Simulation of some Mechanisms in Reflex Plasma Reactor

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1. INTRODUCTION

Nowadays, there is a considerable interest in plasma processing of materials involving industrial processes like etching, stripping, sputtering, thin film deposition etc. For those purposes, radio-frequency plasmas have been widely used [1]. More recently, a new type of plasma suitable for surface modification was developed starting from a modified PIG (Philips Ionization Gauge) discharge [2-5]. The discovery of the Penning discharge by Philips dates back to 1898, but experimental developments only began in 1936 with the construction of an ionization gauge by Penning [6, 7]. Up to now, the widen used applications have been high vacuum pumps gauges, ions or electrons sources, microwave sources and amplifiers, high voltage rectifiers and hot plasma installations [8, 9].

The basic principle of the discharge is that an electron within the discharge oscillates back and forth between two cold cathodes and spends a long time before it is removed from the discharge. This process leads to a high ionization degree, such as capacitive coupled, RF discharge plasma of the double-diode type [2].

2. EXPERIMENTAL SETUP

The most important aspect of the reactor is its design principle (Fig. 1), which contains two parallel plane cathodes, a ring anode between them and a Helmholtz system coils which generate the magnetic field [10, 11]. A detailed description of the reactor was presented in a previous paper [2].

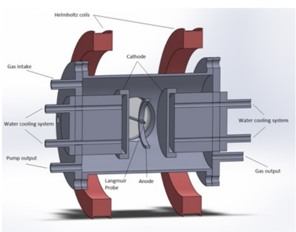

Fig. 1 Schematic representation of the reactor

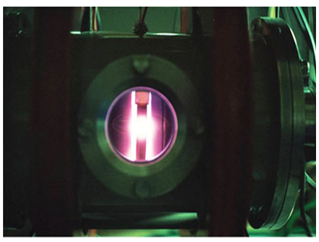

Fig.2 Bulk plasma

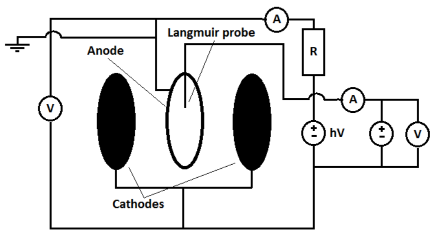

Fig.3 Electrical circuit

The electrons density was measured with a cylindrical Langmuir probe (Ø 2.5mm) parallel to magnetic field axis.

In order to determine the field distribution and particle trajectories, numerical simulations were performed. In the simulation process it was taken into account the argon plasma at a pressure of 0.5 Torr. After breakdown, the voltage is set to 500 V, while the discharge current was stabilized at 100 mA. The circular plane cathodes are made of stainless steel, aluminum or copper.

3. ANALYSIS

We used COMSOL Multiphysics to simulate the electrical field, electrical potential and the electron concentration inside the reactors core. For the electrical field we used MatLab plot function processing to illustrate the electric field (Fig. 4). The electric field combined with the axial magnetic field determined the drift velocity (Fig. 5) before the plasma state:

$$v_d = \frac{\vec{E} \times \vec{B}}{B^2}$$

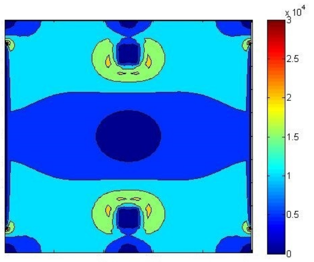

Fig. 4 Electric field

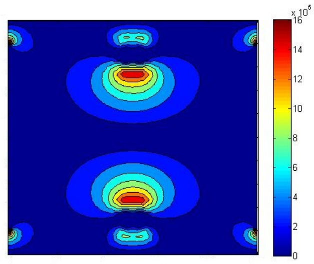

Fig. 5 Drift velocity in electric field with 125 Gauss magnetic field

Simulations of magnetic field shown, for a value of 125 Gauss, a difference between maximum and minimum values was smaller than 1% [10]. Therefore we presumed the magnetic field as constant.

Fig. 6 Simulated magnetic field

In *Fig. 7* we can see how the bulk plasma is being formed between the two cathodes and inside the anode ring. After plasma stabilization, in front of the cathodes, the density drops a low value due to a high velocity of electrons that ensures a stable discharge current. It presents a stable form of plasma with the highest value of electron density ($10^{17}m^{-3}$) in the middle of the core, confirming that the geometry of the discharge helps to insure a confinement of the plasma.

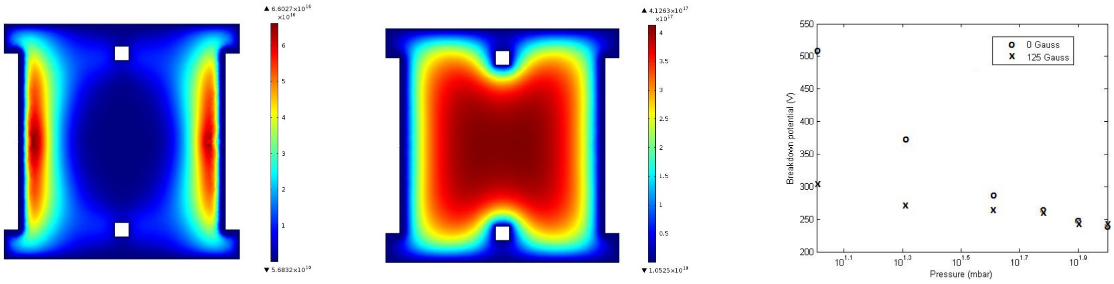

Fig.7 Different plasma states (from ignition to stable discharge) and breakdown voltage

The measured and simulated electron density varies in relation to the radius (*Fig. 8*) at a current of 30 mA. We can observe that the relative evolutions of electron densities presents similarities, in the bulk plasma the electronic concentration is relative uniformity followed by a high decrease near plasma extremities. At the same time we can be observed a difference between the absolute values, by a factor with a known value of 1:4.

The generated electrons oscillate between the two cathodes creating a so-called pendulum effect (*Fig. 9*) [4].

The reflex discharge axial magnetic field serves two purposes:

- the lifetime of the electrons is substantially higher due to the increase of secondary electron reflections between the two cathodes;
- the radial ion loss due to interactions with the side-walls is greatly reduced due to magnetic field confinement.

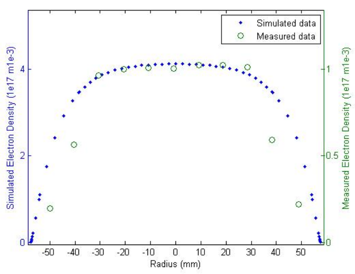

Fig.8 Radial variation of n_e for I=30 mA

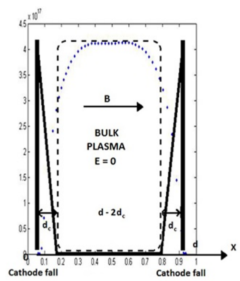

Fig.9 Schematic representation of pendulum effect and axial dependence of electron density

This effect is responsible for an increased ionization rate and amplification of discharge current (*Fig.10*) (Hollow Cathode Effect).

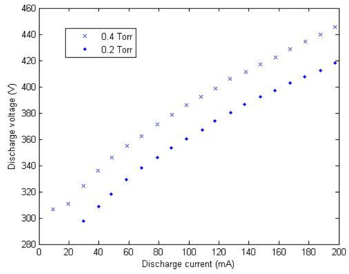

Fig.10 Typical current-voltage characteristic

4. CONCLUSIONS

The paper presents the modeling of the DC reflex plasma reactor and the simulation of some mechanisms in this type of plasma discharge. The electric field distribution, electron drift velocity before plasma state as well as electric potential and electron density evolutions were simulated. Correlations between experimental and simulated spatial distributions of electron concentrations were emphasized.

Our future task is simulation of breakdown characteristic in DC reflex plasma reactor.

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