# CONSTRUCTION AND CHARACTERIZATION OF A LOW PRESSURE PLASMA REACTOR USING DC GLOW DISCHARGE

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A partial ionized plasma source of DC-glow discharge at low pressures has been constructed, characterized, and operated as home-built plasma system. The using system technique is a direct current discharge, formed between two metal electrodes, a flat cathode with diameter 14.5 cm and an anode of the same shape. High voltage DC power supply has been built for delivering 4kV maximum output to discharging electrodes. The glow length (inter- electrodes spacing) was varied from (4-6) cm and pressure produced from ($6.5\times10^{-2}$ - $1\times10^{-1}$) mbar. The performance of the system via the determination of (I-V) and (I-P) characteristics curves was studied using $N_2$ as discharging gas source. As a result of ionization processes of $N_2$ gas it is possible to estimate that the current density values at breakdown voltage indicated the discharge is operating in the abnormal glow region. The characteristics of glow discharge (plasma) column were observed influenced with inter- electrode spacing and gas pressure, and the negative glow, Faraday dark and positive column regions are recognized.

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## 1. Introduction

Low pressure plasma technology provides several varieties of applications in micro-electronic industry and materials surfaces processing. There has been a recent explosion interest in the area of glow discharge plasmas. Some of these applications may be listed as: etching and in semiconductor wafer processing, polymerization in fabrication of optical fibers, treatment of fibrous materials, surface modification by deposition of diamond films and corrosion resistance coatings , plasma immersed ion implantation for plasma nitriding , flat plate displays, high-pressure arcs and jets for ceramic coating and plasma paralysis applications, etc (Ref. 1-4).

Space and laboratory plasmas classified by their electron temperature Te, and charge particle density (Ref. 1). One types of processing plasmas that is relevant to this project is low-pressure dc- glow discharges.

## 2. Direct current glow discharge process

Glow discharge is a kind of plasma. It is an ionized gas consisting of equal concentrations of positive and negative charges and a large number of neutral species (Ref. 4-6) 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. The mechanism of

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the gas breakdown can be explained as follows: a few electrons are emitted from the electrodes due to the omnipresent cosmic radiation. Without applying a potential difference, the electrons emitted from the cathode are not able to sustain the discharge. However when a potential difference is applied, the electrons are accelerated by the electric field in front of the cathode and collide with the gas atoms. The most important collisions are the inelastic collisions, leading to excitation and ionization. The excitation collisions, followed by de-excitations with the emission of radiation, are responsible for the characteristic name of the 'glow' discharge. 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 ion induced 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 self-sustaining plasma. The voltage at which breakdown occurs is described by Paschen's law (Ref. 2, 5).

$$V_B = Apd/\ln(pd) + B \quad (1)$$

Here we have used $V_B = E_B\, d$ for the breakdown voltage and have taken the mean free path $l_m$ to be inversely proportional to the gas pressure $p$. $A$ and $B$ are constants. Equation 1 exhibits a minimum with respect to $pd$, called the Paschen minimum. At large values of $pd$, the number of collisions within the length of the tube is large. Thus the electrons pick up very little energy between collisions so that the probability of ionization decreases. To compensate for this decrease, $V_B$ rises. For small $pd$, $V_B$ rises again because the collisions within the plasma column are too few.

There are other important aspects of the dc discharge like its *I–V* characteristic, and the alternate dark and luminous bands that correspond to various regions like the cathode and anode sheaths, the positive column, the Faraday dark space, etc. These aspects are treated in detail in standard references (Ref. 1, 2, 4), and will not be discussed here. So what are the typical parameters of GD? Here they are (Ref. 1, 8):

The aim of our work is to introduce plasma processes topic to our country by construction and operation home built DC-glow discharge plasma system. This paper describes the important technical procedure that go to explain the electrical discharges of plasma reactor source. Paper has two sections; the first deals with the experimental work in-house built low-pressure plasma system. The principle components of system are the ion source of anode and cathode fixture assemblies, high voltage dc power supply and vacuum system. The second section discuses in detail some discharges analyses and the qualitative changes that take place in the formation mechanisms and the characteristics of plasma source, as pressure-current characteristics and inter-electrodes spacing with the breakdown voltage.

## 3. Experimental procedure (Reactor and Diagnostics)

### *DC-glow discharge plasma (reactive ion) system*

In-home built system was used for this work, has been manufactured and based on the following principal components:

### *1-Ion Source*

The function of the ion source is to continuously supply an adequate number of positive and negative charges. It is a low pressure gas discharge unite consists of evacuated chamber, a target(cathode) and anode disk of stainless steel .The cathode faced the anode, which provide electric field for the gas discharge. Figure 1 shows the schematic of the plasma chamber, the electrical electrodes and the associated DC-power supply of 4 kV. The bottom of the cathode electrode is shielded by insulator disk (ceramic and thermal teflon). The top of cathode is shielded by cathode space assembly which included the ceramic insulator and St.St holder. The diameter of the top electrodes is (14.5cm) while that of the target electrode (effective area of cathode dark space) is 7.5 cm and the gap distance between them is varied from 4 to 6 cm. The high voltage power supply is operated at range of 300-1200 volt.

| | |
|---|---|
| ***Pressure*** | ***0.01 - 10 Torr*** |
| **Dimensions** | **0.1 – 10 cm** |
| **Voltage** | **100 – 2000 V** |
| **Current** | **0.1 – 100 mA** |
| **Temperature** | **300 – 1000 K** |
| **Charged particle density** | **$10^6$ – $10^{13}$ $cm^{-3}$** |
| **Plasma electrons (energy)** | **0.1 – 3 eV** |
| **Plasma ions** | **kT gas** |
| **Ions at cathode** | **1 – 1000 eV** |

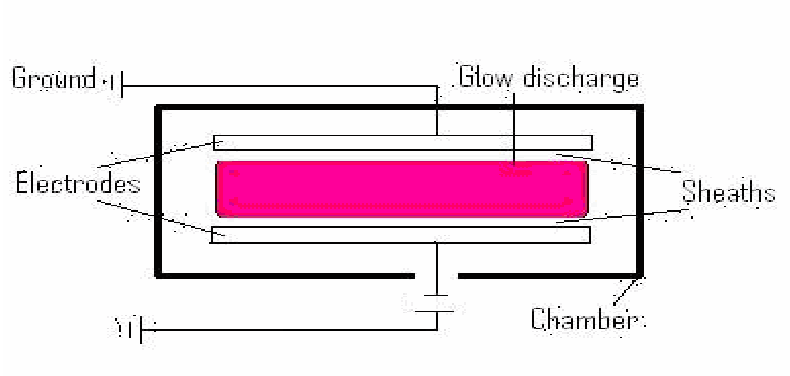


*Fig. 1. Schematic of the plasma chamber.*

### *2-Vacuum System*

The vacuum system consists of turbo pump assisted by a mechanical rotary pump.

Pumping system of the mechanical rotary pump (Blazer of 60 m3/h) and turbo pump (Varian, V-1000HT). Penning (Edward CP25-K with controller 1102) and pirani gauges (LH-Thermovac with COMBITRON CM350) were necessary to install the plasma chamber in order to monitor actual pressure there and to measure the partial pressures of $N_2$ gas.

## 4. Experimental Set-up

Fig. (6) a photograph of the main experimental set – up used in this work. On the left hand side one sees ( 1) vacuum pumps system ( rotary and turbo pumps) and on the center (2) the plasma chamber ( a cylindrical stainless steel vacuumed chamber with length(50cm) and diameter of (50cm) , (3) the right hand side power supplies of Langmuir probes, (4) penning and pirani heads and readers, (5). H.V DC- power supply (4 kv), (6) ammeter for discharge current measurements, (7) $N_2$ gas source,(8) Langmuir probes (circular wire of tungsten, it surface covered by ceramic and inserted from the side of chamber), (9) anode electrode ,and (10) cathode assembly electrode (two circular electrodes, one of which has movable shift denoted " anode" and fixed electrode denoted" cathode " .

### 5. Experimental results and discussion

The main characteristics of a plasma discharge such as the breakdown voltage, the I-V, I-P and plasma column characteristics depend on the gas pressure and inter-electrode spacing. The measurements were made using dc voltage (0-1100V).


*Fig. 2. Low pressure (dc-glow discharge) plasma system.*

The breakdown voltage is related to the electrode spacing parameter pd (Pashen low), where p is the gas pressure and d is the inter- electrode gap spacing as show in previuse section which illustrated in figure 3. Breakdown potential voltage below Pashen min.value can be decreased by increasing the electrodes spacing parameter pd. For large values of pd > 4.6 cm), breakdown voltage increases essentially linearly with pd. For small pd there is a limiting value of pd= $A^{-1}$ ln $(1+1/\delta_{sec})$ below which breakdown cannot occur, where A is constant and $\delta_{sec}$ is the secondary electron emission coefficient . The values of $V_{min}$ and (pd) min play an important role in the more complicated problem of the cathode sheath (Ref. 2)

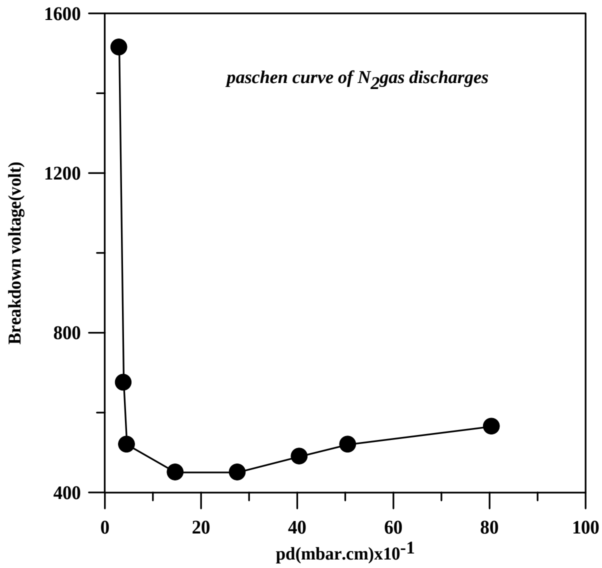


*Fig. 3. the DC breakdown voltage as a function of the product of gas pressure p and electrode spacing d for the plane parallel electrodes in $N_2$.*

The variations of discharge current with applied voltage obtained with a pressure of ($6.5X10^{-2}$ - $1X10^{-1}$ mbar) and electrode spacing ( 4-6 cm) are shown in figure 4. The discharge current is increased by increasing the applied voltage as one would expect but the variation of current is not linear (Ref. 9, 11) . The current density after short transient evolves into a child low sheath with time –varying current density and sheath thickness .The child low current density $J_c$ for applied voltage $V_o$ across sheath of the thickness S is given by (Ref. 9):

$$J_e = 4/9 \, Eo \, ( 2e / M) \, ½ \, V_o^{3/2} / S^2 \qquad (2)$$

where $E_0$ is the free space permittivity and e and M is the charge and particles mass. This behavior attributed to the increment in mobility of plasma particles which is a good agreement with Child –Longmuir equation (Ref. 12) . Examinations at various pressures emphasizes, that although the ion currents are usually interpreted in terms of gas pressure, it is more accurate to consider the gas density. If the gas pressure is increased the gas density increased leads to increase the ion current. This is indicated that the ions may undergo several collisions during their paths through the dark space region .It is important to realize that several processes operate simultaneously within the plasma ,also excitation, fragmentation and ionization may occur (Ref. 9) . The current-voltage (I-V) character eristic of a discharge can give valuable information about its mechanisms described for the case of glow discharge. The discharge was operated by propounding an over potential of 1 kV. The power supply voltage was then adjusted to vary the discharge current. Comparison between the I-V curve for low –pressure a glow discharges indicates that the Townsend mode and initial fall in voltage (negative resistively) are absent. These regions of the I-V curve are observable of pressures lower than ($6.5X10^{-2}$) mbar. At higher pressures breakdown rapidly followed by a transition to the normal glow discharge mode where the discharge voltage is relatively constant. When the pressure is increased, the average discharge voltage is found to decrease from approximately 900 volt of ($6.5X10^{-2}$) mbar to 600 volt at ($9.0X\ 10^{-2}$) mbar at inter-electrode spacing of 4.6 cm. Evidently as the pressure is raised the discharge becomes more conductive. The dependence to nonlinear at short gap distance (electrodes spacing), but becomes linear at larger gaps. This is representative of an increase in the length of the positive column in the discharge where the electric field remained constant.

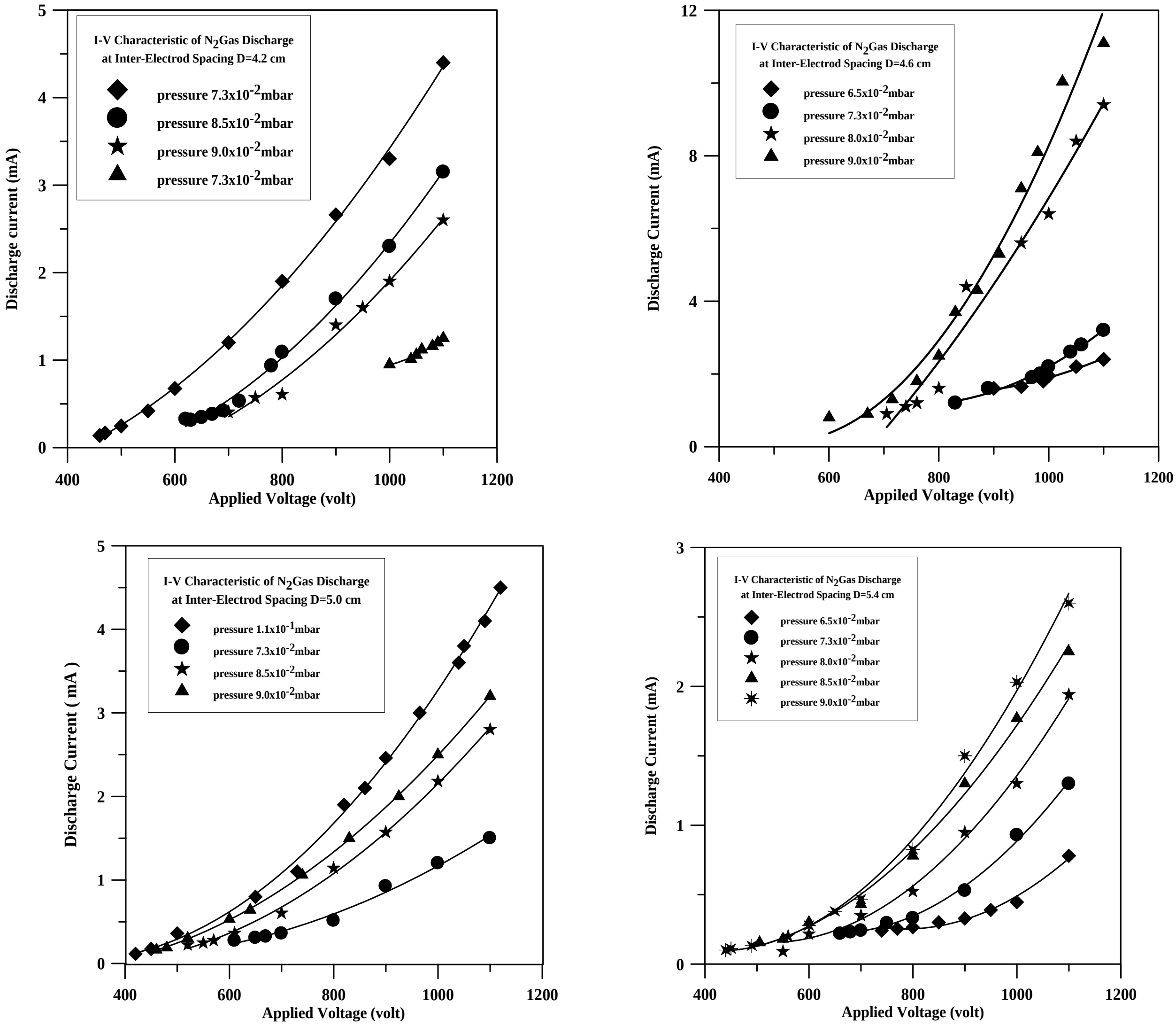


*Fig. 4. (I-V) characteristics curves using $N_2$ as discharging gas source.*

The I-P characteristics of N2 gas discharge shows increment in glow discharge current with increasing the produced pressure in reactor chamber at constant applied voltage as shown in figure 5. This behavior result of “the increasing of chamber pressure leads to increase of generation of ions and free species in glow column, which leads to increase the propebility of secondary electron emission. So the measured total current is the summation of ions and emission electrons currents (Ref. 11).

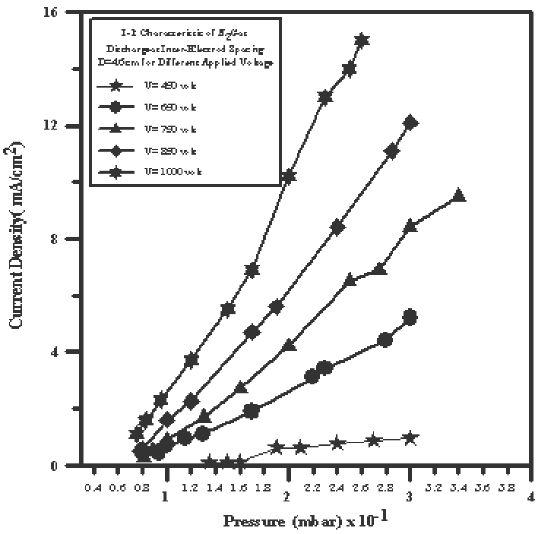


*Fig. 5. (I-P) characteristics curves using $N_2$ as discharging gas source.*

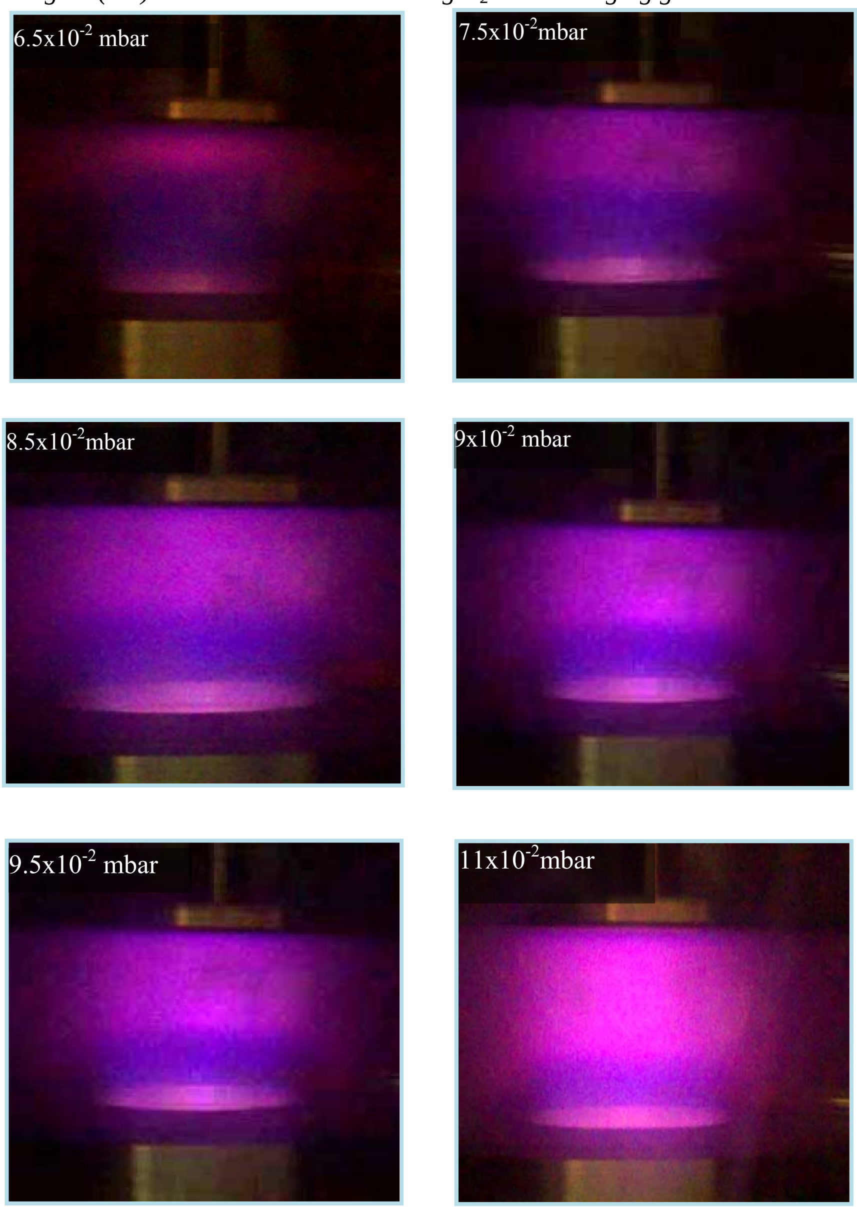


*Fig. 6. Plasma column at various N2pressures discharges (6.5, 7.3, 8.5, 9, 9.5, 11*10-2 mbar respectively.*

Column (emitted light intensity) at various pressures in the discharges. The light intensity peaks near the break down voltage are caused by excitation impact, and the peaks near the cathode are probably to be ascribed to excitation by high-energy positive ions and neutral particles (Ref. 12). It should be noticed that relative intensity peaks at the cathode rises very rapidly as the discharge current and, thus, produced pressure and the electrodes applied voltage are increased. We can recognize the negative glow, Farday dark and positive column regions, which are the main structure of DC-glow discharge (plasma) column.

## 6. Conclusions

We can concluded the following points from this work .First, the I-V characteristics of gas discharges refers that the plasma reactor system operated in abnormal glow discharge region, which is very important parameter in microelectronic industry .Second, the inter-electrode spacing, gas pressure and cathode potential imposes a great effect on the glow discharge current, and satisfied a good agreement with Child –Langmiur equation. Finley the size and intensity of produced plasma (glow) column depends on the cathode-anode gap spacing and gas pressure.

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