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Study on the characteristics of Hysteresis Loop and Resistance of Glow Discharge Plasma using Argon Gas

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ABSTRACT: Hysteresis in discharge current is produced in a low-pressure, magnetic field free, Glow discharge plasma by varying discharge voltage. The variation in area of the hysteresis loops with pressure, electrode distance and load resistor studied. To understand, the nonlinear behaviour of the I-V characteristics, the changes in gas resistance with electrode voltage, pressure and load resistor were studied. After many trials we propose the best suitable empirical equation for the exponential decrease of the gas resistance with electrode voltage as; $R = R_{min} + Ae^{-0.008V}$, which is a novel one and matches well with our experimental results.

INTRODUCTION

When a sufficiently high potential difference is applied between two electrodes placed in a gas, the latter will break down into positive ions and electrons, giving rise to a gas discharge [1]. The electrons are accelerated by the electric field in front of the cathode and collide with the gas atoms. The ionization collisions create new electrons and ions. The ions are accelerated by the electric field toward the cathode, where they release new electrons by ioninduced secondary electron emission. The electrons give rise to new ionization collisions, creating new ions and electrons. These processes of electron emission at the cathode and ionization in the plasma make the glow discharge a self-sustaining plasma. [1,2] The occurrence of sudden jumps and hysteresis in discharge current when the discharge voltage is varied is a well-known phenomenon [3,4]. The voltage current characteristic of a glow discharge is highly non-linear, as are like many other plasma phenomena, and ordinary linear physics cannot be applied to explain their structure[1]. The chaotic behaviour in the discharge plasma is always associated with the occurrence of hysteresis and negative differential resistance in the current-voltage (I-V) characteristic of the discharge [5-7]. Similar observations of negative resistance related phenomena are found in glow discharges, carbon arcs, thermionic converters, fluorescent lamps and four-layer diodes [8]. In this work, we have studied the current-voltage (I-V) characteristics in normal glow discharge plasma for different electrode separation distances, working gas pressures and load resistors using argon as working gas.

EXPERIMENTAL SET UP

The experimental setup consists of cylindrical stainless steel vacuum chamber. The cylindrical chamber is approximately 300mm diameter and 800mm length. The thickness of the vessel is around 5mm. The chamber is mounted horizontally on an aluminium stand at a height of 1000mm from the ground. The Pirani gauge head is connected to the chamber for monitoring the pressure inside the chamber. The diagram of the experimental system is given figure 1. Two electrodes made of copper are placed inside discharge tube through Wilson fed through from the end sides of glass tube. The Wilson fed through arrangement allows us to change the separation during the experiment. Different size of electrodes can be used. The thin circular mica sheets about 7 cm diameters are placed around both electrodes to prevent the field lines beyond the electrodes.

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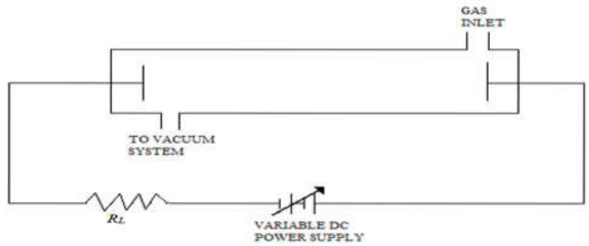


FIGURE 1: Experimental Set Up

Discharge voltage has been supplied by a DC power supply of range 0 - 1.5KV with a maximum current rating of 1 Ampere. A load resistor is introduced in series with the discharge tube to limit the discharge current. The reason for this is that when there is no discharge then the circuit is not closed so no current flows. But when the breakdown occurs, now the path is conducting, a huge amount of current may flow in the circuit. Since resistance of discharge is very small, the discharge may extract a lot of current from the power supply. This may damage the power supply; the load resistor in series helps to avoid this. By measuring the voltage across the load resistor the current flowing through the circuit can be calculated.

RESULTS AND DISCUSSION

Normally I-V characteristics study is done with the plotting of discharge current against electrode voltage. In our work, we have taken the readings of discharge current by increasing the applied potential in a step of 10V from 0 to 900 volt and then also by decreasing the potential by 10V step back to 0 volt. The forward and backward readings were taken continuously. For measuring the discharge current (I_d) inside the plasma, the potential drop across the load resistor (V_R) is measured and divided with the load resistance (R_L).

$$I_d = \frac{V_R}{R_L}$$

If the applied voltage is taken as V_a, and voltage drop across load resistor as V_R then the voltage across the electrodes V_e is given by,

$$V_e = V_a - V_R$$

We can calculate the gas resistance R_G by dividing the electrode voltage V_e by the discharge current I_d,

$$R_G = \frac{V_e}{I_d}$$

The graphs we have plotted here were this electrode voltage against the discharge current for the I-V characteristics study and the gas resistance versus electrode voltage graph for getting an idea about the variation of gas resistance in different configurations.

Variation with Load resistor

In the first case, the gas pressure and electrode separation distance were kept fixed as 0.6 mbar and 40 cm respectively and the experiment was conducted to obtain I-V characteristic curves for three different resistor values. The obtained characteristic curves are shown in fig 2. From this, it is clear that the maximum discharge current is different in three cases. The maximum current is obtained when R_L = 2KΩ, (I_d = 25.44mA) and less current is obtained when R_L = 10K Ω (I_d = 6.25mA). This indicates that the resistance of glow discharge increases when load resistor is increased. It is also observed that the area of the hysteresis loop formed by the I-V curves was more for the small resistor and less for the larger resistor case.

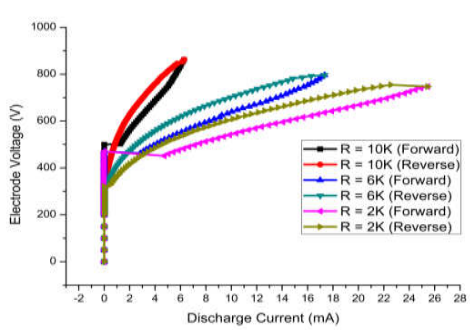


FIGURE 2: I-V Characteristics for different load resistance values

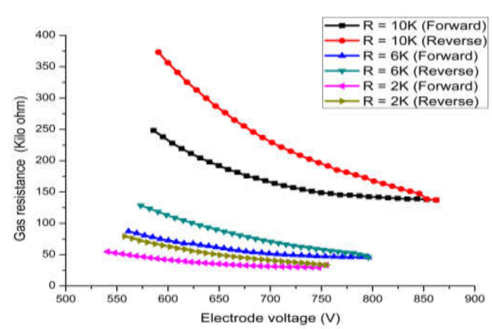


FIGURE 3 : Gas resistances versus electrode voltage for different load resistance values

To further corroborate this behaviour, the variation of glow discharge resistance with load resistor was studied. The gas resistance versus electrode voltage plot is shown in figure 3 for the corresponding I-V characteristics of figure 2. A notable observation from the graph is that the plot for the load resistor having value 10KΩ is more shifted upwards than the plots for the other two load resistor values. We can see from the graph that the value of gas resistance decreases with decrease in load resistance. The maximum value of gas resistance was observed for a load resistance of value 10KΩ and minimum value for load resistor having value 2KΩ.

Variation with Gas Pressure

In the second case, the load resistance and electrode separation distance were kept fixed as 6KΩ and 40 cm respectively and the experiment was conducted to obtain I-V characteristic curves for three different gas pressure values. The obtained characteristic curves are shown in figure 4. The maximum discharge current in plasma was obtained for the gas pressure value of 1 mbar, (I_d = 22.57mA) and minimum value of discharge current in plasma was obtained for a gas pressure value of 0.2 mbar, (I_d = 4.2 mA). That is, the discharge current in the plasma increases with increase in the gas pressure. At high pressure, the charge density is higher inside the discharge tube and this increases the current through the discharge. The area of the hysteresis loops formed from the I-V curves increases when we go from 0.2 mbar to 1.0 mbar. The maximum area of hysteresis loop was obtained for the gas pressure value of 1.0 mbar and minimum area of hysteresis loop was obtained for a gas pressure of 0.2 mbar.

The gas resistance versus electrode voltage plot is shown in figure 5 for the corresponding I-V characteristics of Figure 4. From the graph, it is clear that the maximum value of gas resistance increases with decrease in gas pressure. The maximum value of gas resistance was obtained for a gas pressure of 0.2 mbar. As in the previous cases, the reverse curve shows larger gas resistance values than the forward curve for a particular value of electrode voltage. The plot for the gas pressure value of 0.2mbar is shifted more upwards than the other two plots.

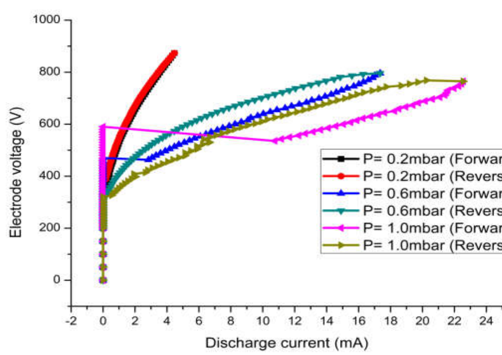


FIGURE 4: I-V Characteristics for different Gas Pressure

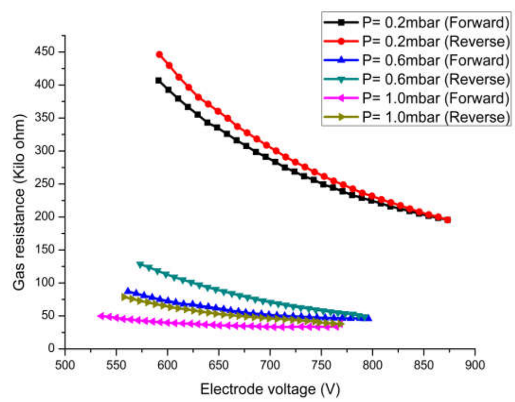


FIGURE 5: Load Resistance Variations for different Gas Pressure

Variation with Electrode Separation Distance

To study the effect of electrode separation distance, the gas pressure and load resistance were kept fixed as 0.6 mbar and 6K respectively and the experiment was conducted to obtain I-V characteristic curves for three different electrode separation distances. The obtained characteristic curves are shown in figure 6. For the three values of electrode separation distances, the maximum value of discharge current in plasma was identical. They are 16mA, 15.9mA and 17.24mA respectively for the three electrode separation distances 30 cm, 40 cm and 50 cm. Also the forward and reverse path in the plot was same for three distances. Hence the area of the hysteresis loop formed by I-V curve also same. The only noticeable difference was for the starting of increasing current, the required electrode voltage is different in three cases. That is for starting the discharge, the electrode voltage required is more in the case of D = 50 cm, and low in the case of D = 30 cm. The reason for this was clear from the Paschen law. From Paschen law, the break down Voltage V_B is a function of Pressure x distance [11, 12]. Since the pressure was fixed, for greater D, the required V_B also high. From these results, it can be concluded that the electrode separation distance do not influence the maximum discharge current and hysteresis area.

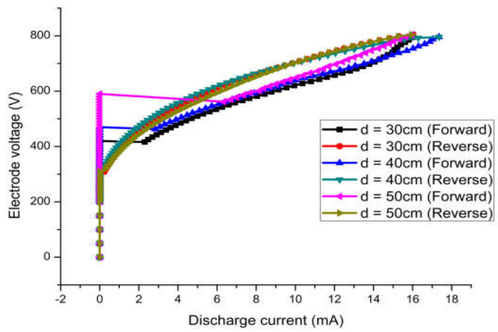


FIGURE 6: I-V characteristics for different electrode separation lengths

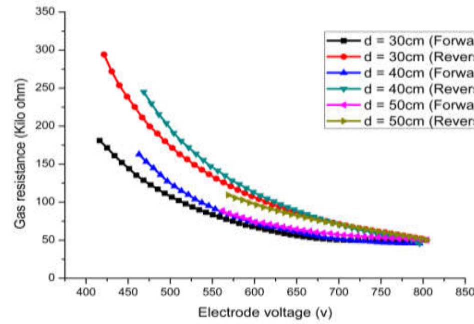


FIGURE 7: Gas resistances versus electrode voltage for different electrode separation lengths

The gas resistance versus electrode voltage plot is shown in figure 7 for the corresponding I-V characteristics of figure 6. From the graph, the minimum value of gas resistance for different electrode separation distances was nearly identical and also the variation of gas resistance for three electrode separation distances in similar way.

Reasons for Hysteresis

Since the hysteresis curve is the result of current versus voltage graph, the dimension of the area (V×I) is power. So the area formed is actually the power loss. From our readings and findings, the reason for the power loss is particle missing or in other words losses in the form of charge densities. As we increase the electrode voltage (forward case) more ionization occurs and the charge density increases. Since the number of charged particle, electrons and ions increases, the current also high. But as time increases, the electron – ion recombination occurs. This leads to, decrease of the charge density. It is considered as the particle missing. So when we are decreasing the applied voltage (reverse case), the discharge current lags or less than in the case of forward.

Studies on Gas Resistance in Various Conditions

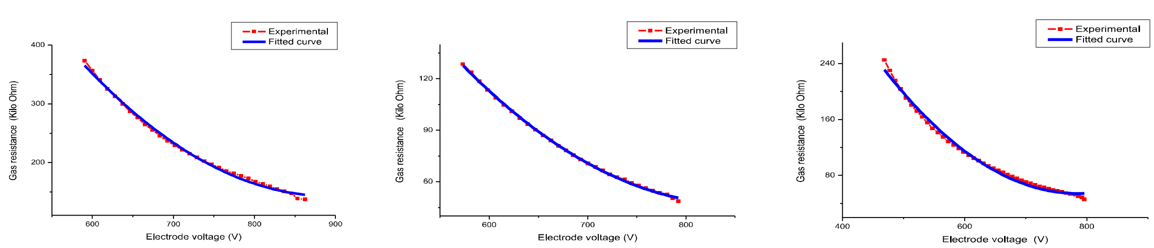
Here we have plotted the gas resistance versus electrode voltage graph for three varying parameters; gas pressure, load resistance and electrode separation length. In all these cases the resultant plots show an exponential decreasing nature of gas resistance with electrode voltage. Hence we have tried to fit the resultant graphs with an exponential function. After many trials we found the best suitable equation for our situation as follows:

$$y = y_0 + Ae^{R_0 x}.$$

Whenever we are fitting the curve with our experimental results, the value of R_o is in between -0.007and -0.009. So we chose the rate of decrease R_o as -0.008 and fitted the graphs. In the present situation, y_0 is the minimum value of gas resistance and that occurs for the maximum value of electrode voltage and 'A' the gas resistance at zero electrode voltage. So in our situations, this value of A is very large, and it is the value of gas resistance just before starting the breakdown. For fitting the curve, the $y_{0,}$ the minimum value of gas résistance, is the resistance value at applied voltage 900V, the maximum voltage that applied in our study. So the empirical formula we proposed from our study is as given below.

$$R = R_{min} + Ae^{-0.008V}$$

Where, R_{min} is the minimum value of gas resistance at applied voltage 900V.



R_L = 10K, P = 0.6 mbar, d = 40 cm R_L = 6K, P = 0.4mbar, d = 40 cm R_L = 6K, P = 0.6 mbar, d = 30 cm

FIGURE 8: experimental and fitted curves for gas resistance variation with electrode voltage in different conditions

We repeated the experiment by varying control parameters like load resistor, electrode separation distances and gas pressure, and plotted gas resistance versus electrode voltage graphs. The so obtained graphs are fitted using the above stated proposed equation and were well fit with it. The results are shown in figure 8.

CONCLUSION

The behaviour of I-V characteristics was studied by varying load resistor, gas pressure and electrode separation distances. When we considered the cases of the variation with load resistor and gas pressure, we could find that the maximum discharge current and the area of the hysteresis loop formed by the I-V curves were proportional to both the varying parameters individually. But when we considered the case of variation with electrode separation distances, we could find that the maximum discharge current in plasma and area of the hysteresis loop formed for different values of electrode separation distances were identical. We conclude that, the electrode separation distance has no influence on the area formed by the I-V curve while load resistors and gas pressure has significant influence on it. We considered the nature of gas resistance with electrode voltage. The gas resistance increases with decrease in gas pressure and load resistor values. But it was possible to observe that the nature of gas resistance was same for the three values of electrode separation distances. In all the cases gas resistance shows an exponential decrease with increasing electrode voltage. Through this study, suitable formulae for representing the variation of gas resistance with electrode voltage at different configurations were proposed. The proposed formulae were matching well with experimental results.

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