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PLASMA ACTIVATED EB-DEPOSITION: DIFFERENT MODES OF ARC DISCHARGE AND PLASMA CHARACTERISTICS

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The results of experimental study of the operating parameters of a non-self-sustaining arc discharge in the process of electron-beam evaporation of a cathode are presented in the paper. The conditions of ignition and burning of the arc discharge were studied. The plasma parameters, ion current on the substrate, and current-voltage characteristic of the discharge in Cr and Ti vapors are investigated depending on the electron beam power. It was shown that thermionic emission mechanism is not capable for providing of charge transfer on the cathode surface. The different arc modes are realized in the process of cathode heating by a focused electron beam. The arc can be permanently stable in two modes depending on the power of the electron beam. The regime of diffuse binding of the cathode spot is realized at beam power of more than 2.5 kW. At a lower power regime, a contracted spot is existed in the region of cathode heating by electron beam.

INTRODUCTION

The vacuum arc discharge has been and remains the subject of intensive scientific research for last years. This is due to the fact that the mechanisms occurring in the discharge are quite complex and interesting for fundamental research. In recent decades, the use of the vacuum arc has been widely developed in many technologies (1–4).

The arc in a vacuum can exist with a contracted cathode spot (CS) [5, 6] or in a diffuse form [7–9]. The appearance of CS during the formation of arc discharge is caused by the need of large ($10…10^4$ A) currents transfer through the surface of a cold and practically unemitted cathode. This possibility is realized in the CS due to the high energy concentration in a small region on the surface of the electrode (the characteristic dimension of the CS is $r \sim 10^{-4}…10^{-2}$ cm). In such case, the current is transferred both by ions from the near-electrode plasma and electrons emitted from the metal from the CS region due to the high temperature and electric field created by the volume charge in the near-cathode plasma.

One of the theories describing the processes in the cathode region of the vacuum arc is the ectonic theory developed in report [6].

During the deposition process from a vacuum arc discharge with cathode spots, the drop phase is presented in the ion flow, which is not desirable. The plasma fluxes of evaporable materials without drops can generate the arc discharge with diffuse binding of the cathode discharge.

Despite the fact that the diffuse regime at the cathodes of vacuum arcs has been known for a long time, the mechanism of its existence has become clear only to the present time [10–13].

Similar to the diffuse regime at the cathodes of gas arcs, the diffusion regime at the cathodes of vacuum arcs occurs in cases when the average temperature of the cathode surface is enough high, usually about 2000 K.

The characteristic features of this discharge are a relatively low current density at the cathode, in the order of $10^5…10^6$ A·m^{-2}, and the ability to generate a stable highly ionized plasma without a fraction of microdroplets. The latter feature is attractive for different applications [1–3, 14, 15].

However, the understanding of the diffusion regime at the cathodes of vacuum arcs remains unclear. Thus, in the pioneering paper [7], a stationary vacuum arc with diffuse binding on a chromium cathode was investigated. Chromium was placed in a heat-insulated crucible. Then, an arc with a CS was ignited on the cathode. As the crucible was heated, the arc passed a diffuse shape. However, the calculation of the thermionic current showed a significant discrepancy with the experiment. On this basis, the authors of [7] concluded that there is an abnormally high electron emission (AHEE) in the vacuum arc with diffuse binding on the chromium cathode. In accordance with the conclusions of [7], the currents densities at AHEE exceed the current densities calculated by the Richardson formula by 3…5 orders of magnitude.

It has been shown by many authors that in the case of a chromium cathode, the usual mechanism of current transfer to the cathode of an arc discharge can not provide a current density of the order of $10^5…10^6$ A·m^{-2} observed in the experiment [6, 7]. An exception is the arc with a cathode of Gd that is characterized by very low work output.

In [16], a physical model of the cathode layer of a vacuum arc with an evaporation cathode was proposed, which made it possible to explain the results of the experiment with a vacuum arc on a chromium cathode [7] without attracting AHEE. This model is based on the idea of the presence of a local potential maximum at the outer boundary of the cathode layer.

According to the results of calculations in [16] of the parameters of the cathode layer of the arc, 20…27% of chromium ions are returned to the cathode surface under the experimental conditions [7]. As a result, charge transfer at the cathode is almost completely provided by ions.

Despite the fact that in recent years the understanding of cathodic phenomena in arc discharges has significantly improved due to progress both in experiment and in theory, interest in them is still unabated. Thus, Benilov and co-authors attempted to clarify the physics of current transport in the diffusion regime, which can occur on the cathodes of vacuum arcs, if the average temperature of the cathode surface is high enough, about 2000 K [12].

Recently, the EB-PVD method with plasma activation (EB-PVD PA) has reached a high level of development in the world [1, 2]. It is widely used on an industrial scale due to the high productivity inherent in this method. The EB-PVD PA method is based on the combination of electron-beam evaporation with ionization of vapors by various kinds of discharges, with hollow cathode, high-frequency and arc. This makes it possible to separately and effectively control the rate of evaporation of the material and the degree of its ionization. The degree of ionization is regulated by the discharge current, the ion energy by the bias potential on the coated article, and the evaporation rate is determined by the power of the electron beam. In the diffuse form of the arc, the discharge is distributed over the entire surface of the cathode and the drop phase is absent.

That is why high-speed evaporation by an electron beam with plasma activation is the only PVD method suitable for a variety of applications that fully meet the basic requirements of industrial application:

– high performance;

– hemical purity of the method of generation of the coating substance;

– ensuring high adhesion and coating quality;

– manufacturability, reproducibility of results;

– reliability of equipment;

– maximum ecological purity of the process.

In the literature, similar systems of SBP used for various applications are described in detail [1, 2]. The power of electron guns in these systems ranges from 60 to 300 kW. These are large industrial units. With such powers, the realization of the local evaporation regime in this type of discharge is very difficult.

The above features of the vacuum arc discharge in the vapor of a cathode evaporated by an electron beam make it expedient and relevant to study its properties and characteristics, as well as various designs of plasma sources based on it. It is of interest to consider the conditions for the ignition and burning of an arc discharge on an evaporated material at lower electron beam powers in the range 1…30 kW.

To ignite the arc discharge on the evaporated material (cathode), two basic conditions must be fulfilled. First, the vapor density above the evaporated cathode should be more than 1…10 Pa and thermionic emission should provide arc current within $10...10^3$ A [19]. For refractory materials (Ti, Mo, W), these conditions can be achieved in the same temperature range. For other materials (Cu, Al, chromium), the optimum temperatures for electron emission and vapor density do not coincide. The temperature at which the coating process is already underway is still insufficient for electron emission.

In the present paper, a variant of the EB-PVD PA method (the idea of which is set forth in the patent [17, 18] – AIS method) is considered with the use of an axial sharp-focus electron beam gun and anodes (ionizers) of different design. A significant difference between the AIS method is that the non-self-sustained arc discharge burns on the evaporated material (cathode) in the focus zone of the electron beam. High energy density of the electron beam ($10^5…10^6$ W/cm^2) creates a local area of elevated temperature on the working surface of the evaporated cathode. The amount of overheating can reach from several hundred to thousands of degrees, depending on the scanning speed. Such a superheat allows us to consider the rest of the cathode area as an integral-cold one.

The region of action of the focused electron beam is the zone of preferential burning of the cathode spot of the vacuum arc. When scanning with an electron beam, the discharge region moves over the entire surface of the cathode. The cathode spot does not leave this zone.

The conditions of ignition and burning of an arc discharge with a limited area of existence of the cathode spot were studied in the work. Volt-ampere characteristics of the discharge in chromium vapor, plasma parameters and ion current on the substrate are investigated depending on the electron beam power.

1. MATERAILS AND METHODS

The experiments were carried out on an installation with an electron beam gun with a power of up to 30 kW. To obtain a high vacuum, diffusion and electric arc sorption pumps were used. The limiting pressure in the vacuum chamber was $5·10^{-4}$ Pa. In the evaporation mode, the pressure in the chamber was raised to $7·10^{-3}$ Pa. The electron gun had a differential pumping system, so the pressure in the gun in the sputtering mode did not exceed $1·10^{-3}$ Pa.

The evaporated material in the form of a rod with a cross section of 20 to 20 mm and a length of 150 mm was placed in a water-cooled crucible. The end surface of the evaporated material was constantly in the upper plane of the crucible by means of a feed mechanism. The electron beam was focused on the evaporated material with a spot diameter of – 1 mm. The entire surface was heated by scanning the electron beam. The deflection system formed a rectangular raster with a frequency of 200 to 50 Hz. The cooled crucible and the evaporated material were under the potential of the earth. At some distance from the evaporated material – the cathode an anode was located. The discharge was ignited between the water-cooled cathode and the anode in the vapor of the cathode material. Chromium and titanium were used as working materials in the experiments. The discharge ignition proceeded as follows. The electron beam was focused on the evaporated material (cathode). With the help of the scanning system, the beam was scanned over the entire surface of the cathode, then tension was applied between the cathode and the anode. With an increase in the electron beam current, when the vapor pressure in the discharge gap reached a certain level, ignition of the discharge occurred.

Several variants of anodes have been tested to select the optimal design (Fig. 1). In the first variant, the anode has small dimensions (anode area ~ 10 cm^2, see Fig. 1,a). It is made of tungsten wire with a diameter of 3 mm in the form of a ring with a diameter of 60 mm or as two parallel rods arranged symmetrically in front of the cathode at a distance of 60 mm from each other. In the second variant, the evaporator (see Fig. 1,b) has a large anode area (200 cm^2). An increase in area leads to a decrease in the anode voltage drop and a decrease in the probability of formation of an anode spot.

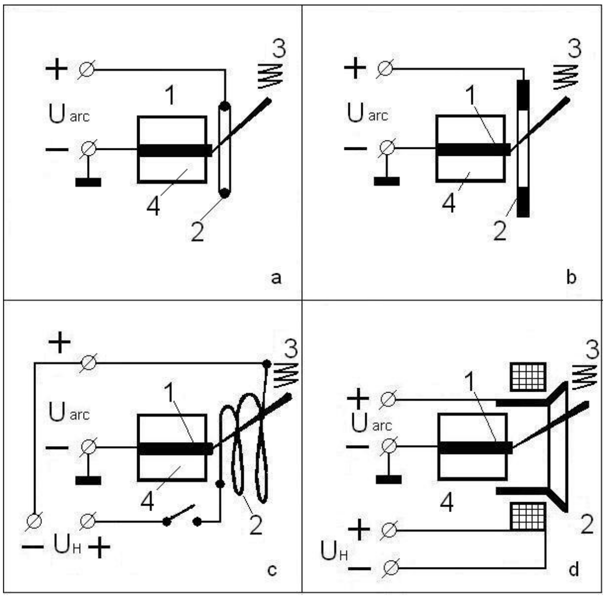

Fig. 1. The variants of scheme: a – with small area anode, b – with large area anode, c – with spiral anode, d – with large area anode with solenoid; 1 – evaporated material – cathode, 2 – anode, 3 – electron beam, 4 – solenoid

In order to increase the efficiency of ionization, two other designs of the evaporator have been studied, which make it possible to discharge in a magnetic field (see Fig. 1,c,d). In one of them, the anode is made of tungsten or molybdenum wire in the form of a conical spiral coil connected at one end to a power source. The other end of the coil was free or connected to an additional power source (see Fig. 1,c). In the first case, the discharge current or an additional source passing through the turns of the spiral created a magnetic field proportional to the current. In the second variant, the large area anode was provided with a short solenoid (see Fig. 1,d).

The ion current density was studied using a probe with a flat working surface of about 0.5 cm. The lateral surface of the probe was covered with a screen. Measurement of the ion current density was carried out at a distance of 0.35 m from the cathode. The total ion current was measured using a 25 cm diameter collector placed at a distance of 0.25 m from the cathode

Concentration, electron temperature and plasma potential were determined from the analysis of the probe characteristics of a single electrostatic probe. Mass spectrometric studies of the plasma were carried out using a radio-frequency single-field mass spectrometer MX-7303, whose sensor was adapted for plasma studies. The average ion energy was calculated from the current-voltage curves of the ion current on the collector of a multigrid electrostatic probe. By differentiating these curves, the energy distribution of the ions was determined. Spectral analysis of the signals was carried out using the Fast Fourier Transform (FFT) function of the Tektronix 2012B oscilloscope. The degree of ionization of the vapor stream was determined as the fraction of the ion flux in the total flux of particles condensing on the surface of the substrate

2. RESULTS AND DISCUSSION

2.1. IGNITION OF THE ARC DISCHARGE

To investigate the conditions necessary for ignition of the arc discharge in the vapor of the cathode material, an experimental dependence of the discharge current on the electron beam current was obtained for two values of the accelerating voltage of an electron gun of 16 and 20 kV. The diameter of the focused electron beam was unchanged and was ~ 1 mm. The voltage of the arcing power source was 100 V.

After the voltage is applied between the cathode, the evaporated electron beam, and the anode located near the evaporating material and increasing the electron beam current to 10…20 mA, ignition of the discharge in chromium vapor is observed (Fig. 2).

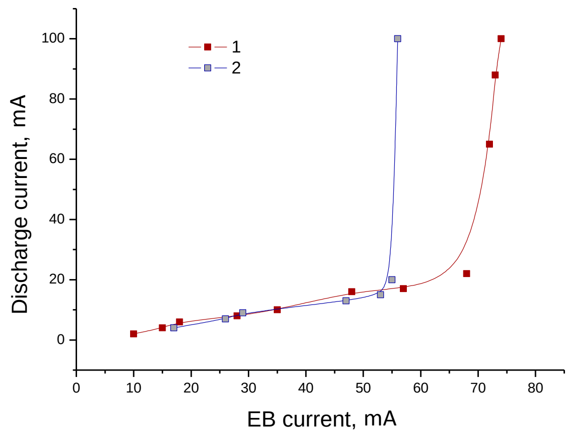

Fig. 2. Dependence of the discharge current on the current of the electron beam at accelerating voltages: 1 – 16, 2 – 20 kV

As can be seen from the data in Fig. 2, at low values of the electron beam power (less than 1.1 kW), a weak-current discharge stage is observed. In this case, the discharge current did not exceed the secondary electron emission current from the cathode, which is approximately equal to half the electron beam current.

The achievement of an electron beam power equal to 1.1...1.2 kW ensured a density of chromium vapor near the heated surface of the cathode at a level of (3...5)·10^{13} cm^{-3}, and was accompanied by a sharp increase in the discharge current. A further increase in the power of the electron beam leads to the appearance of a non-self-sustaining arc discharge burning in the vapor of the cathode material.

It should also be noted that a vacuum-arc discharge with an integrally cold cathode exists on the working surface of the cathode only as long as its temperature is insufficient for the current to flow through thermionic emission. When the temperature rises, this type of discharge goes into an arc discharge with diffuse binding at the cathode [7]. Therefore, a vacuum arc discharge with an integral cold cathode should be considered from the point of view of the transition stage in the development of an arc discharge with a hot cathode, and we should speak specifically of the dynamics of the development of cathode spots in time, as the cathode warms up. If after the ignition of the discharge the power of the electron beam decreased or the scanning frequency increased (i.e., the temperature at the beam focus decreased), the discharge transitioned into an independent form with a contracted spot and a chaotic motion of the CS along the cathode and the surface of the crucible.

The experimentally measured rate of evaporation of chromium for a given design of the evaporator (crucible), depending on the power of the electron beam, is $V = 2.8\ W^{2.1}$, where в is the evaporation rate g/h, and W is the power of the electron beam, kW. Based on the rate of evaporation, an estimate was made of the temperature of the cathode and the vapor pressure above it. The evaporation area was assumed to be 10mm^2. Calculations (based on tables [23]) showed, with a beam power of 1 kW, the spot temperature is 1670 K, and the vapor pressure is 1.3 Pa. These parameters correspond to the start of arc ignition. With a beam power of 3 kW, the calculated temperature and pressure values are 1800 K and 10 Pa, respectively. Estimating the value of the thermionic current according to Richardson's formula gives values for the temperature of 1800 K at a level of less than 10^{-3} A. This again confirms the need for arc-discharge studies with diffuse binding of the cathode spot to answer the question of the mechanisms of charge transfer at the cathode surface.

As already noted above, heating of the cathode to a temperature *T*, which corresponds to a saturated vapor pressure of the order of 1.3 Pa, can be considered a necessary condition for igniting a discharge in the vapor of a cathode material heated by an electron beam. This is the stabilization of the cathode spot on the working surface of the cathode. The area of existence of a cathode spot (CS) of a given discharge type is the cathode heating zone by a sharp-focus electron beam.

2.2. THE MAIN CHARACTERISTICS OF A NON-SELF-SUSTAINING ARC DISCHARGE

The current-voltage characteristics of a non-self-sustained high-current discharge in chromium vapor, depending on the power of the electron beam, are shown in Fig. 3 at a scanning frequency of 50x200 Hz.

Volt-ampere characteristics are typical for an arc discharge in the non-free mode [19].The electron beam power during the removal of each of the current-voltage characteristics remained constant, which ensured a certain rate of evaporation.

Arc voltage is the most suitable parameter for understanding cathode processes, since it reflects them in a less distorted form than ion current or most other parameters. The presence of high-frequency oscillations in the arc is usually associated with the evolution of cathode spots. In the literature [20, 21], it is suggested that the oscillations of the discharge current arising in this case are related to the lifetime of the arc. Measurement of the spectrum of noise generated by an arc discharge showed that the power of the electron beam has a decisive influence on the processes occurring in the near-cathode region.

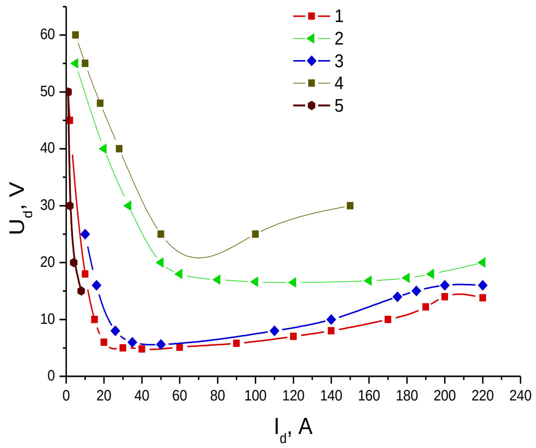

Fig. 3. Volt-ampere characteristics of a non-self-maintaine arc discharge.
Cathode: 1, 2, 3 – Cr, 4 – Ti, 5 – W;
the electron beam power kW:
1 – 3.5, 2 – 2.5, 3 – 3, 4 – 6, 5 – Rod W;
R = 0.75 mm, Ar, p = 2.6 bar [13]

At power values of 2.5 kW, high-frequency oscillations are observed in the spectrum. The spectrum shows the 1/f-nature of the intensity at low frequencies with two broad peaks at frequencies of 1.0 and 2.3 MHz (Fig. 4).

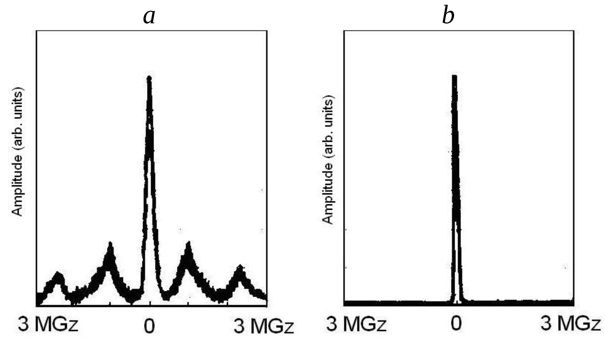

Fig. 4. The spectra of arc discharge noises at arc current value 120 A and electron beam power:
a – 2.5; b – 3.5 kW

This regime corresponds to a higher burning voltage of the discharge (see curve 2, Fig. 3). The same oscillations are also characteristic for the initial stage of ignition of the arc discharge at a higher power of the electron beam.

Such high-frequency oscillations are characteristic of a vacuum arc with a contracted cathode spot. For comparison, the FFT spectrum of an arc with a cold chromium cathode (Arc PVD) was taken, it is shown in Fig. 5.

As we can see, the same 1/f nature of the dependence of the intensity of oscillations to 5 MHz is observed, a wide maximum at 7.0 MHz and “white” noise for faster oscillations.

With an increase in the power of the electron beam to 3...3.5 kW, and an increase in the discharge current of more than 30 A, a decrease in the voltage drop across the discharge is observed to a value of the order of the ionization potential of chromium, which is characteristic of an arc with a “hot” cathode (curves 3, curves 1, Fig. 3).

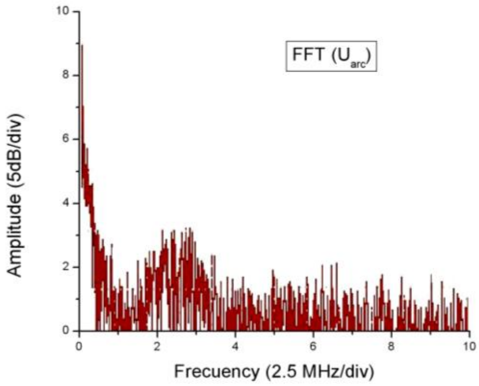

Fig. 5. The spectra of arc discharge noises at arc with spot cathode on Cr

High-frequency oscillations disappear in the spectrum (see Fig. 4,b). A transition occurs from the “noisy” arc mode burning in the cathode spots contracted, which is characterized by the presence of high-frequency voltage oscillations on the arc, to the “quiet” arc regime with parameters inherent in the hot cathode arc. As our experiments showed, in this case the size of the diffuse cathode spot coincides with the region of heating of the cathode by an electron beam. The working surface of the cathode can be considered integral cold; the thermal emission current from this region will be much less than from the superheated focal region of the cathode. In arc mode with a hot (diffuse) cathode, the voltage drop on the arc becomes minimally possible, of the order of the ionization potential of the evaporated material, which ensures a single ionization of the evaporated material and a significant reduction in the droplet component.

At arc currents above 200 A, there is a tendency for an increase in the combustion voltage, a transition to an independent arc discharge, similar to that described in [7, 19]. However, under conditions of intense cooling of the cathode lateral surface, the realization of such a discharge shape is difficult.

The results of measuring the total ion current as a function of the arc current are shown in Fig. 6 for various anode designs of the electron-beam evaporator.

The minimum values of the ion current are observed for variants without a magnetic field (plot 1, 2). In addition, there is a current limitation for the tungsten anode. The experiments observed contracted anode spots when the arc current reaches ~ 100 A. With a further increase in the discharge current, this led to the destruction of the anode.

This is explained by the fact that under conditions that make it difficult to supply electrons to the anode, for example, at small anode sizes, the value of the positive anode drop of the potential increases, and when the value of the ionization potential of the vapor exceeds the anode spots, anode spots appear [19, 22, 24].

The second version of the evaporator (see Fig. 1,b) had an anode of a large area (200 cm^2). An increase in the area of the anode should lead to a decrease in the anode drop in the potential and prevent the formation of anode spots, which was observed experimentally.

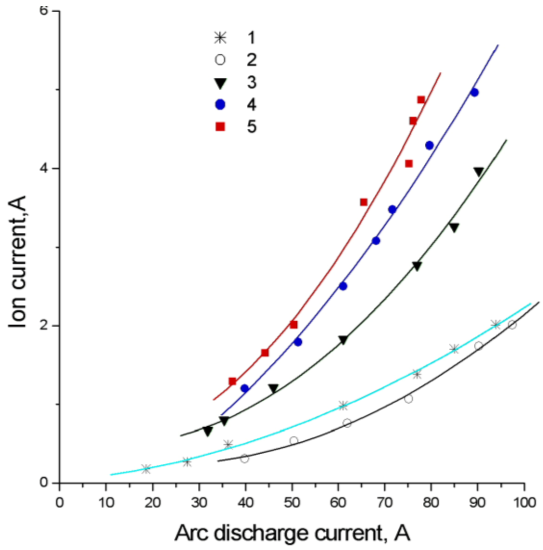

Fig. 6. The dependence of ion current on the collector and arc current: 1 – lower area anode; 2 – larger area anode; 3 – spiral anode; 4 – spiral anode, conducted with additional power supply; 5 – large area anode combined with small solenoid

The dependences of the total current on the collector (see Fig. 6) and the ion current density (Fig. 7) practically coincide with the analogous dependences for the previous construction. As can be seen, the use of an anode of a larger area eliminated the conditions for the formation of anode spots and made it possible to significantly increase the arc current without destroying the anode.

Ignition of a discharge in a magnetic field leads to an increase in the efficiency of the ionization process, due to the elongation of the electron drift path, and, consequently, an increase in the number of collisions. This effect is equivalent to an increase in pressure and a corresponding change in the number of ionizing collisions [19, 25].

Two designs of evaporators have been studied that make it possible to do discharge in a magnetic field (see Fig. 1,c,d). In the design, where the anode was made in the form of a conical spiral of 3.5 turns, when a discharge current flows through the turns of the spiral, a magnetic field is created with a voltage proportional to the discharge current. The dependence of the ion current density on the arc current at fixed values of the magnetic field strength is shown in Fig. 7.

It follows from the dependences that in the presence of a magnetic field the ion current increases by a factor of three for a fixed discharge current. When discharge current varying within 40..160 A and the magnetic field strength 0...6·10^3 A/m, it is possible to change the ion current density to the probe more than an order with a constant vaporization rate that allows to actively influence the deposition process condensate.

It should be noted that only the change in the shape of the anode (ring-helix) leads to an increase in the ion current (see Fig. 6) by a factor of ~ 2. However, this design of the anode has the same drawback as the first one. At an arc current of ~ 115 A, anodized spots appear on the anode, resulting in the destruction of the anode.

The most effective design is the large area anode with a short solenoid (see Fig. 1,d). Fig. 8 shows the radial distribution of the ion current density. As we see, in the presence of a magnetic field (H = 4.8·10^3 A/m), the nature of the directional pattern changes, it becomes elongated along the axis of the flow.

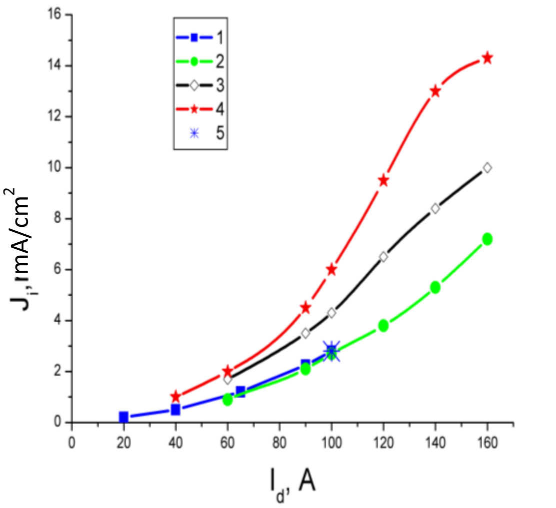

Fig. 7. The dependence of ion current on arc current at regimes: 1 – lower area anode, H=0; 2, 3, 4 – larger area anode; 2 – H = 0; 3 – H = 3.6·10^3 A/м; 4 – H = 6·10^3 A/м; 5 – current of anode failure

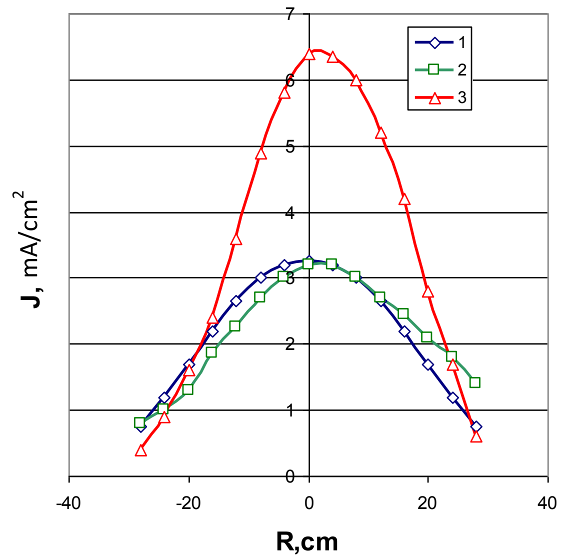

Fig. 8. The radial distribution of ion current: 1 – theoretical dependence-cosά; 2 – I_d = 145 A, H = 0; 3 – I_d=145 A, H = 4.8·10^3 A/м

An increase in the directivity of the plasma flow makes it possible to increase the proportion of the useful coating material used. The half-width of the radial distribution (corresponding to the characteristic size of the covered product) is more than 0.3 m.

The degree of ionization of the vapor stream was determined as the fraction of the ion flux in the total flux of condensed particles on the surface of the substrate.

The electron temperature depends little on the arc current, the average value is 0.5 eV. An increase in the magnetic field in the discharge zone leads to an increase in the electron temperature, as well as the degree of ionization (Fig. 9)

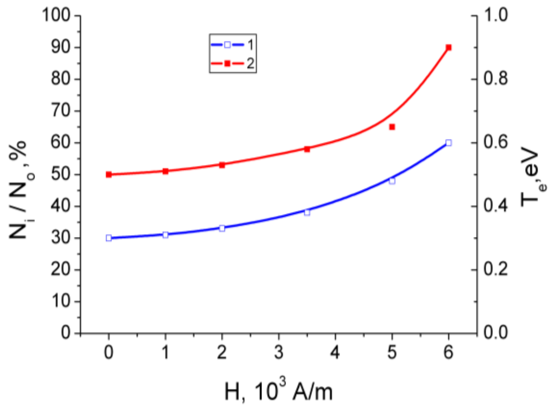

Fig. 9. The electron temperature (1) and the degree of ionization of the vapor stream (2) as a function of the magnetic field strenght

The average energy of the ions is E = (6±0.8) eV. An increase in the energy of the ions increases with increasing magnetic field. At a magnetic field strength equal to H = 3.6·10^3 A/m, the ion energy increases to 11 eV.

CONCLUSIONS

Results shown that different arc modes were realized during the cathode heating process by a focused electron beam The character of the cathode spot binding to the electrode surface was changed depending on the power of the electron beam. It was established that the arc can exist for a long time in two modes. The regime of diffuse binding of the cathode spot is realized at beam power of more than 2.5 kW. At a lower power regime, a contracted spot is existed in the region of cathode heating by electron beam.

It was shown that in the case of the chromium cathode thermionic emission mechanism is not capable for providing of charge transfer on the cathode surface. Our results supplement the experimental data obtained by other authors in studies of this type arcs, and thus contribute to clarifying the mechanism of charge transfer on the surface of the chromium cathode.

The degree of ionization of the vapor stream is controlled by parameters in the discharge in the range 5...70%. The ion current depends on the magnitude of the arc current and the intensity of the ionizer magnetic field. The magnitude of the ion current measured by the collector at a distance of 0.25 m from the evaporator was 5…12 A at the arc current of 80…160 A. The evaporation rate at an electron beam power of 6.4 kW was 140 g/h.

The chromium plasma generated by a non-self-sustaining arc discharge is characterized by a density $n = 10^{10}…10^{13}$ cm^{-3}, depending on the current and the magnetic field strength. The average value of the energy of chromium ions is E_i = (6 ± 0.8) eV (at H = 0); the electron temperature is $T_e \sim 0.5…0.9$ eV. The plasma consists of singly charged Cr^+ ions.

The results show that the specific feature of the non-self-sustaining arc discharge in the process of electron-beam evaporation is single-charge and low ion energy in the discharge plasma. The proposed method makes the possibility to regulate the degree of vapors ionization, ion energy in combination with a high evaporation rate. These parameters allow effectively influencing on the structure of coatings and significantly expanding the possibilities of technological regimes. The presence of a system of differential evacuation of the electron gun gives the possibility to carry out the processes of effective coatings synthesis by the plasma-chemical method.

The method is applicable for ion-plasma deposition of coatings with high productivity. The proposed scheme of a source of vacuum-arc plasma with evaporation by an electron beam was realized in an industrial installation AIR-3 for deposition of ion-plasma coatings with high efficiency.

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ЭЛЕКТРОННО-ЛУЧЕВОЕ ОСАЖДЕНИЕ С ПЛАЗМЕННОЙ АКТИВАЦИЕЙ: РАЗЛИЧНЫЕ РЕЖИМЫ ДУГОВОГО РАЗРЯДА И ХАРАКТЕРИСТИКИ ПЛАЗМЫ

В. Сафонов

Представлены результаты экспериментального исследования рабочих параметров несамостоятельного дугового разряда в процессе электронно-лучевого испарения катода. Изучены условия зажигания и горения дугового разряда. Исследованы вольт-амперные характеристики разряда в парах Cr и Ti, параметры плазмы, ионный ток на подложку в зависимости от мощности электронного луча. Показано, что механизм термоэлектронной эмиссии не способен обеспечить перенос заряда на поверхности катода. Установлено, что при нагреве катода сфокусированным электронным лучом реализуются различные режимы дугового разряда. В зависимости от мощности электронного луча дуга может устойчиво существовать в двух режимах: при мощности луча более 2,5 кВт – с диффузной привязкой катодного пятна, а при меньшей мощности – с контрагированным пятном, существующим в области нагрева катода электронным лучом.

ЕЛЕКТРОННО-ПРОМЕНЕВЕ ОСАДЖЕННЯ З ПЛАЗМОВОЮ АКТИВАЦІЄЮ: РІЗНІ РЕЖИМИ ДУГОВОГО РОЗРЯДУ ТА ХАРАКТЕРИСТИКИ ПЛАЗМИ

В. Сафонов

Представлені результати експериментального дослідження робочих параметрів несамостійного дугового розряду в процесі електронно-променевого випаровування катода. Вивчені умови запалювання і горіння дугового розряду. Досліджені вольт-амперні характеристики розряду в парах Cr і Ti, параметри плазми, іонний струм на підкладку в залежності від потужності електронного променя. Показано, що такий механізм, як термоелектронна емісія, не здатний забезпечити перенесення заряду на поверхні катода. Встановлено, що при нагріванні катода сфокусованим електронним променем реалізуються різні режими дугового розряду. Залежно від потужності електронного променя дуга може стійко існувати в двох режимах: при потужності променя більше 2,5 кВт – з дифузною прив'язкою катодної плями, а при меншій потужності – з контрагірованою плямою, яка існує в області нагріву катода електронним променем.

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