



ARGON HELIUM MIXTURE PLASMA CHARACTERIZATION BY ELECTROSTATIC PROBE

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RESUME

Les paramètres électriques d'un plasma de mélange helium-argon sont déterminés par la technique de la sonde de Langmuir. L'effet du tau d'hélium R et la puissance radio fréquence RF sur ces paramètres est étudié. Dans toutes les expériences, la pression totale est maintenue constante, elle est égale à 0,1 mbar et la puissance RF varie de 50 W à 100 W. Notons que la température électronique du plasma du mélange helium argon est de l'ordre de 11 eV, elle est plus élevée que celle des plasmas d'argon et d'hélium purs. La densité électronique augmente avec la puissance RF d'une part, et d'autre part, elle est moins élevée que celle du plasma d'argon.

MOTS-CLES: Plasma, Puissance RF, Sonde électrostatique, Tau d'hélium.

ABSTRACT

The electrical parameters of helium-argon mixture plasma were determined using the Langmuir probe. The effects of helium rate R and RF power on these parameters have been studied. In all cases, the total pressure is maintained constant, it is equal to 0,1 mbar and RF power varies from 50 W to 100 W. It is found that the electron temperature of the helium-argon mixture plasma (11 eV) is much higher than that of the argon and helium pure plasmas (3 and 4 eV respectively) and the electron density is much lower than that of the argon plasma on the other hand. It is also found that the electron density increases with the RF power.

KEYWORDS: Plasma, RF power, Electrostatic probe, Helium rate.

1. INTRODUCTION

The interest of plasma processing study is due to its important application in various fields of technology, such as the chemical analysis of solids, etching in semiconductors system, material processing [1-3], sputtering deposition [4-6], etc. In the last application, the growth kinetics of sputtered film depends on the types of particles making up the plasma, flux and energies [7]. In other words, the study of the sputtered thin films properties requires the measurement of the plasma parameters (plasma

potential V_0 , floating potential V_f , electron temperature T_e , electron density N_e , ion density N_i , etc). Despite the large number of scientific works, the relationships between sputtered films properties and plasma parameters are not fully understood. However, several techniques such as Optical emission spectroscopy (OE) [5, 8], Absorption spectroscopy [8], Self excited electron resonance (SEER) [9], Langmuir probe (LP) [10-16], etc. are available to determine plasma parameters.

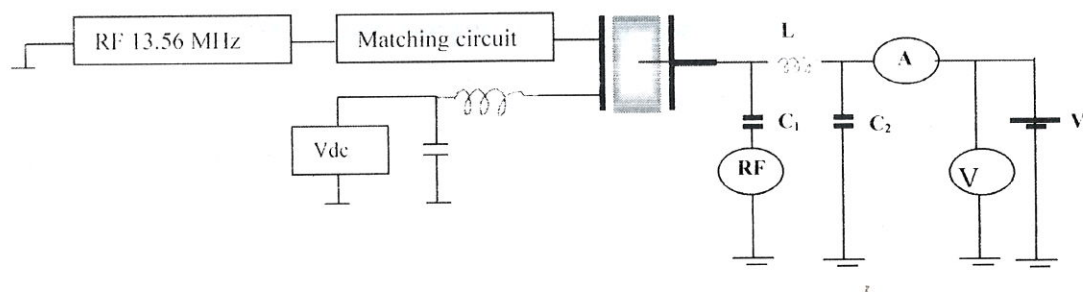


Figure 1: Schematic of RF sputtering circuit with electrical Langmuir probe circuit.

The probe technique is an excellent tool and simple means for plasma parameters measurements, it was introduced by Langmuir in the 1920.

Its use in RF plasma has induced two problems [17-18]: the RF interference and contamination effect. These problems can be overcome respectively by tuning and applying a large bias voltage to the probe. Moreover, the experimental data were collected quickly.

In the present work, we have characterized the binary mixture plasma of two inert gases of helium and argon. The effects of helium rate R and RF power on the He-Ar mixture plasma parameters have been studied, where the helium rate R is defined as being the ratio of the partial pressure of helium to the total mixture pressure and given by:

$$R = \frac{[He]}{[He] + [Ar]}$$

2. EXPERIMENTAL PROCEDURE

The plasmas studied were generated in a sputtering machine of Alcatel SM 601 type constituted of two circular parallel electrodes 5 cm apart. The cathode used as a target is coupled with an RF power generator (13.56 MHz) flexible to 400 W, the anode used as a substrate and stainless steel deposition chamber are grounded. The system operates in capacitive mode and the thin films are elaborated by the sputtering of a solid target.

The RF power was applied through a 50Ω impedance shielded wire, all the applied power was dissipated in the plasma when the impedance of the system target-plasma – substrate and the feeding wire are equal.

This situation can be achieved by the matching network (Fig. 1) (for more details see [19]).

Before the introduction of gas, the vacuum chamber is evacuated up to 10^{-6} Torr.

To carry out the electrical characterization of our plasma a cylindrical electrostatic probe is used. It is a 0,2 mm diameter, 10 mm length tungsten wire, held in a Pyrex tube. The Langmuir probe was inserted through one of the side flanges of the deposition chamber, and was positioned at the center of the chamber (at 2,5 cm from each electrode).

It's known that in RF plasma, the plasma potential oscillates with the same waveform which is applied to generate the plasma. The synchronization in phase and module of the probe bias potential with that of plasma potential is ensured by a compensation passive system (Fig. 1).

For each power, the probe voltage V_p ranges between - 60 V and + 60 V and for each probe potential V_p , we measure the continuous part of the probe collected current I_p . Before performing a measurement, the probe is highly biased in order to clean it by electron impact. The graphical representation of these currents I_p as a function of the probe bias potential V_p , allows to obtain the probe characteristic $I_p(V_p)$ (Fig. 2). This characteristic contains three distinct regions, electron saturation region, ion saturation region and transition region.

3. EXPRESSION OF DATA ANALYSIS

When the emission of secondary electron from the probe, the probe etching and the bombardment of the probe by high energy electron are disregarded, the equations allowing the determination of plasma parameters are as follows:

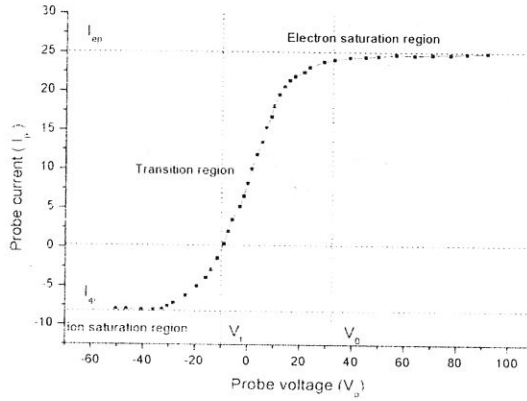


Figure 2: Langmuir probe characteristic $I_p(V_p)$.

The floating potential V_f corresponds to the potential for which the probe current is zero ($I_p|_{V_f} = 0$). the plasma potential V_0 corresponds to the inflection point of the characteristic $\left(\frac{d^2 I_p}{dV^2}\right)_{V=V_0} = 0$ [20]. the electron

density N_e and the electron temperature T_e are calculated respectively from Eqs. 1 and 2.

$$N_e = \int_0^\infty F(E) dE$$

(1)

$$T_e = \frac{2}{3} \frac{\int_0^\infty E F(E) dE}{N_e}$$

(2)

Where $F(E)$ is the electron energy distribution function (EEDF) and is given by the Druyvesteyn formula [21]:

$$[F(E)]_{E=e(V_0-V_p)} = \frac{-4}{A_p e^2} \left(\frac{m_e (V_0 - V_p)}{2e} \right)^{1/2} \frac{d^2 I_p}{dV_p^2}$$

(3)

Where A_p is the probe surface, m_e and e are electron mass and electron charge respectively.

4. RESULTS AND DISCUSSION

The plasma potential and floating potential versus the helium rate R for different RF powers are reported in Fig. 3. As can be seen in this figure, the plasma and floating

potentials are included respectively in the range of 23 to 24 V and 9 to 10 V, therefore the difference is practically constant (14 V). Thus the helium rate and RF power have only a little influence on the plasma and floating potentials. This suggests that the RF power and pressure influence more the cathode sheath thickness and self bias potential.

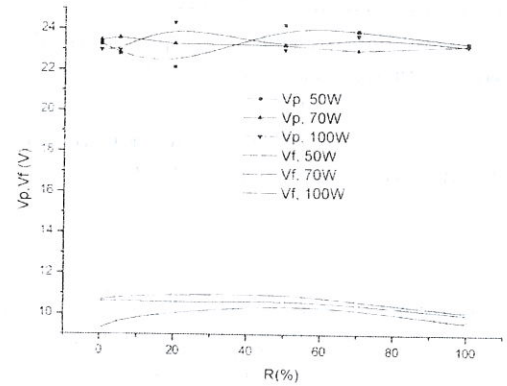


Figure 3: Variation of plasma potential V_0 (full symbol) and floating potential V_f (empty symbol) versus the helium rate R and for different RF powers.

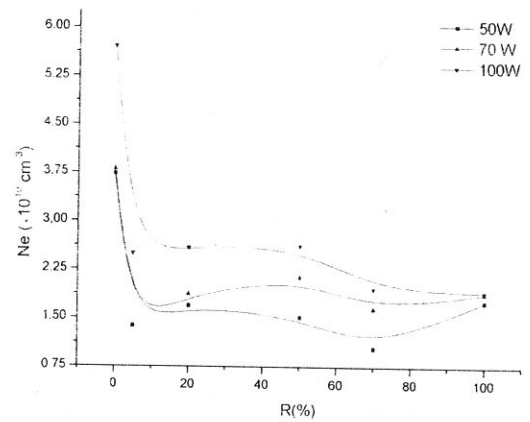


Figure 4: Variation of electron density N_e versus the helium rate R and for different RF powers.

The curve of the electron density versus the helium rate for different RF powers is shown in Fig. 4. From this figure we note that, for a pure argon plasma ($R=0\%$), the electron density N_e is rather high, however as soon as helium is introduced, the value of the electron density falls with relatively low values. This reduction can be explained as follows: For weak helium rates, the argon atoms are more dominating in the deposition chamber. Thus, the electrons see more argon atoms than helium atoms, on the other hand, the electron – argon atom collision cross section is higher than that of electron – helium atom, and the argon ionization energy ($E_{iAr} = 15,76\text{ eV}$) is lower than that of helium ($E_{iHe} = 24,56\text{ eV}$). Thus, the electron density decreases with increasing helium rate.

Fig. 4 shows also that the electron density increases with RF power. This is related to the fact that there is also an increase in the self bias potential with RF power [19] and the Surf effect [22-23].

Fig. 5 presents the evolution of the electron temperature T_e versus the helium rate R for 50 W, 70 W and 100 W RF power. From this figure, we note that under equivalent conditions, the electron temperature of a pure argon plasma ($R = 0\%$) is lower than that of a pure helium plasma ($R = 100\%$). The measurements taken in these pure plasmas respectively give T_e values ranging between (2,7 – 2,8 eV) and (3,5 – 4 eV).

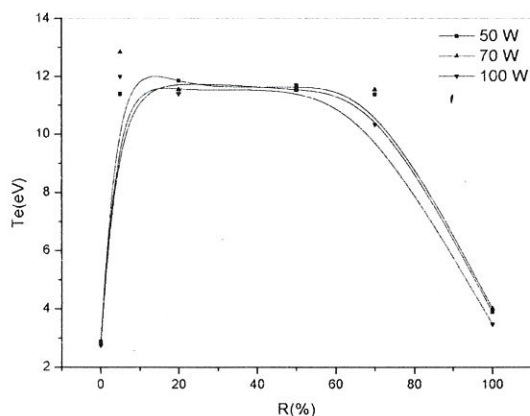
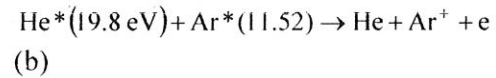
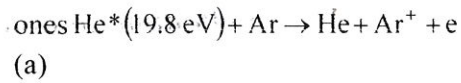


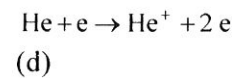
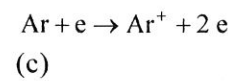
Figure 5: Variation of the electron temperature T_e versus the helium rate and for different RF powers.

It is noted that the electron temperature in the helium argon mixtures plasmas is much higher than that of the helium and argon pure plasmas; its value is about 11 eV and which is independent of the RF power. This phenomenon is mainly related to the Penning effect between two different atoms, where these two last



These reactions led to the creation of the high energy electron, which is higher when there are reactions between metastable (b) types.

For R ranging from 0% up to 70% and at the fixed power, the variation of the electron density with helium rate is the inverse of the electron temperature variation. The opposite variation of both parameters shows that in helium-argon mixture plasmas, the transferred energy from the discharge to the active species (electrons) remains mainly stored in the form of electrons energy and will not be transmitted to ionize the neutrals; therefore, the majority of the electrons are created by Penning effect. On the other hand, in the argon and helium pure plasmas the electron energy is transmitted to make up the gas (in the ionizing ones) and the electrons are created by direct ionization process:



In other words, if a most electron energy is transmuted to the ion creation, electrons will be cooled, but if the electron energy is not transmuted to the gas atoms, the electrons remain energetic.

5. CONCLUSION

Characterization of helium-argon mixture plasma was determined using a cylindrical electrostatic probe. The probe tip was positioned at the center of the deposition chamber. Measurements showed that in the



plasma mixture, the electron temperature is much higher than that of pure gases; its value is about 11 eV. We note that the RF power have no effect on this parameter. The electron density for pure argon plasma ($R=0\%$) is rather high, but as soon as a small quantity of helium is introduced, it falls with relatively low values. The plasma and floating potentials are unaffected with neither RF power nor helium rate.

LIST OF SYMBOLS

Symbol	Definition	Symbol	Definition
A_p	Probe surface	N_e	Electron density
Ar	Argon	N_i	Ion density
e	Electron charge	OE	Optical emission spectroscopy
EEDF	Electron energy distribution function	R	Helium rate
E_{iAr}	Argon ionization energy	RF	Radio frequency
E_{iHe}	Helium ionization energy	SEER	Self excited electron resonance
He	Helium	T_e	Electron temperature
I_p	Probe current	V_0	Plasma potential
LP	Langmuir probe	V_f	Floating potential
m_e	Electron mass	V_p	Probe voltage

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