# An Application of Non-self-Maintained Discharge for a Coatings Deposition[1]

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**Abstract – Non-self-maintained gaseous discharge, in which the vacuum-arc plasma gun is used as a source of supplementary charges, is characterized by a great currents and high values of ionization coefficient. This kind of discharge is widely adopted for thermo-chemical treatment of products, but still it is not used for a coatings deposition. In this paper we have shown the possibility of a-C:H films synthesis from a such discharge. The films obtained are characterized by high transparence and good adhesion to metal and dielectric substrates. In addition, such parameters as temperature and density of electrons, ionization coefficient and plasma potential distributions have been determined by the single probe method for the plasma of non-self-maintained discharge in nitro-gen and propane-butane mixture.**

## 1. Introduction

The glow and vacuum arc discharges are widely used for the coating deposition. Furthermore, there is also the non-self-maintained gaseous discharge in which the vacuum-arc plasma gun is applied as a source of supplementary charges. This type of discharge is characterized by high currents (dozens and hundreds of Amperes) and high ionization coefficient. At first this discharge was observed by *Sablev L.P.* and was called by him as *two-step vacuum-arc discharge* [1], featuring a metal-gaseous stage of plasma and a gaseous stage of plasma. Although this discharge has been using for the chemical heat treatment (in particular, for nitriding) of products nearly during 20 years [2], nevertheless many of its parameters still not have been investigated and what is more, there is absent the information about application of this discharge to coatings deposition processes. The last fact is concerned, evidently, with a low energy of a directional motion of ions in such discharge that results in a low speed of the coatings growth.

In this paper we present the results of the measurements of the some plasma parameters: electron temperature and density, ionization coefficient and the distribution of the floating potential, obtained by a single probe method in concrete vacuum system. We show also (on example by a-C:H films) that two-step vacuum-arc discharge may be used in the coating deposition technologies.

## 2. Experimental details

The measurements of plasma parameters was carried out at the vacuum-arc plasma installation of "Bulat"-type (Fig. 1), re-equipped for creating the dense and directed flow of gaseous ions. The vacuum-arc plasma gun, included cathode 1 and anode 2, was used here as a source of supplementary charges. Anode 2 is electrically connected with vacuum chamber 3 and is surrounded by the focusing electromagnetic coil. Vacuum-arc discharge was excited between cathode 1 and anode 2, supplying with electrons the discharge gap between the chamber 3 walls and anode 7. To prevent the penetration of metal ions to this discharge gap, the aperture of anode 2 was overlapped by the screen 4, that is practically impermeable to metal ions and permeable to electrons. Anode 7 was placed into the plasma concentrator 6, which is 20 cm diameter cylinder, surrounded by electromagnetic coil. Vacuum arc discharge and non-self-maintained gaseous discharge were excited with the aid of power sources PS 1 and PS 2 respectively. The parameters of gas plasma were measured by probe 5, which could move along the axis of concentrator 6 and revolve around it. The probe isolator could be prolonged, so the plasma parameters could be measured over the whole chamber 3. The volt-ampere characteristic of the single probe 5 was obtained with the aid of the power unit 9. Thin arrows show the directions of electrons drift motion and thick arrow show the motion direction of gaseous ions.

After the system was pumped to $5 \cdot 10^{-5}$ Torr the power supply sources PS 1 and PS 2 were switched on and the arc discharge between cathode 1 and anode 2 was excited. The arc discharge current was established on 100 A, and discharge voltage was near 27 V. The power supply unit PS 2 provides the voltage of 110 V between anode 7 and chamber 3 in absence of current. The gas is letting in through the admission valve (not shown) that enable to maintain a pressure inside chamber 3 on a specified level. The plasma parameters were measured for both gases: nitrogen and propane-butane mixture. During the measurements, the voltage between the anode 7 and the vacuum chamber 3 walls was maintained at a level of 60 V.

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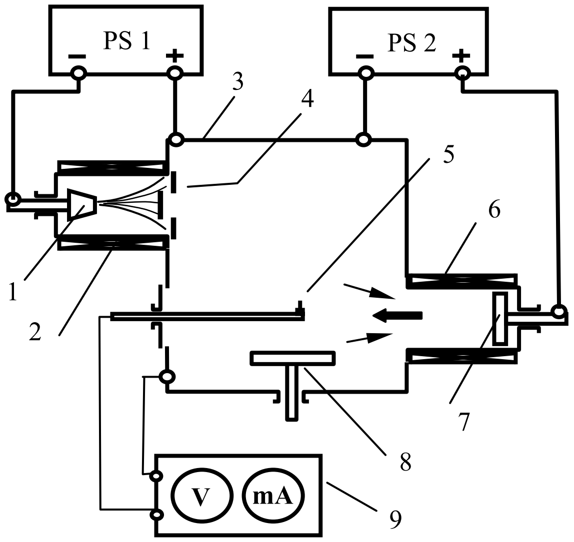

Fig. 1. Scheme of the experimental setup. 1 — Cathode; 2 — Anode; 3 — Vacuum chamber; 4 — Screen; 5 — Probe; 6 — Plasma concentrator; 7 — Anode; 8 — Fixture; 9 — Power supply unit. Power sources PS 1 and PS 2 supply arc and gaseous discharges

### 3. Results and discussion

The gaseous discharge between anode 7 and chamber walls 3 ignites starting with a pressure of $(1.4–1.6)\cdot10^{-4}$ Torr. The discharge current in nitrogen (Fig. 2) grows with a pressure and reach a maximum value of 120 A at $(4–6)\cdot10^{-3}$ Torr. The presence of the magnetic field in concentrator 6 (Fig. 1) with a strength of 50 Gauss, increases the discharge current 1.5 times as much of it in absence of magnetic field.

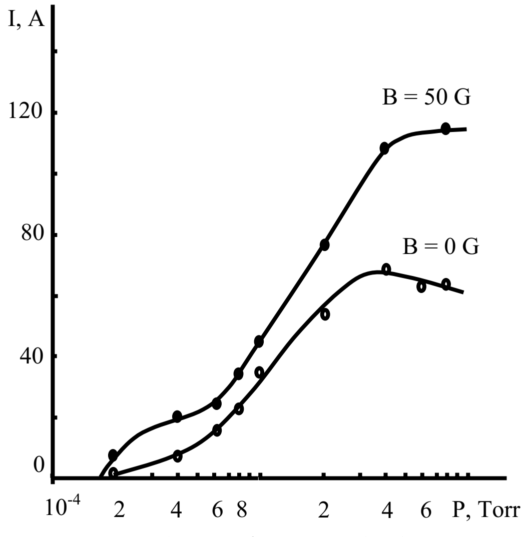

Fig. 2. Dependence of gaseous discharge current on the pressure of nitrogen for two magnetic field strengths: B=0 and B=50 Gauss. The gaseous discharge voltage is 60 V

The full ion current has a similar dependence on the pressure and reach up to 3 A at a distance of 10 cm from the outlet of concentrator. Under the same voltage (60 V) between anode 7 and vacuum chamber 3 the ion and electron currents in propane-butane mixture are near of 70 % of those in nitrogen.

Temperature and density of electrons was calculated from the probe volt-ampere characteristics that were obtained at numerous of points inside of the vacuum chamber 3 (Fig. 1). Maximum electron density was observed near the output of concentrator 6, whereas the temperature of electrons was practically identical over entire volume of the chamber.

The noticeable feature of two-step vacuum-arc discharge is that electron temperature (Fig. 3) can reach up to (22–25) eV that is several times higher than it is observed in vacuum arc plasma (1.5–4.5 eV) [3]. Obviously, so high temperature can have the primary electrons, which have been accelerated in the vacuum-arc plasma gun by a voltage drop (~27 V) between cathode 1 and anode 2 (Fig. 1) and have been scattered elastically on the gas molecules in the chamber. An increase in the pressure leads to the growing in the frequency of inelastic collisions that produce the excitation, dissociations and ionizations of the gas molecules. As a result the temperature of electrons is reduced. The maximum of electron density is observed in the region of $(1–4)\cdot10^{-3}$ Torr. The temperature of electrons in hydrocarbon plasma has a similar dependence on the pressure (not shown in Fig. 3) but approximately is 2 times less than in nitrogen discharge. This fact points out a greater number of the channels of energy transmission from electrons to the molecules in hydrocarbon plasma in comparison with the nitrogen one.

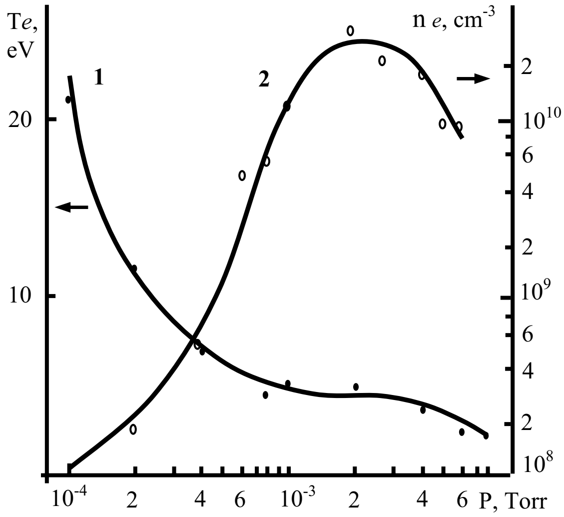

Fig. 3. Electron temperature (1) and density (2) in nitrogen plasma of non-self maintained discharge as a function of the pressure

The ion current density (Fig. 4) has a maximum at the axis of the concentrator 6 at outlet section and reaches up to 40 $mA/cm^2$ in a presence of magnetic field and is two times less in the absence of field. Ion current quickly decreases on moving to two sides from the outlet section; for example, it is two times less at a distance of 15 cm from the outlet of concentrator.

A great current in gaseous discharge indicates a high level of ionization coefficient. This parameter of two-step vacuum-arc discharge not had been measured earlier and, in view of high discharge current, it was surmised that it may reach up to dozens of percents. By knowing the density of electrons, one can calculate the coefficient of ionization as a ratio of electron density to the gas molecules concentration at different pressures. As it is seen in Fig. 5, the maximum of coefficient of ionization is observed at a pressure region of $8\cdot10^{-4}$–$2\cdot10^{-3}$ Torr and not exceeds of 0.1%. So, the coefficient of ionization in plasma of two-step vacuum-arc discharge is considerably lower than it is in vacuum arc discharge (where it may approach to 100 % [4]) and it is several orders higher than degree of ionization in glow-discharge column ($10^{-6}$–$10^{-4}$) % [5].

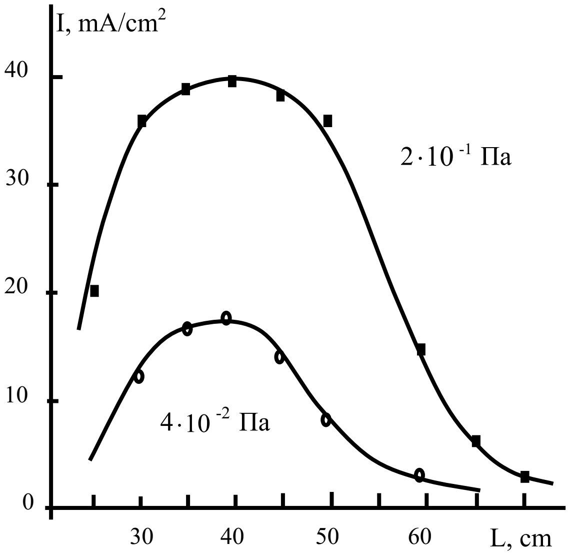

Fig. 4. Ion current density on the axis of the plasma concentrator as a function of the distance from anode. B = 50 Gauss

It is known, that a floating potential is several volts lower than a plasma potential is [6]. So, the distribution of plasma potential may be evaluated by information about course of the floating potential. The main feature of the floating potential distribution (Fig. 6) inside the experimental setup is its steep slope at the outlet of concentrator 6 (Fig. 1). Therefore, the largest value of the energy of ions may be expected just after output of concentrator, as later on, the ions will be lose in its energy due to collision with the gas molecules. It may be noted also the decrease in both: the value of plasma potential and potential gradient when the pressure is growing. Such tendency takes place in a pressure range from $2\cdot10^{-4}$ to $1\cdot10^{-2}$ Torr.

For the a-C:H films deposition, the non-self-maintained discharge was exited in propane-butane mixture under a pressure of $4\cdot10^{-3}$ Torr. The discharge current was 50 A and the voltage between anode 7 and chamber 3 (see Fig. 1) was 90 V. The films were deposited on the glass and stainless steel substrates that were being rotated about the axis of the fixture 8 (Fig. 1), periodically leaving from a zone of the densest ion flow that moved from concentrator 6 (Fig. 1). Under this conditions the coatings growth rate was 4.5 microns/hour. These films are transparent in optical band even when its thickness reach 5 $\mu$m and has a good adhesion to the substrate surfaces. Their Vickers microhardness was 1200–1500 kG/mm² that is essentially lower than vacuum arc deposited coatings have. It is quite possible that the reason of this fact is in insufficient degree of dissociation and low energy of the gaseous ions being condensed.

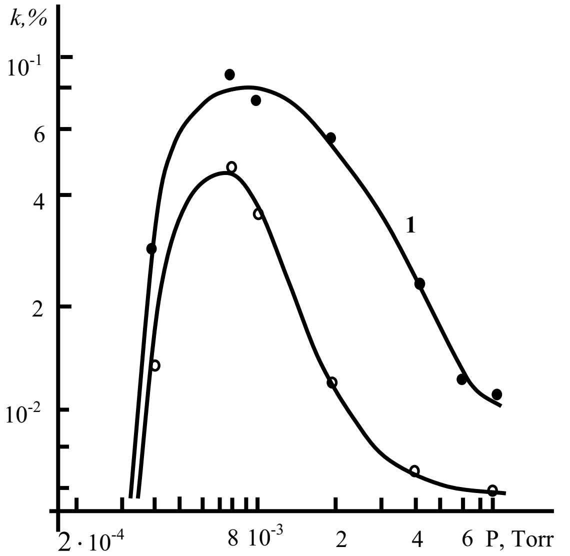

Fig. 5. Coefficient of ionization (%) in two-step vacuum-arc discharge: 1 — in nitrogen plasma; 2 — in propane-butane plasma

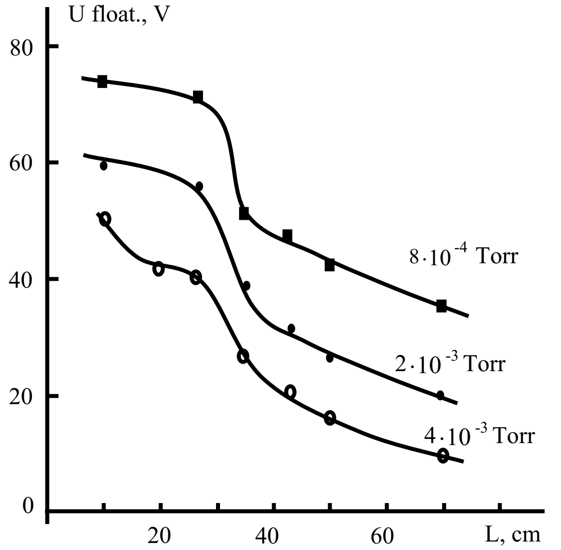

Fig. 6. Floating potential in propane-butane plasma at the axis of concentrator as a function of the distance from anode

## 4. Conclusion

The temperature and density of electrons, ionization coefficient and potential distribution were determined by a single probe method in nitrogen and propane-butane plasma of non-self-maintained discharge, where the vacuum arc plasma gun was used as a source of supplementary charges. In contrast to glow discharge, the directed and dense flux of ions was produced in the positive part of the glow gap. It got a possibility of the synthesizing of the a-C:H films with a high rates of deposition without using of high-voltage RF-oscillator that is applied usually for the glow discharge excitation.

## References

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