**Physico-Chemical nanomaterials science**

**Estimation of Discharge Arc Current Density in the Technology of Obtaining Ceramic Nanocoatings With Activation of Metal Vapor**

**Melnyk I.V., Melnyk V.G., Tuhai S.B.**

*Electronic Devices and Systems Department, Faculty of Electronics, National Technical University of Ukraine ‘Igor Sikorsky Kiev Polytechnical Institute’, Prospect Peremogy, 37, korpus 12, 03056, Kyiv, Ukraine.*

*E-mail: imelnik@phbme.kpi.ua*

The High Voltage Glow Discharge Electron Guns (HVGDEG) are widely used in industry for obtaining the coating from chemically-complex ceramics, including advanced nanocoatings [1, 2]. The main advantages of applying such type of electron guns for providing Physical Vapor Deposition (PVD) of thin films from complex compound is the simplicity of gun construction and evacuation equipment, as well as operation of HVGDEGs in the soft vacuum with the possibility of using different gases, including noble and active ones [1 – 4]. The operation pressure of HVGDEGs is usually in range of 1 – 10 Pa, but it also strongly depended on the using operation gas [3, 4]. If maintaining of the chemical reaction between the evaporated metal and residual gas in the soft vacuum without additional activation is impossible, the non-simultaneous arc discharge with the cooled ring electrode, located under the crucible, can be used for providing the activation of such reaction [3]. Corresponded electrodes’ scheme of the equipment for arc discharge lighting is presented at Fig. 1 [3].

For providing the estimation of the level of activation of evaporated material and probability of its chemical reaction with the residual gas in such conditions, the pervious estimations of the electric parameters of arc lighting is necessary. Therefore, obtaining of analytical relations for such estimations is the subject of this report.

**Fig. 1. Shematic view of arc ionization equipment. 1 – crucible, 2 – ring-like electrode, 3 – electron beam, 4 – vapor of evaporated materials, 5 – substrate**

The distribution of electric field potential at the plane of ring electrode is defined by solving of the simple differential equation:

$\frac{d^{2}φ\left(r\right)}{dr^{2}}=C\_{1}+\frac{C\_{2}}{\sqrt{φ\left(r\right)}}$, (1)

where *C*1 and *C*2 – the equation coefficients, depended on the power of electron beam, pressure of residual gas and on concentration of meal vapor. Considering of these coefficients is the separate problem and it isn’t connected with the subject of this report.

By using the corresponded analytical transforming, with taking into account the initial value of potential at the surface of ring φ*R* = φ*d*, the differential equation (1) is reduced to the cubic one:

$2C\_{2}t^{3}-t^{2}+C\_{1}r^{2}=0$, (2)

where

$t\left(r\right)=φ\left(r\right)+φ\_{0}.$ (3)

Set of equations (2, 3) is solved analytically with using well-known Cordano formula [5]. Corresponded solution can be written as follows:

$D\left(r\right)=\frac{1}{36C\_{2}^{6}}+\frac{C\_{1}^{2}r^{4}}{16C\_{2}^{2}}-\frac{C\_{1}r^{2}}{532C\_{2}C\_{2}^{3}}+\frac{1}{46656C\_{2}^{6}}$. (4)

$$t\left(r\right)=\sqrt[3]{\frac{1}{216C\_{2}^{3}}-\frac{C\_{1}r^{2}}{4C\_{2}}+\sqrt{D\left(r\right)}}+\sqrt[3]{\frac{1}{216C\_{2}^{3}}-\frac{C\_{1}r^{2}}{4C\_{2}}+\sqrt{D\left(r\right)}}.$$

Numerical solution of the set of equation (4), with taking into account the initial condition φ*R* = φ*d*, is presented at Fig 2.

With knowing the potential distribution φ(*r*), the current density of non-simultaneous arc discharge is defined as follows:

$j\left(r\right)=\left(2e\right)^{1.5}\sqrt{φ\left(r\right)}\left(N\_{im}\sqrt{\frac{1}{m\_{im}}}+N\_{ig}\sqrt{\frac{1}{m\_{ig}}}+\left(N\_{im}+N\_{ig}\right)\sqrt{\frac{1}{m\_{e}}}\right)$, (5)

where *e* – charge of electron, *Nim* – the concentration of ions of evaporated metal, *Nig* – concentration of ions of residual gas, *mim* and *mig* – corresponded masses of metal ions and gas ions correspondently, *me* – mass of electron.

Dependences *j*(*r*), obtained with using the set of equations (4, 5), are presented at Fig. 3. All calculations have been provided for evaporation of titanium in the nitrogen media with beam power *Pb* = 10 kW.



**Fig. 2. Dependences of the potential distribution in the plane of ring for different voltage on the ring *Ur*, obtained with using the set of equations (4).**



**Fig. 3. Dependences of the current density of arc discharge in the plane of ring electrode, obtained with using the relations (4, 5)**

1. *Feinaeugle P., Mattausch G., Schmidt S., Roegner* *F.H.* A new generation of plasma-based electron beam sources with high power density as a novel tool for high-rate PVD”. // Society of Vacuum Coaters, 54-th Annual Technical Conference Proceedings, Chicago. 2011. pp. 202–209.
2. *Mattausch G., Zimmermann B., Fietzke F., Heinss J.P. at all* Gas discharge electron sources – proven and novel tools for thin-film technologies. // Elektrotechnica and Electronica (E+E)”, vol. 49, 2014, № 5-6. pp. 183–195.
3. *Denbnovetskiy S., Melnyk V., Melnyk I., Tugai B., Tuhai S., Wojcik W., Lawicki T., Assambay A., Luganskaya S.* Principles of operation of high voltage glow discharge electron guns and particularities of its technological application. // Proceedings of SPIE – The International Society of Optical Engineering. – 2017. – P. 10445 – 10455.
4. *Melnyk I., Tyhai S., Pochynok A.*  Universal Complex Model for Estimation the Beam Current Density of High Voltage Glow Discharge Electron Guns. // Lecture Notes in Networks and Systems, 2021, 152, с. 319-341.
5. *Bronshtein I.N., Semendiaev K.A.* Tutorial Book on Mathematic for Engineers and Students of Higher Educational Technical Institutions. Moscow, “Nauka”, 1981.