PLASMA CHARACTERISTICS OF TWO-STEP VACUUM-ARC DISCHARGE AND ITS APPLICATION FOR A COATINGS DEPOSITION

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Non-self-maintained gaseous discharge, where 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 well adapted for thermo-chemical treatment of products but still is not applied for a coatings deposition. In this paper we show the possibility of a-C:H films synthesis from a plasma of this discharge. The films obtained have a high transparence and good adhesion to metal and dielectric substrates. In addition, such parameters as temperature and density of electrons, ionization coefficient, plasma potential distribution and ion energy have been determined by probe methods for the plasma of non-self-maintained discharge in both: nitrogen and propane-butane mixture.

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1. INTRODUCTION

Non-self-maintained gaseous discharge where the vacuum-arc plasma gun is used as a source of supplementary charges at first was observed by L.P. Sablev with coworkers, who called it "two-step vacuum-arc discharge" [1], featuring a metal-gaseous stage of plasma and a gaseous stage of plasma. Recently these authors have proposed the method of formation of energetic flux of gaseous ions in two-step vacuum-arc discharge by addition of accessory chamber and accessory anode to the main chamber and main anode [2]. In their equipment that flux was destined for the intensification of nitriding process. Although this discharge has been using for the heating and chemical treatment (mainly, for nitriding) of products nearly during 20 years [3], nevertheless many of its parameters still not have been investigated and what is more, there is no information about application of this discharge to coatings deposition processes.

In this paper we present the results of the measurements of such plasma parameters as: electron temperature and density, ionization coefficient, floating potential and ion energy distribution. All data have been obtained by a single and two-grid probe in wide range of pressure. We show also (on example by a-C:H films) that two-step vacuum-arc discharge may be successfully used for the coating deposition.

2. EXPERIMENTAL DETAILS

Non-self-maintained gaseous discharge was exited between hollow cathode (vacuum chamber 4, Fig. 1) and hollow anode 9. Vacuum-arc plasma gun, included cathode 1 and anode 2, served as a source of supplementary charges. To prevent the penetration of the metal ions into gaseous stage of discharge, the aperture of anode 2 was overlapped by the screen 5, which is mainly permeable to electrons. Hollow anode 9 is surrounded by electromagnetic coil 8. Vacuum arc discharge 3 and non-self-maintained gaseous discharge are supplied by power sources PS 1 and PS 2 respectively. The parameters of gas plasma were measured by probe 6 (single or two-grid), which was supplied by power unit 14 and could move along the axis of the hollow anode 9. Thin arrows 12 show the direction of the drift of electrons and thick arrow 11 shows the direction of the gaseous ions motion.

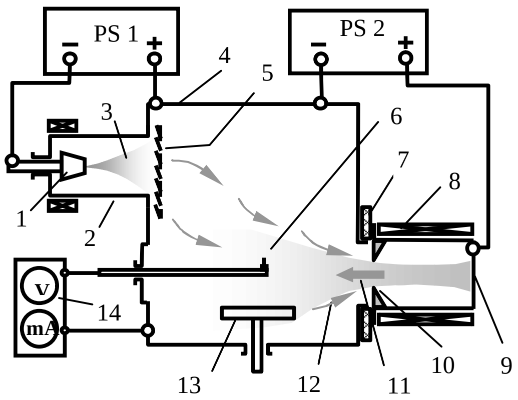

Fig.1. Scheme of experimental setup: 1– cathode and 2 – anode of the vacuum-arc gun; 3– vacuum-arc discharge; 4 – vacuum chamber; 5 – screen; 6 – probe; 7 – insulator; 8 – electromagnetic coil; 9 – hollow anode; 10 – aperture; 11 – ion motion direction; 12 – electron motion direction; 13 – fixture; 14 – power supply unit. Power sources PS 1 and PS 2 supply arc and gaseous

After the system was pumped to $5 \cdot 10^{-5}$ Torr the power supply source PS 1 was switched on exciting the arc discharge between cathode 1 and anode 2. Arc current was established at 100 A, and discharge voltage became settled near 27 V. The voltage at the gaseous discharge gap was maintained by PS 2 power source at 70 V. Working gas is let in through the admission valve (not shown) that enable to maintain a pressure inside the chamber 4 on a specified level. Plasma parameters have been measured for both gases: nitrogen and propane-butane mixture.

3. RESULTS AND DISCUSSION

3.1 ELECTRON TEMPERATURE AND DENSITY

When the magnetic field strength in hollow anode 9 (Fig. 1) is 50 G, the gaseous discharge current in nitrogen appears under a pressure of $2 \cdot 10^{-4}$ Torr and grows with a pressure up to (4-6)·10^{-3} Torr, where it riches up to 120 A. In absence of magnetic field the discharge current is 1.5 times lower. The current of ions ejected from the hollow anode has a similar dependence on the pressure and reaches up to 3 A. The noticeable feature of two-step vacuum-arc discharge is a relatively high electron temperature (Fig. 2) that can reach up to (22 – 25) eV at low pressures. It is several times higher than one observed in vacuum arc plasma (~3 eV) [4]. So high temperature can have the primary electrons, which are accelerated in plasma gun by a voltage drop between cathode 1 and

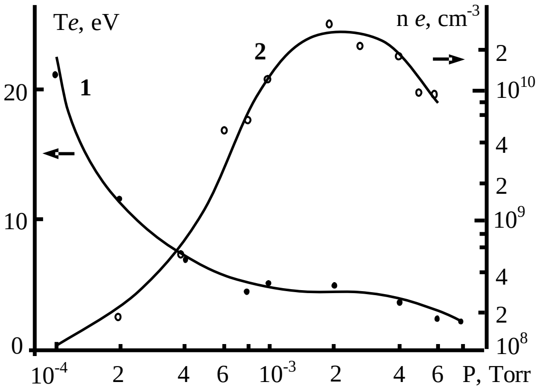

Fig.2. Electron temperature (1) and density (2) in nitrogen plasma of non-self maintained discharge as a function of pressure

anode 2 (Fig. 1) and are scattered elastically on the gas molecules in chamber. Maximum of electron density is observed at the pressures of (1-4)·10^{-3} Torr. Coefficient of ionization, which has been calculated as a ratio of electron density to the gas molecules concentration, reaches up to 0.1% at a pressure region of 8·10^{-4}-2·10^{-3} Torr. This value is considerably lower than one is in vacuum arc discharge (where it may approach to 100 % [5]) and it is several orders higher than degree of ionization in glow-discharge column (10^{-6} – 10^{-4}) % [6].

3.2. A-C:H FILMS DEPOSITION

For the a-C:H films deposition the non-self-maintained discharge was exited in propane-butane mixture under a pressure of 4·10^{-3} Torr. The films were deposited on the glass and stainless steel substrates that were rotating about the axis of the fixture, periodically leaving from a zone of the densest ion flow ejected from the hollow anode (Fig.3). The discharge current was 50 A

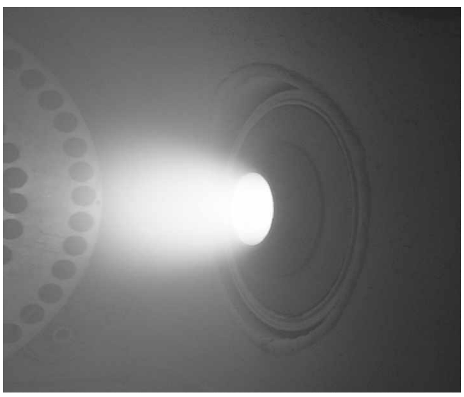

Fig.3. Ejection of the gaseous ions from the hollow anode

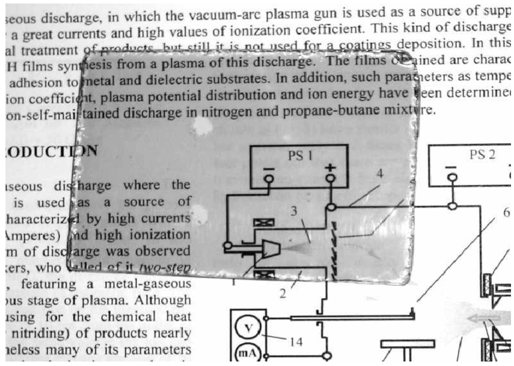

Fig.4. Transparency of the a-C:H film, which has a thickness of 2.5 microns, deposited onto glass substrate. Two blank spots arose after removing of aquadag masks brushed for the measuring of film thickness

and the voltage between anode 9 and chamber 4 (Fig. 1) was 90 V. Under this conditions the coatings growth rate was 4.5 micron/hour. These films have a good adhesion to the substrate and are transparent in optical band even when their thicknesses reach up to several microns (Fig.4). Their Vickers microhardness is essentially lower than vacuum arc deposited coatings have. The reason of this fact lies evidently in insufficient degree of dissociation of the hydrocarbon gas molecules under available discharge conditions.

3.3. ENERGY OF IONS

Ion energy distribution and mean ion energy have been calculated from integral ions energetic spectrums obtained by two-grid probe [7]. As it is seen at Fig.5, energy of ions notably depends from aperture diameter of the hollow anode. When aperture is large, the main part of ions has energy near zero. The decreasing in aperture diameter leads to the growing of ion energy, evidently due to enhancing in the electrical potential gradient in hollow anode. The floating potential measurements show the growth in electrical field from 0.5 V/cm in the chamber to 1.5 or 3 V/cm (depending on aperture diameter) just after entrance into hollow anode. Under middle values of the pressure and distances from anode the maximums of the ion energy distributions occupy intermediate positions between peaks of the curves 1 and 2.

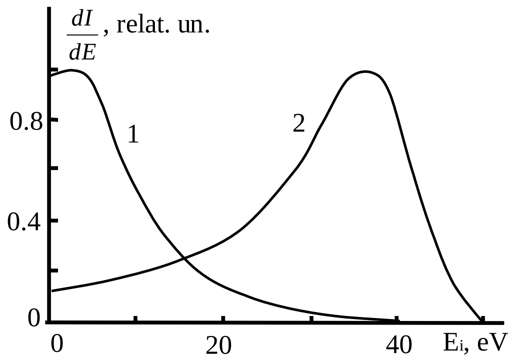

Fig.5. Typical ion energy distribution in two-step gaseous discharge with a hollow anode: 1)high pressures, long distances from anode and 21 cm aperture; 2) low pressures, short distances from anode and 7 cm aperture. The discharge voltage is 70 V

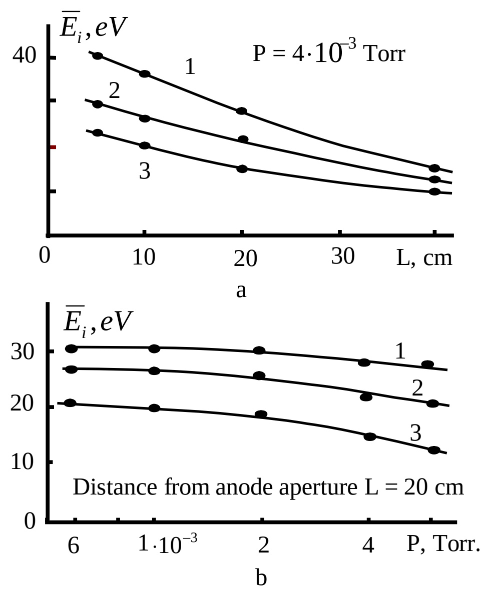

Fig.6. Mean energy of nitrogen ions as a function of the distance from anode aperture – (a); and as a function of the pressure – (b) for the different anode aperture diameters: 1 – 7cm; 2 – 13 cm; 3 – 21 cm. Voltage drop on the gaseous discharge gap is 70 V

Mean ion energy as a function of the gas pressure and distance from the aperture of the hollow anode is shown at Figs. 6 a, b, for the three aperture diameters. Ion energy noticeably decreases with a distance from anode aperture and less distinctly decreases with a pressure. It was found also that mean ion energy grows proportionally to the voltage on the gaseous discharge gap.

CONCLUSIONS

Some plasma parameters of non-self-maintained gaseous discharge exited between hollow anode and hollow cathode are investigated. The main results are:

1. The discharge current grows essentially with a presence of magnetic field in a hollow anode.
2. Ion current is near 3% of the discharge current value.
3. The density of electrons reach up to $2 \cdot 10^{10}$ cm^{-3} and coefficient of ionization is near of 0,1%.
4. Maximum electric field in discharge is observed in hollow anode near aperture, which is the boundary between hollow anode and vacuum chamber.
5. Mean energy of ions, which are ejecting from the hollow anode, grows with a voltage on the gaseous discharge gap and with decreasing: of the aperture diameter, of the distance to aperture and of the gas pressure.
6. This kind of non-self-maintained gaseous discharge may be effectively used for the coatings deposition technologies.

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ХАРАКТЕРИСТИКИ ПЛАЗМЫ ДВУХСТУПЕНЧАТОГО ВАКУУМНО-ДУГОВОГО РАЗРЯДА И ЕГО ПРИМЕНЕНИЕ ДЛЯ НАНЕСЕНИЯ ПОКРЫТИЙ

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Исследован ряд характеристик плазмы двухступенчатого вакуумно-дугового разряда. Методом одиночного и двухсеточного зонда определены: температура и плотность электронов, коэффициент ионизации, распределение потенциала в разрядном промежутке и энергия ионов. Данные получены в широком диапазоне давлений для двух газов: азота и пропанобутановой смеси. Показана возможность синтеза гидрогенизированных углеродных покрытий из плазмы газовой ступени двухступенчатого вакуумно-дугового разряда, возбуждаемого в пропанобутановой смеси.

ХАРАКТЕРИСТИКИ ПЛАЗМИ ДВОСТУПІНЧАСТОГО ВАКУУМНО-ДУГОВОГО РОЗРЯДУ ТА ЙОГО ЗАСТОСУВАННЯ ДЛЯ НАНЕСЕННЯ ПОКРИТТІВ

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Досліджено ряд характеристик плазми двоступінчастого вакуумно-дугового розряду. За допомогою одиночного та двосіткового зонду визначені: температура і концентрація електронів, коефіцієнт іонізації, розподіл потенціалу на розрядному проміжку та енергія іонів. Дані отримано в широкому діапазоні тиску для двох газів: азоту і пропанобутанової суміші. Показана можливість синтезу гідрогенізованих вуглецевих покриттів із плазми газового ступеню двоступінчастого вакуумно-дугового розряду, що збуджується в пропанобутановій суміші.