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An effective approach for designing a low pressure DC glow discharge plasma reactor

M.F. Bekkara [a], [*], Y. Benmimoun [a], [**], A. Tilmatine [b], K. Miloudi [a], S. Flazi [c]

[a] L.S.T.E Laboratory, M.S Mascara University, BP 305 Mascara, 29000 Algeria
[b] APELEC Laboratory, Djillali Liabes University, Sidi-Bel-Abbes, Algeria
[c] LHTDE Laboratory, University of Science and Technology of Oran USTO-MB, Algeria

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ABSTRACT

Most plasma reactors are designed for research purposes and they are less appropriate for industry. To facilitate the engineering of an industrial reactor, an effective approach based only on the calculated Paschen curve, the simulation of the electric field and the breakdown reduced field is proposed. The results show that the experimental Paschen curve is different from the theoretical one; consequently the recalculation of the electric parameters is discussed. The experimental voltage/Current characteristic is used to identify the abnormal glow discharge regime and also to correlate the visual aspect of the discharge with its regimes.

1. Introduction

The cold plasma techniques have been greatly developed in recent years, especially those such as thin films deposition using sputtering. The main reason is the need to develop new materials for the requirements of the surface treatment in the fields of semiconductors, micro-electronics and especially photovoltaic.

Besides, an attention is specifically drawn to the development and realisation of projects such as the Sahara Solar Breeder (SSB) in the Algerian desert and where are located the highest solar reservoirs in the world. The latter project will tackle the issues on solar cell design technology with a particular focus on the utilisation of Sahara silicon sands. Thus, the need to develop the technologies for silicon thin film deposition with plasma reactors is increasingly felt [1–4].

There are many types of plasma reactors in the world; though, the designing is still very difficult to achieve.

Till now they are generally used in research field and in measuring internal and external cold plasma parameters (see for example ref [5] where a plasma reactor has been constructed just for a DC glow discharge diagnostic).

Noting also that some contributions to facilitate the industrialization of the plasma reactors are performed like in Ref. [6] where the authors tried to bridge the gap between the research and the processing oriented plasma reactors by the construction of a multi-reactor system.

Except the latter, till now, there is no specific procedure for the design of plasma reactors which witnesses their extrem complexity for industrialization. Our work is carried out in this view, ie to introduce this technology to the industry through a new and very simple design approach. The plasma reactor prototype is functional and it was used for an analysis relating to the ignition of the electrical discharge and its operating regimes correlated with the *U*/*I* characteristic.

2. Materials and design methods

The design of the cold plasma reactor includes the conception of a vacuum chamber equipped with electrodes and a sealed gas inlet system. The main design parameters are:

1) - The maximum interelectrodes distance evaluated before the conception.
2) - The type of chamber material which must resist to the pressure difference applied to its walls [7,8].

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[*] Corresponding author.
[**] Corresponding author.

E-mail addresses: fethi.bekkara@gmail.com, bekkara.fethi@univ-mascara.dz (M.F. Bekkara), ybenmimoun2000@yahoo.com, ybenmimoun@univ-mascara.dz (Y. Benmimoun).

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2.1. Interelectrodes distance

The plasma reactor is designed in a DC configuration, and has two electrodes “cathode and anode”, with an adjustable interelectrodes distance; the maximal interelectrodes spacing is calculated approximately because the final geometry of the reactor depends on it.

The Paschen curve is used to provide data on the ignition voltage of argon plasma according to the product of the interelectrodes distance d and the pressure p of argon gas inside the reactor. The sputtering operating parameters are chosen in a way that allows them to be localized as close as possible to the minimal product $(pd)_{min}$; this choice is justified by the fact that it is necessary to choose an ignition voltage V_b which is closest to the minimal breakdown voltage V_{bmin} in order to optimize the DC power supply [5,9,11,12].

To calculate the approximate interelectrodes distance, it must be ensured that:

1) For an optimization issue, a pd product located around $(pd)_{min}$ is chosen, knowing that: [13].

$$(pd)_{\text{min } Argon} = 1,1999 \text{ mBar.cm} \tag{1}$$

$$V_{b \text{ min } Argon} = 137\text{V} \tag{2}$$

2) The operating pressure of sputtering should be set approximately around: [14,19].

$$p_{Argon} \approx 10^{-1}\text{mbar} \tag{3}$$

From (1) and (3), the approximate distance d is:

$$d \approx 12\text{cm} \tag{4}$$

To facilitate the experimental study and to make the design more flexible, a variable interelectrodes spacing between 0 and 15 cm is chosen:

$$0 \le d_{chosen} \le 15\text{cm} \tag{5}$$

2.2. Mechanical stresses and construction material

The construction material of the vacuum chamber must resist the high mechanical stresses due to the different pressures exerted on the reactor walls. The reactor walls are subjected to a pressure difference, given by the following formula:

$$\Delta p = p_{outside} - p_{inside} \tag{6}$$

$$\Delta p = p_{Atmospheric} - p_{Argon} \tag{7}$$

$$\Delta p \approx 1.01325\text{Bar} \tag{8}$$

For safety reasons and to eliminate the risk of implosion during operation, relatively thick and solid steel is used as manufacturing material, knowing that:

$$\Delta p_{tolerated\ solidsteel} = 50\text{Bar} \gg \Delta p \tag{9}$$

The used solid steel type can withstand 50 bar, ie 50 times the pressure difference ΔP estimated in formula (8).

2.3. 3D design

The plasma reactor, Fig. 1, is mainly composed of:

1) A cylindrical tube (the body of the reactor).
2) Two thick discs used as lids.
3) Visualization windows.
4) A cathodic electrode system.
5) A controlled movable anodic electrode system.
6) Other parts (assembly, valves, connections, seals …).

2.3.1. Electrodes system

The cathode has been designed in such a way that the target could be replaced easily by another one with different material depending on the type of desired material for thin film deposition. The cathode is hollow and can house a possible cooling system and/or a magnetron system for other modes of reactor configuration. The anode, which is also a substrate holder is a simple steel disc which is made mobile with a sliding system, the mechanical system motion is assured by a small electric motor - located at the bottom of the mechanical assembly - and is controlled from the outside of the vacuum chamber allowing the adjustment of the interelectrodes distance without interrupting reactor operation.

2.4. Electric field topography

This stage consists in simulating electric potential and electric field within the reactor using the finite element method to predict ionization initiation and plasma generation. The system is geometrically symmetric, the Cartesian coordinates are sufficient for dimensioning.

The simulation was made for three interelectrodes distances: $d_1 = 4$ cm, $d_2 = 8$ cm and $d_3 = 12$ cm, see Fig. 2.

Dirichlet boundary conditions are chosen to validate the following assumptions:

1) The cathode and the target boundary surface potential carried to $V_{Target} = 600$ V.
2) The Anode surface is grounded.
3) The reactor walls have zero charge and are grounded.
4) The interior of reactor is considered as a plasmagene gas “Argon” and not plasma.

Simulation of the electric potential in the reactor shows that the interelectrodes distance diminution has as results the compression of the equipotential lines on the mobile anode side; this will

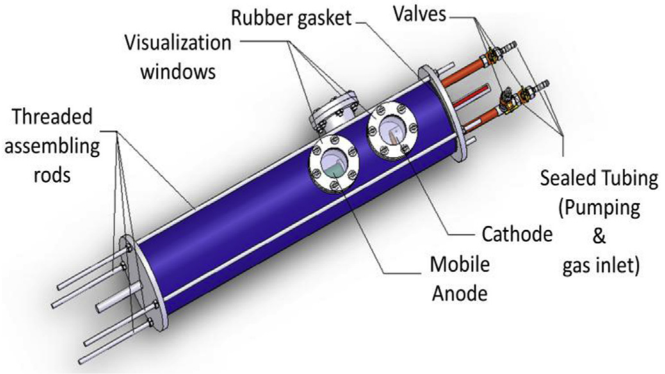

Fig. 1. Reactor assembly in 3D.

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