THE RADIO FREQUENCY UNIPOLAR HOLLOW CATHODE DISCHARGE INDUCED BY THE RF DISCHARGE IN THE PLASMA-CHEMICAL REACTOR

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1. Introduction

In recent years there have been a considerable growing interest in the application of plasma-chemical processes in the surface and coating technologies, treatments of various materials and deposition of thin films. The task of the plasma-chemical technologies is now to develop such plasma devices that are suitable for deposition of composite thin films and multilayer structures. The other task is the deposition of thin films on the internal walls of cavities, holes and complex shapes of hollow substrates.

The results that have been obtained in the deposition of thin films by means of the radio frequency low pressure chemical reactor with the several supersonic plasma jet channels (RPJ) [1-5] indicate, that it is able to deposit the composite thin films and multilayer structures and also can in the particular case deposit the thin films onto internal walls of cavities, tubes and on the components with complicated shapes.

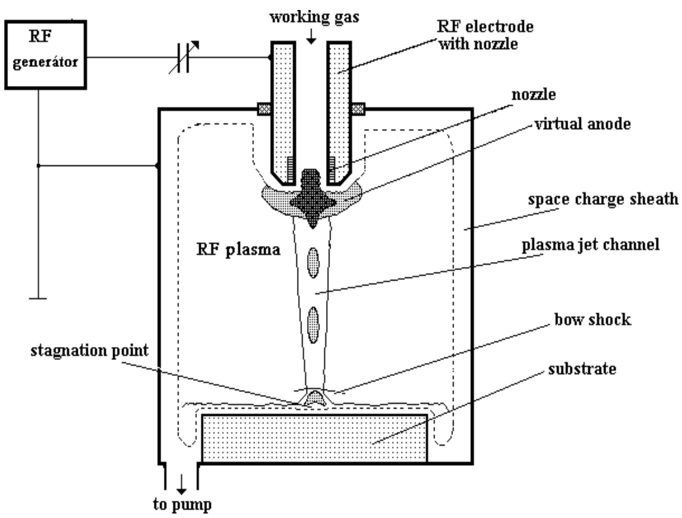

Fig. 1.

The working of the RPJ reactor has been described in detail in the reviews [1-5]. For this reason here will be described only briefly. In its simplest one plasma jet RPJ reactor consist the radio frequency plasma chemical reactor with two electrodes (see Fig. 1). The substrate is placed on the grounded electrode. The nozzle in the RF electrode connected with radiofrequency signal (13.56 or 27.12 MHz) admits the working gas into the reactor. which was continuously pumped by a combination of rotary vane pump and Roots pump. The working gas pressure is maintained at several tens Pa. At the RF power below a certain limit (for example < 20 W) only a primary RF discharge is generated in the reactor chamber. However at conditions when the RF power exceeds this limit an intensive unipolar RF hollow cathode discharge is generated inside the nozzle. The measurements presented in [1-5] show that the virtual anode is created in the neighbourhood of the space charge sheath around the RF electrode. The incoming working gas forces the hollow cathode discharge from the nozzle into the reactor chamber and the plasma of this discharge is add to the primary RF plasma in the reactor chamber. For supersonic working gas flow at the nozzle output the well-defined plasma jet is superimposed on the plasma of the primary RF discharge.

The results that have been obtained by deposition of thin films by means of RPJ reactor [6], [7] indicate that on of the main processes that determine the properties of deposited thin film is the sputtering of the nozzle material. The sputtering of the nozzle surface material is predominately caused due to bombardment of the surface cathode (nozzle) of the unipolar RF hollow cathode discharge by the positive ions. Because the frequency of the positive ions oscillation is in our experimental condition much smaller that frequency of the RF signal the sputtering yield of the nozzle material is a function of the DC component of the cathode current distribution along the hollow cathode (nozzle) axis.

The aim of the present work is to perform the measurement of the DC component of the cathode current along the cathode (nozzle) axis of the RF hollow cathode discharge generated inside the nozzle. This measurement is supplemented by the measurement of the axial dependence of the vibrational temperature inside the RF hollow cathode discharge On the base of these experimental results it is discussed the processes inside the RF unipolar hollow cathode discharge.

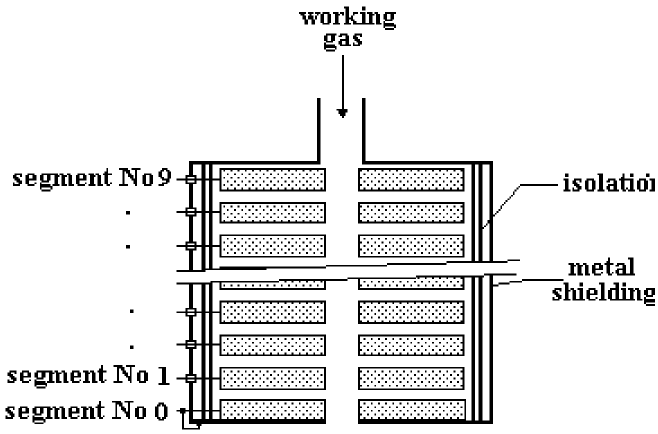

Fig. 2.

2. Experiment

To measure the axial distribution of the DC current component of the hollow cathode current along the axis a special RF electrode with nozzle has been developed. The electrode is divided into nine segments (see Fig. 2). The segmented electrode is made so that simulated the customary RF electrode as much as possible:

The thickness of the segments is 1.5 mm. Each segment is separated by an isolation plate the thickness of which is 0.5 mm. The segments are isolated from the plasma into the reactor chamber by the isolation sheet. The isolation sheet is cover by the metal sheet which is connect with the first segment (see Fig. 2 segment No 0). By this way only the current of the RF hollow cathode discharge flow on the segments.

During the measurement all segments are connected together except that one which DC current component is measured.

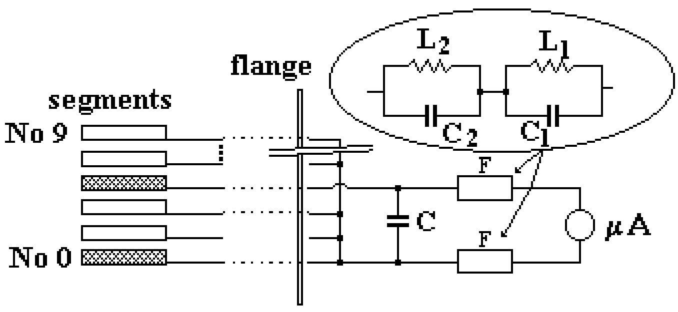

Fig. 3.

The DC component of the current to each segment is measured by the measuring set up which is shown on the Fig. 3. The influence of the RF field can brings the error to the obtained results. For this reason the measuring circuit is located in the place and configured in such a manner that this errors are minimised. The measuring set up consists with the DC small μ-ampermetr separated from ground and with two LC filters for RF frequency signal and second harmonic one. The capacitor shorts the RF current from the segments which DC current component is just measured.

The example of the results obtained for the supersonic flow of the working gas on the nozzle output is presented on the Fig.4. A similar results have been obtained for subsonic flow only the current to the segments are higher.

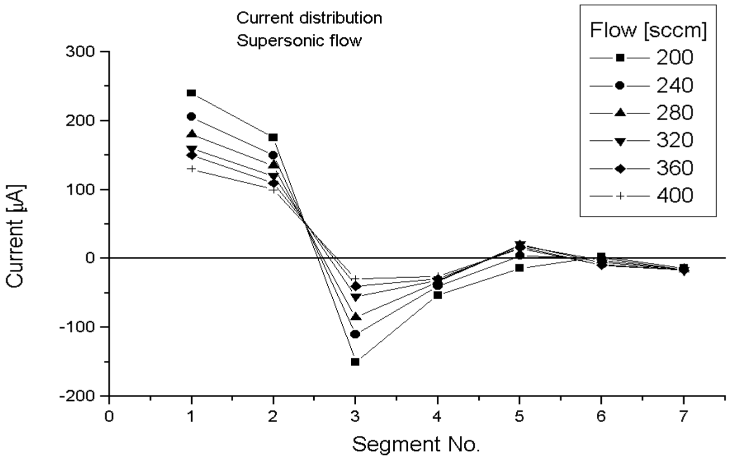

Fig. 4.

The measurements of the DC current distribution has been supplemented by the measurement of the vibrational temperature inside the nozzle (RF hollow cathode discharge). For this reason has been used the non-segmented RF electrode with longitudinal narrow schlier (thickness 1 mm). The electrode has been covered by quartz glass tube in order to hold the same flow properties as in the case without schlier. The internal diameter of this nozzle was 4 mm. The measurement of the emitted light and dispersion of this light has been performed by monochromator SPM2 with the equipments for scanning light signal. From the scanned spectrums have been possible to recognise vibrational bands of the second positive system for nitrogen molecule and calculate the vibrational temperatures of the excited state $C^3\Pi_u$. The longitudinal dependence of the vibrational temperatures on distance from edge of the nozzle in both directions inside and outside is possible to see on Fig. 5. The vibrational temperature can be possible assumed to be closer to the electron temperature.

3. Discussion and conclusion

The presented results show that the properties of the unipolar RF hollow cathode discharge differ from the properties of DC longitudinal hollow cathode discharge [8], [9].

The DC longitudinal hollow cathode is generated by DC voltage which is applied between the cylindrical cathode and anode of the discharge. For longitudinal DC hollow cathode discharge, it has been experimentally and theoretically found that the cathode current density monotonously decreases from the beginning of the hollow cathode [8], [9].

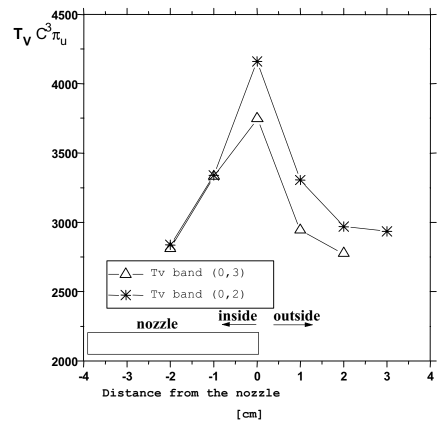

Fig. 5.

In the unipolar RF hollow cathode discharge according to the presented experimental results from the point of view of the DC current component can be found three different regions:

Due to the small diameter of the nozzle it can be expected that the RF field penetrates to the nozzle (hollow cathode) only near to its outlet. The experiment shows that in this region the potential drop across the cathode fall (space charge sheath) is sufficient that the cathode current is controlled by so called "hollow cathode effect". Thus in this nozzle's region the RF hollow cathode discharge is created. In this hollow cathode discharge the sputtering of the nozzle surface material is predominately caused due to ion bombardment of the surface cathode (nozzle) and the sputtered particles are involved in the plasmachemical processes inside the reactor.

Due to the small diameter of the nozzle the RF field does not penetrated upstream to the nozzle. Therefore it should be expected that upstream from the hollow cathode discharge region only afterglow plasma exists. This predictions is in agreement with the measurements of the vibrational temperature. This measurements show that the vibrational and therefore electron temperature upstream from the nozzle outlet rapidly decrease (see Fig. 5). In the second region closer to the RF hollow cathode discharge the DC electron current component predominated. Further in the third part the DC component of the current to the nozzle is approximately zero which manifest that the DC component of the potential drop across the space charge sheath is approximate equal to the floating potential. The experimental results presented in this paper show that only the region near the nozzle outlet contributed to the sputtering of the nozzle surface and is involved in the plasmachemical processes inside the nozzle. This result is in agreement with [10] where study of the nozzle outlet sputtering has been made.

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