Double probe for measuring the plasma parameters

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Abstract

In this work the diode planer magnetron sputtering device was designed and fabricated. This device consists of two aluminum discs (8cm) diameter and (5mm) thick. The distance between the two electrodes is 2cm, 3cm, 4cm and 5cm.

Design and construction a double probe of tungsten wire with (0.1mm) diameter and (1.2mm) length has been done to investigate electron temperature, electron and ion density under different distances between cathode and anode. The probes were situated in the center of plasma between anode and cathode.

The results of this work show that, when the distance between cathode and anode increased, the electron temperature decreased. Also, the electron density increases with the increasing of the distance between the two electrodes. The behavior of ion density is similar to that of electrons but the value is higher.

قياس متغيرات البلازما بأستخدام المجس الثنائي

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الخلاصة

في هذا العمل تم تصميم وتصنيع منظومة الترذيذ المغناطيسي المستمر المستوية. تحتوي هذه المنظومة على قطبين من الألمنيوم بقطر (8سم) وبسمك (5ملم) والمسافة التي تفصل بينهما هي 2سم، 3سم، 4سم و5سم. بالإضافة إلى ذلك تم تصميم وتصنيع مجس ثنائي بقطر (0.1ملم) وطول (1.2ملم) مصنوع من مادة التنكستن لتشخيص درجة حرارة الإلكترون وكثافة الإلكترونات وكثافة الايونات بمسافات مختلفة بين الكاثود والآنود.

تم دراسة تأثير المسافة بين الأقطاب على خواص البلازما وبينت النتائج في هذه الدراسة أنه عند زيادة المسافة بين الكاثود والآنود فأن درجة حرارة الإلكترون تقل وكذلك فأن كثافة الالكترونات تزداد بزيادة المسافة بين الأقطاب وان سلوك كثافة الايونات نفس سلوك الالكترونات ولكن بقيمة أعلى.

Introduction

Plasma may be defined as a conglomeration of mobile positively and negatively charged particles, there being approximately the same density of positive charges as of negative. Or it is matter heated beyond its gaseous state, heated to a temperature so high that atoms are stripped of at least one electron in their outer shells, so that what remains are positive ions in a sea of free electrons [1-3]. However, in general, plasma must satisfy the following criteria [4]:

1- Quasi-neutrality. A plasma maintains almost perfect charge balance:

$$-q_e n_e = q_i n_i \pm \Delta$$

where Δ is tiny.

2- Interactions between individual charged particles are insignificant compared to collective effects. This condition requires that the number of particles in the Debye sphere

$\Lambda >> 1$. Λ is also called the plasma parameter.

3- The electron-neutral collision cross-section is much smaller than the electron-ion cross-section $\sigma_{en} << \sigma_{ei}$. Thus a weakly ionized $(\approx 1\%)$ gas can behave like a plasma because the long range Coulomb forces have an effect much more significant than that associated with collisions with neutrals.

Plasma Diagnostics

Because of the complexity of the physical and chemical environment in a plasma process, a large array of process monitors, historically termed "Plasma diagnostics", are required to characterize the plasma, or to properly monitor important control parameters.

Plasma diagnostics are used to deduce information about the state of the plasma from observations of physical processes and their effects. The information is used to verify performance of the experiment and for control of the plasma volume regarding its topology and boundary. It is important to describe the plasma, which is done by comparing theoretical predictions with measurements. This is done in terms of a number of plasma parameters [5].

Plasma diagnostics encompasses all methods and techniques employed for the determination of macroscopic as well as of microscopic properties and parameters of plasmas as a function of space and time.

There are many different diagnostic tools that can be used, depending on the type of plasma under investigation and the specific information that is required [5, 6]:

1- Electrostatic probes.
2- Surface probes.
3- Microwave interferometry.
4- Impedance analysis.
5- Quantitative plasma mass spectroscopy.
6- Emission and absorption spectroscopy.

7- Laser fluorescence spectroscopy.
Parameters that characterizing plasma are the electron (n_e), ion (n_i) and neutral (n_0) densities, the respective temperatures (energies) of these species, and the magnetic (B) and electric (E) fields. Since laboratory plasma range from small-volume configurations of $10^{-16} m^3$ (e.g. micro pinches) to large-volume system of about 50 m^3 (magnetic fusion device JET), and density and temperature cover a range from 10^{14} to $10^{30} m^{-3}$ and from $10^3 K$ to several times $10^8 K$ (1eV – 10eV), respectively, a large variety of different methods is used which originate in a number of fields of physics and applied physics [4,5].

Double Langmuir Probe

In some types of plasma discharges there does not exist an electrode or reference point that is in good contact with the plasma. This reference point is needed when applying a bias voltage to a Langmuir probe.

In other situations, the plasma potential may change with time, which will create difficulties in maintaining a constant voltage difference between a probe and the plasma potential. In these situations the single Langmuir probes are not readily applicable, so that Johnson and Malter (1950) developed a technique that overcomes some limitations of the single probe [7, 8].

It involved the use of two Langmuir probes biased with respect to each other and isolated from ground. This allows the probes to electrically float with regard to the plasma therefore allowing the probes to follow the changes in the plasma potential.

Double probe method is widely used for the study of plasmas properties. Most of the probe theories consider the case of plasma at rest [9, 10].

However, in some plasmas the electron drift velocity in the axial direction, which is principally responsible for carrying the discharge current, may reach an appreciable fraction of the thermal velocity, altering the electron drift velocity distribution from maxwellian to drift-maxwellian form.

Under these circumstances, it is important to recognize the signature of the drifting electrons in the double probe characteristic. [11]

A double probe consists of two electrodes that are inserted into plasma. The spacing between the probes must be small enough that the properties of the plasma can be taken to be constant over that interval. In the case of a cylindrical double probe, the electrodes are nothing more than two exposed lengths of wire.

In this work double home – made Langmuir probe was used to investigate the plasma column of glow discharge in argon gas and reactive precursor which was introduced into the plasma chamber. It composed with tungsten wire and the tip is cylindrical, covered with glass house for insulation, the diameter and length of the tungsten probe out side the glass house are 0.1 mm and 1.2 mm, respectively

The electrical circuit and voltage – current characteristic of the double probe method is shown in Figs.1 and 2 respectively.
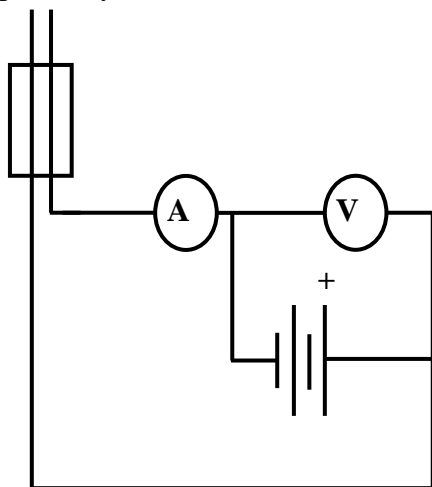

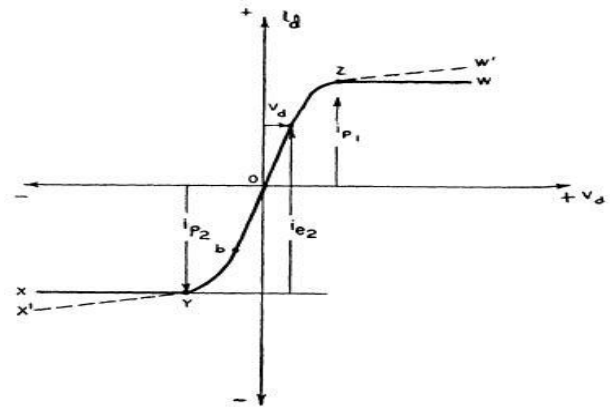*Fig. 1: Basic double probe circuit.*

Fig. 2: Schematic diagram of the double probe characteristic

The electron temperature has been determined from the way in which I_d, the probe current, varies with V_d, the probe voltage, by floating double probe method of Dote [11] which was modified the equivalent resistance method by Johnson and Malter [7].

The expression for electron temperature (Te) is given by [11]:

$$T_e = \frac{e}{k} \frac{\sum I_{PO}}{4\left\{\left(\dfrac{dI_d}{dV_d}\right)_O - 0.82S\right\}} \qquad (1)$$

where, Te=the electron temperature, e =the electron charge, k=Boltzmann constant, $\sum I_{PO} = I_{P_1O} + I_{P_2O}$,

$\left(\dfrac{dI_d}{dV_d}\right)_O$ = Slope from the current – voltage characteristics

From the characteristic curve the ion saturation current (I_{sat}) is given by:

$$I_{sat} = \frac{1}{4} A e n_e \bar{v} \qquad (2)$$

where A =effective electron or ion collection geometrical area of the probe, n_e =electron density and $\bar{v}$ =mean speed. The factor $1/4$ in the above equation is composed of two factors of $1/2$. One accounts for the fact that at the sheath edge the density is half the plasma

density. The other is merely the average of the direction cosine over a hemisphere.

The velocity distribution of each species can be represented by a Maxwell-Boltzmann distribution and the energy distribution quantified by a temperature. However, often the electron temperature is considerably higher than the ion and gas temperature, i.e. [6]

$$kT_e >> kT_i \approx kT_g$$

where T_i is the ion temperature and T_g is the gas temperature. In low pressure (<100Pa) plasmas, the gas and ion temperatures can be 300K while the electron temperatures may be over 20000K. In the literatures, the temperature and other energies are often presented in terms of electron volts (eV)[6].

The mean speed is given by:

$$\bar{v}_e = \sqrt{\frac{8kT_e}{\pi m_e}} \qquad (3)$$

where $m_e =$ the electron mass. Therefore, a simple rearrangement of equations (2) and (3) leads to an expression for the electron density:

$$n_e = 4 \frac{I_{sat}}{Ae\sqrt{\frac{8kT_e}{\pi m_e}}} \qquad (4)$$

Experimental Setup

In this work, the planer magnetron sputtering system was designed and fabricated. This system consists of two aluminum disc 8 cm diameter and 5 mm thick. Fig.3 shows the experimental set – up of this system.

The principle operation of this device is glow discharge. In addition this device is operated in a constant mode (where the external constant applied voltage 1 kV).

The planer magnetron sputtering in our design can be named (diode planer sputtering).

The chamber which was designed used with Edward's vacuum system

pumped by two stage rotary pump of Leybold company of Germany to a base pressure of about 10^{-2} mbar, after that it is pumped by oil diffusion pump of Edward company of Britain to a base pressure of about 10^{-5} mbar.

Two different gauges were used to measure the pressure. The Pirani gauge head of Edward company was used to measure the vacuum pressure of the chamber of about 10^{-3} mbar. The Penning gauge head made by Edward company was used to measure vacuum of about 10^{-6} mbar. Fig.4 shows the vacuum system.
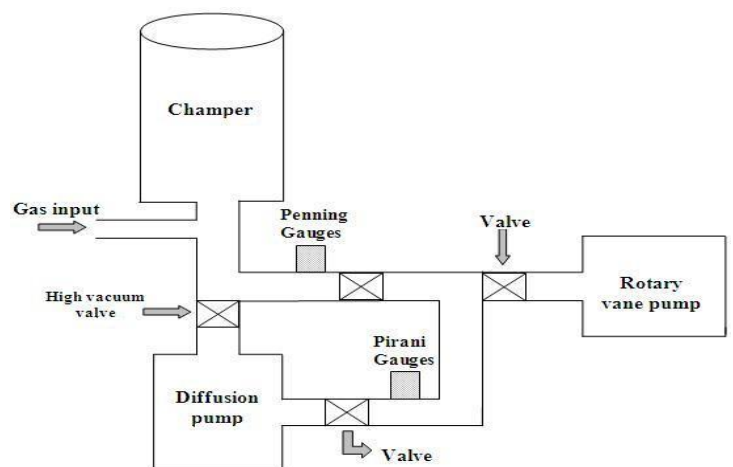

Fig. 3: experimental set – up

Fig. 4: The diagram of the vacuum system

Results and Discussion

To investigate the plasma parameters in the positive column region of the glow discharge, Langmuir double probe was situated in the center of plasma between anode and cathode. Fig.5 shows I – V characteristics curve of double probe at distances of 2, 3, 4 and 5cm between the two electrodes.

As a whole the experimental results show that the $I-V$ characteristics curve is symmetric because the probes have the same cross section. The maximum current that circulates for the double probe is similar to the ion saturation current.

The electron temperature can be calculated using equation (1). Figure (6) shows the electron temperature as a function of the distance between the two electrodes, this figure shows that the electron temperature decreases with the increasing of distance.

With the increase of distance between electrodes, electrons mean free path will become shorter. This will result in increasing of electronic inelastic collision and make the electron energy less.

Figs. 7 (a) and (b) shows the electron and ion densities as a function of the distance between the two electrodes, this figure shows that the electron density increases with the increasing of distance. The behavior of ions density is similar to that of electron but the value is higher.

When the distance increases, there are more neutrals present, hence the distance between collisions (mean free path) decreases and less energy is gained between collisions and consequently the increase in the number of collisions means the frequency of ionization will increase leading to an increase in the electron and ion densities.
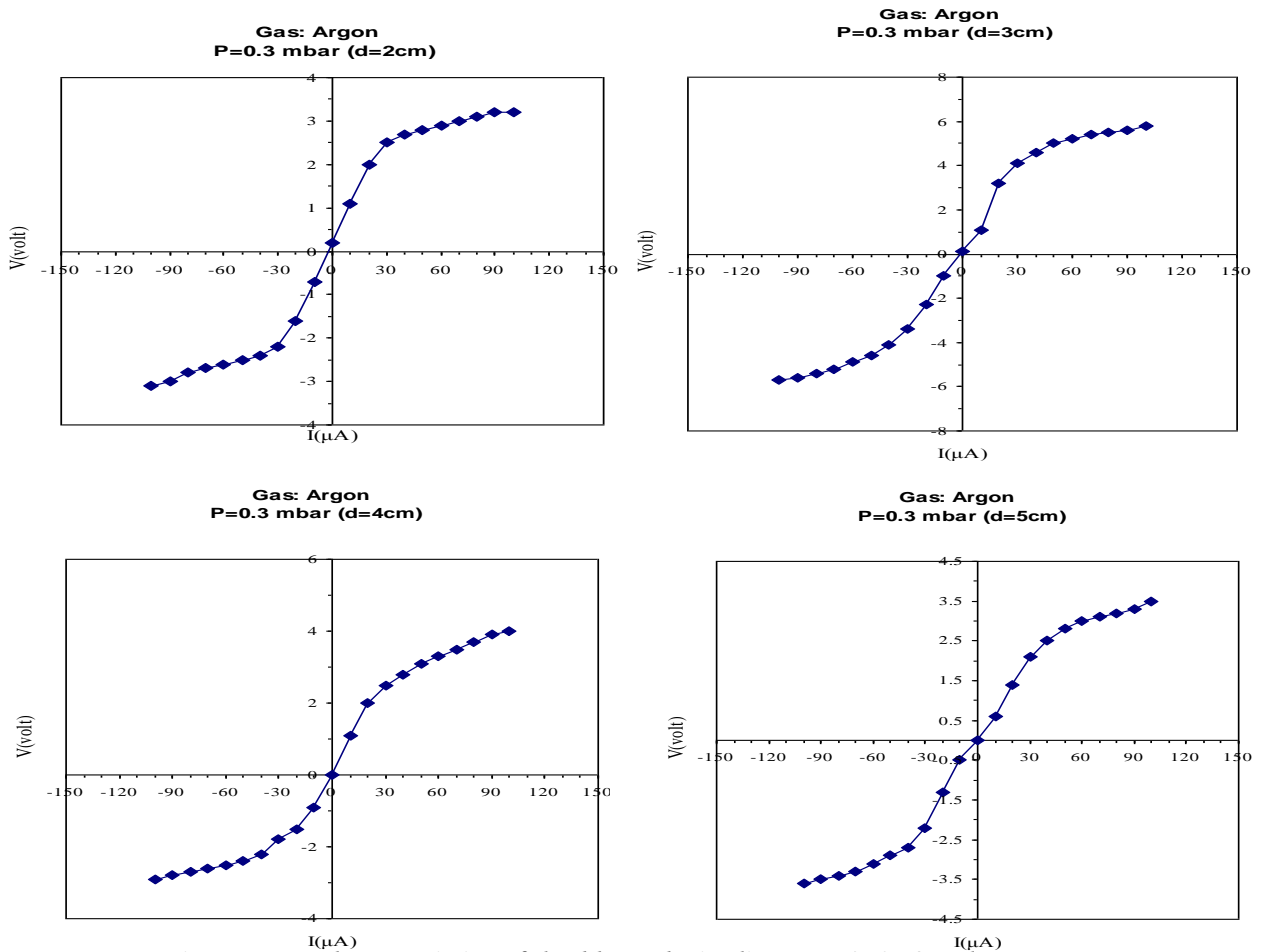

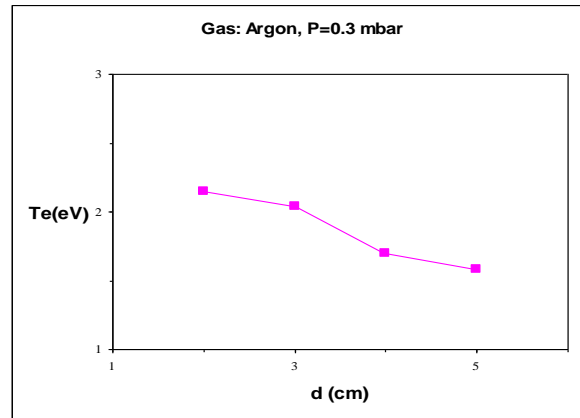*Fig. 5: I – V characteristics of double probe in distances 2, 3, 4 and 5cm.*

Gas: Argon, P=0.3 mbar

Fig. 6: The electron temperature as a function to the distance between the two electrodes.

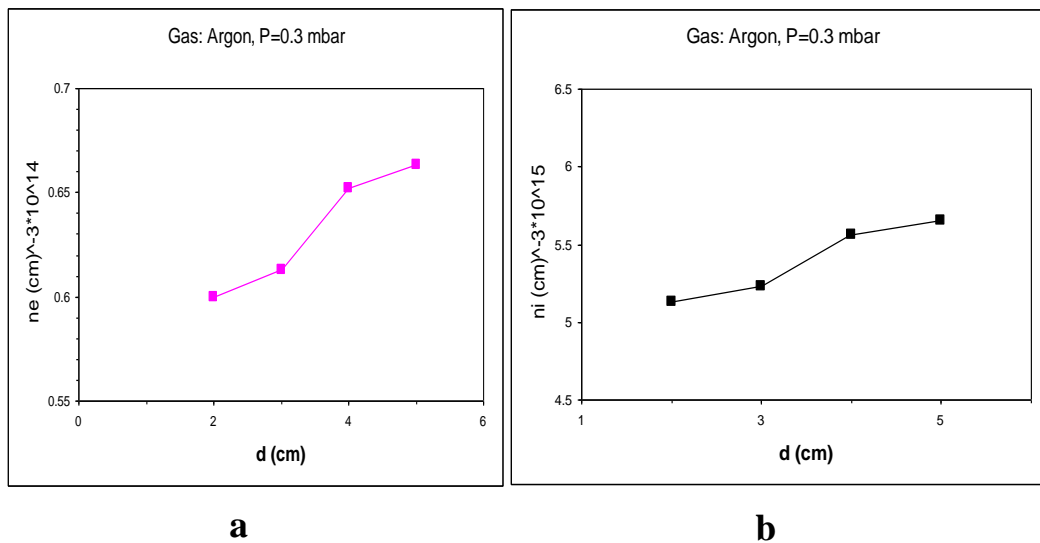**a**   **b**

Fig. 7: The relation between (a) electron densities, (b) ion density, as a function to the distance.

References

1- F.Francis Chen and Jane P. Chang: Introduction of plasma science (Los Angeles, 2002), P.1.

2- A.Krall, Nicholas, Trivelpiece, and Alvin W.: Principles of plasma physics (San Francisco Press, Inc., 1986), P. 2.

3- John Howard: Introduction to plasma physics (Plasma research laboratory, Research school of physical sciences and engineering, Australian national university, 2002), P. 7.

4- A. Dinklage, T. Klinger, G. Marx, L. Schweikhard: Plasma physics (Lect. Notes phys. 670, Springer, Berlin Heideelberg, 2005), P. 5.

5- D. M. Manos and H. F. Dylla: Diagnostics of plasmas for Materials processing (Academic Press, Inc., 1989), P. 117.

6- R. Shishoo: Plasma technologies for textiles (Boca Raton Boston, New York, Washington, 2007), P.7.

7- E. O. Johnson and L. Malter: Physical Review, 80 (1950) 58.

8- F. F. Chen: Plasma diagnostic Techniques(Academic,NewYork,1965) , P.180.

9- S.S.Pradhan and D.C.Jana: Journal of Physical Sciences,10(2006) 158.

10- C. Das, D. C. Jana, A. K. Hui: Journal of Physics, 208, (2010) 012127.

11- Toshihiko Dote: Japan J. Appl. Phys., 7 (1968) 964.