = eV_{sheath} = eV_{rms}$.

References

[**1**] Robertson J. K., Clapp C. W., 1933, Nature **132**, p 479.

[**2**] Hay, R. H., 1938, Can. J. Res. **A16**, 191.

[**3**] Lodge J. I., and Stewart R. W., 1948, Can. J. Res. **A26**, p 205.

[**4**] Levitskii S. N., 1957, Sov. Phys.-Tech. Phys. **27**, p 913.

[**5**] Anderson G., Mayer W., Whener, G., 1962, J. Appl. Phys. **33**, p 2991.

[**6**] Wehner G. K., 1955, Adv. in Electron. and Electron. Phys. 7, p 239.

[**7**] Davidse P. D., Maissel L. I., 1965, 3rd International Vacuum Congress, Stuttgart.

[**8**] Davidse P. D., Maissel L. I., 1966, J. Appl. Phys. 37, p 574.

[**9**] Bohm D., Gross E. P., 1949, Phys. Rev. 75, p 1851.

[**10**] Bohm D., Gross E. P., 1949, Phys. Rev. 75, p 1864.

[**11**] Bohm D., Gross E. P., 1950, Phys. Rev. 79, p 992.

[**12**] Langmuir, I., 1925, Phys. Rev. 26, 585 p 1925.

[**13**] Allen, J. E., 1995, Plasma Sources Sci. Technol. **4**, p 234-241.

[**14**] Farahat S. I., 2004 - *Measurement of Pre-Sheath Potentials in Radio-Frequency Discharges*, Submitted to the The Islamic University Journal of Research.

[**15**] Hasted, **Physics of atomic collision**, Butterworth Ltd., London 1964.

[**16**] Bolton, W., **Electrical Circuit Principles**, Longman, London 1992.

[**17**] Farahat S, I., 2003 - *Measurment of the Energy of Secondary Electron in Radio-Frequency Discharges*, XXIII International Conference on Photonic Electronic and Atomic Collisions, Stockholm, Sweden.

[**18**] Sturrock P. A., **Plasma Physics**, Cambridge University Press 1994.