SOME ASPECTS ON THE DEPENDENCY OF PLASMA COATING WITH PRESSURE

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ABSTRACT.

A phenomendogical approach to plasma coatings (deposition on solid surfaces) and its pressure dependency is described. Specific properties of the near to surface plasma layer such as deposition rate and efficiency are considered. Theoretical calculations are in agreement with experimental results for pyrocarbon deposition on graphite substrate.

1. INTRODUCTION.

The deposition phenomena on a solid substrate of pyrocarbon formed in a R.F plasma of propylene-argon mixtures are not well understood(1,4). Investigation of the plasma pressure dependency on the kinetics of deposition will provide additional information for a better understanding of the coating phenomena. The theoretical model(5-7) takes into account two groups of phenomena interrelated between them, namely :

1. Processes taking place in short lived hot spots (SLHS) formed by impinging accelerated ions on the solid surface by high electric field strengths in the thin sheath(5,6). The SLHS can lead among others to :
   (i) emission of electrons from the surface to the plasma layer. They are accelerated by the high electric field strength in the streath.
   (ii) sputtering excited and non excited atoms, molecules and clusters from the surface into the plasma layer.
   (iii) reactions on the surface accompanied by a change of composition and particle density.
2. In the plasma layer (PL), adjacent to the surface, of thickness ΔL due to the processes described above (1) the following may occur:
   (i) interactions between plasma particles with the particle emitted from the surface as described in (i)-(ii) above (1).
   (ii) interaction between the RF electric field with the one developed near the surface .

(iii) specific hydrodynamic boundary conditions in the PL.

The above 1 and 2 phenomena result in a complicated non uniform space and anisotropic structure of the PL. Generally, those are the phenomena occuring in a plasma-wall interaction(7). In this study the PL properties will be discussed only in connection with the pressure dependence of coating (deposition) parameter.

2. THEORETICAL MODEL AND RESULTS.

The RF plasma considered is a hydrocarbon (C_3H_6)-argon mixtures at pressure (P) ranges from 1 to 10 torr., with flow velocities (v) from 0.5 to 3 $cm.s^{-1}$ and with RF input power of 0.6 Kw. Fig.1 shows the experimental set-up considered here. The electric field strength in the plasma bulk, E_b, is about 50 $V.cm^{-1}$. Under such conditions the ratio P/E is small and equals with the range 2 (10^{-2} - 10^{-1}) $torr.\ cm.V^{-1}$.

The coefficient of ionization in the plasma bulk, α_{ib} can be expressed in a series form :

$$\alpha_{ib}\,(P/E) = C_1 P\ [1 - C_2\,(P/E) + C_3\,(P/E)^2 + \ldots] \qquad (1)$$

Considering only the first two termes , C, and C_2 are coefficients obtained from experimental data.

In the PL, as stated , the condition are more complex than in the plasma bulk. The value of α_{iL} will depend, besides on the P/E ratio, also on P and E separately (spectroscopical emission measurement from PL(7) have confirmed this statement); hydrodynamic boundary conditions affects the transport phenomena, the surface reaction kinetics and the residence time $\delta t \approx L/v$ among others. Moreover, α_{iL} can as well be influenced by the velocity of the gas flow, v(9,10). Phenomenologically taking them into consideration, α_{iL} may be expressed as :

$$\alpha_{iL}\,(\frac{P}{E}, P, E, v) = C_1(P,E,v)\ [1 - C_1(v)\,(\frac{P}{E}) + C_2(v)(\frac{P}{E})^2 + \ldots] - \quad (2)$$

Besides the coefficients C_1 and C_2 now depending on P.E and v Eq(2) is similar to Eq (1).

If β_{iL} is the recombination factor in the PL, the degree of ionization a_{iL} is proportional to $a_{iL} \sim \alpha_{iL} / \beta_{iL}$ or to C_1/β_{iL}. The recombination factor β_{iL} depends only on P.

The flux, j_i, of ions reaching the substrate surface can be set to be proportional to $j_i \sim a_{iL}\,\underline{n}\,\bar{u}_i$ (n is the total number of particles, cm^{-3}, in the plasma layer and $\bar{u}_i$ the mean velocity of ions in the PL). The electron flux from the surface into the plasma layer is $j_e \sim \gamma_e j_i$, where γ_i is the coefficient of electron emission resulting from the bombardment of j_i on the surface. The mass deposition (coating) rate, $\nabla G/\nabla t$ and the efficiency of deposition b may be written as :

$$\frac{\Delta G}{\Delta t} = B \frac{\Delta M}{\Delta t} \cdot \frac{a_{iL}}{f(v)} = B \frac{\Delta M}{\Delta t} \frac{\alpha_{iL}}{\beta_{iL} f(v)} \qquad (3)$$

and

$$b = \frac{\Delta G/\Delta t}{\Delta M/\Delta t} \quad B \frac{\alpha_{i,L}}{\beta_{i,L} f(v)}$$

B is a coefficient of proportionality : f(v) is a certain increasing function of the flow velocity. This unknown function, f(v) needs an ample discussion; as a first approximation it is assumed f(v) $(v+v_o)^2$: $\Delta M/\Delta t$ is the mass input rate of material (C_3H_6 for example) for coating.

$$\frac{\Delta M}{\Delta t} = m.n_m \; v.s = \frac{m.P_m}{kT} \; . \; v.s. \qquad (4)$$

where, P_m is the partial pressure of the coating material, n_m is the concentration in the P.L, cm^{-3}, of the coating material.
For C_3H_6 , m = 42 and using $\eta = 0.86$ as the relative mass of C_3H_6 directly used in the coating one rewrite Eqs(3) and (3a) as :

$$\frac{\Delta G}{\Delta t} = BC_1 S \quad \frac{n_m}{n} \quad \frac{\eta \, m}{\beta_{iL} \, KT} \quad \frac{v}{(v+v_o)^2} \quad P \left[1 + C_1\left(\frac{P}{E}\right) + C_2\left(\frac{P}{E}\right)^2 + \ldots\right] \; -(5)$$

and the efficiency of coating b :

$$b = \frac{B \, a_{iL} \eta}{(v+v_o)^2} = \frac{B \, C_1 \, \eta}{\beta_{iL}(v+v_o)^2} \left[1 - C_1\left(\frac{P}{E}\right) + C_2 \left(\frac{P}{2}\right)^2 + \ldots\right] \ldots\ldots \qquad (6)$$

The pressure dependent $\frac{\Delta G}{\Delta t}$ has a maximum at $P = P_o$ as shown in Fig.2, satisfying the equation,

$$\frac{\partial}{\partial P}\left(\frac{\Delta G}{\Delta t}\right) = 0 \quad \text{or} \quad \frac{\partial \ln (C_1/\beta_{i,L})}{\partial \ln P} = -\left[1 - 2 \, C_2 \left(\frac{P}{E}\right) + \ldots\right] \ldots \qquad (7)$$

The theoretical model of $\frac{\Delta G}{\Delta t}$ and b will be shown to be in agreement with the experimental results plotted in Figd 2 and 3..

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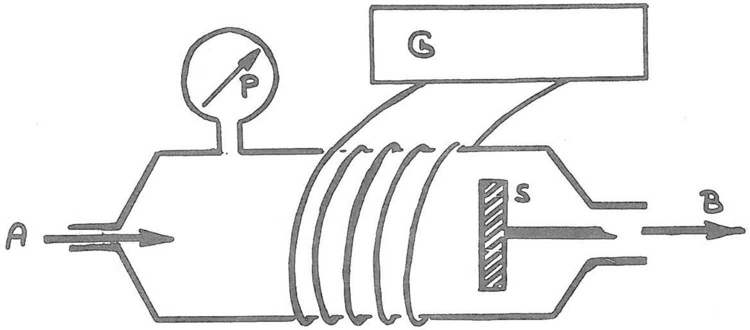

Fig.1 . Deposition Cell.
A-gas inlet; B-to vacuum pump; P-pressure gauge;
G-RF generator; S-graphite sample.

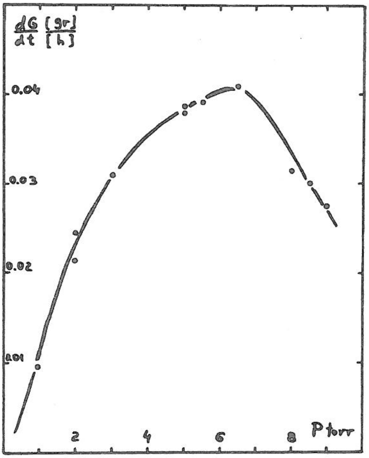

Fig.2. Deposition rate vs. pressure . ($Fl_{C_3H_6} = 22800\ cm^3h^{-1}$)

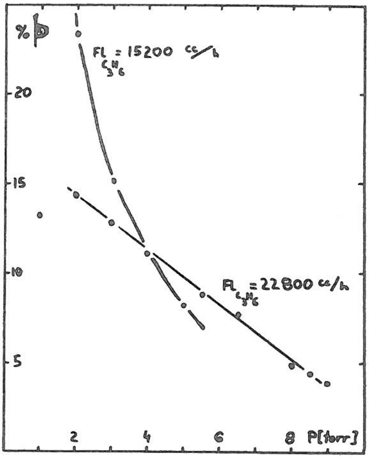

Fig.3. Deposition efficiency vs. pressure.