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Aspects of Metal Surface Glowing Mechanisms with Intensive Electron Beam Bombardment

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The paper gives a brief description and analysis of the main physical processes which can have an effect on the glowing nature of metal element surfaces in different electric vacuum devices when they are bombarded by electron beams. It has been found that the electron glowing effects on metal surfaces according to the electron energy can be explained with the help of the transition scattering on plasma waves or just with the classical transition radiation effect. This fact is rather important in terms of classical physics interpretation of the observed glowing effects on metal surface elements and techniques optimization of metal and electron beams diagnostics as well.

Keywords: Electron beam, Transition radiation, Plasma, Transition scattering.

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1. INTRODUCTION

Questions of the formation and diagnostics of electron beams (EB) with the specified parameters which significantly depend on the mechanisms of surface phenomena on metal elements during the bombardment by EB are of a special interest in the production of electric vacuum devices.

It was shown in [1] that transition radiation which was used in [2] for diagnostics of low-energy EB is the main dominant glowing mechanism at the incidence of electrons from vacuum on metal surface. Further experimental investigations of the surface properties of metals at their bombardment by EB [3] led the authors to the conclusion about new physical phenomenon which is not connected with transition radiation: the possibility of stable transformation of the energy of electrons into the energy of plasma localized over the surface. Thus, the proposed in [3] hypothesis discredits the fundamental results of the nature of radiation initiation at the bombardment of metal surface by electrons [1]. Together with this, consequent investigations of the given phenomenon in [4-6] have shown that transition radiation or transition scattering are the dominant mechanisms of radiation initiation on the surfaces of metal targets. Therefore, a question of the comparative analysis of the results of works [3] and [1, 4-6] is actual form the point of view of determination and statement of fundamental representations of physics of glowing initiation on the metal surface at the bombardment by EB that is one of the determinative factors in diagnostics of metal surface and EB.

2. MAIN BODY

Sorption phenomena play important role in electric vacuum technology and substantially influence the degree of vacuum in devices. Therefore, on the first stages of the technological process of production of any electric vacuum devices a question about thorough cleaning of their internal surfaces arises. There exist different types of cleaning of the electrode surfaces, namely, chemical, thermal, pumping out, and training of electric vacuum devices, etc. However, cleaned details are inevitably covered by thin oxide films, and air components are adsorbed on their surface in structural defects. Structure and chemical composition of the surfaces is more complicated at baked heating in pumping out: impurities contained inside the metal volume diffuse toward the surface, and as a result, new substances appear on oxide film or within it; and this leads to the considerable change in the mechanical and electrical properties of near-surface layers of metals [7].

A sharp burst of desorbed gaseous components of different composition takes place at the bombardment of such "dirty" metal surfaces by electrons. For a number of objects, desorption from their surface, and in some cases destruction of the objects themselves, occurs at electron energies less than 50 eV (the so-called electron-stimulated desorption [8]).

Abundant gas desorption from details is observed at low electron energies of the order of 10-15 eV. And gas release induced by the electron bombardment is usually several times (sometimes, more than one order) exceeds the gas release of these details but at usual thermal degassing, although temperature of the degassed details can be the same in both cases that is demonstrated in Fig. 1. Here, gas discharge [9] can arise in the initial moment of bombardment of the cleaned metal surface.

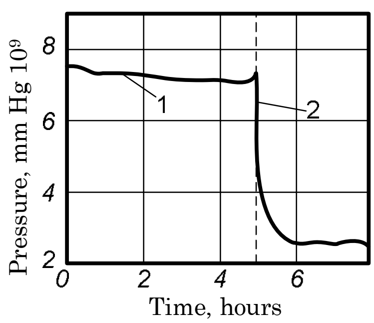

Fig. 1 – Equilibrium gas pressure in the experimental electric vacuum plant arising at the electron bombardment of anode (curve 1) and its heating by separate heater (curve 2)

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It is reasonable to assume that such desorption processes occurred also in the experimental investigations described in [3]. And if take into account that there is not any mention about degree of vacuum in a chamber, then the given assumption is quite appropriate.

Therefore, one can explain the ionization processes arising in the near-anode region and local character of plasma formation. Metal surface contains asperities of different sizes even if it is carefully treated. Thus, at the highest, 14-th class of finish, the height of asperities on the surface is equal in average to 0,5 μm. In fact, metal samples applicable in the experiments by the authors of the paper, have larger asperities (6-11 class). Local heating of surface defects which have restricted contact with the sample promotes the increase in the sublimation of material microparticles, growth of the secondary electron emission due to the decrease in the work function, increase in the diffusion processes in the regions of inhomogeneities that inevitably leads to ionization of "gas cloud" and formation of plasma torch in the region of surface defect.

We also should mention some inaccuracies in work [3] concerning the interpretation of radiation mechanisms of plasma torches on the surface of metal samples. Thus, in the section about the supposed mechanism of the phenomenon, the authors say about the absence of any published materials which explain the arising glowing of anode surfaces during electron bombardment. Citing the Ginzburg paper [1], the authors conclude the impossibility of interpretation of the phenomenon from a perspective of the transition radiation which, however, is not correct. In this paper, one can find the detailed description of the phenomenon of transition radiation which takes place for the case with plasma. Nature of the mentioned phenomena is the same, and the only difference is that transition radiation is generated by moving charge, while transition scattering is possible at scattering of permeability wave on immobile charge. As it will be shown below, just the latter significantly contributes to the initiation mechanism of plasma torch radiation.

Plasma radiation has much more complex character than it was noted in the work [3], since main radiation mechanisms are determined not only by the individual properties of charged and neutral particles which form plasma system, but also by collective – vibrational-wave characteristics. Moreover, specificity of plasma, in particular, its difference from neutral gas is connected with the wave processes. Besides radiation mechanisms connected with the presence of plasma waves (usual scattering, a.k.a. the Thomson scattering in the Ginzburg paper [1]), the so-called transition scattering – scattering of permeability wave on immobile charge – is also present in plasma. Here, waves of the mentioned types interfere that makes the picture of radiation formation more complicated.

During scattering on ions desorbed under the action of electron bombardment from the surface of the studied samples, usual scattering is found to be negligibly small because of large ion mass. Transition scattering does not depend on the particle mass at all [1]. It is clear from here that scattering of plasma waves on ions is practically purely transition one. The given fact is confirmed by the following: intensity of the observed glowing did not depend on the material of bombarded samples.

During radiation of metal targets by intensive EB, transition radiation should take place besides the formation of plasma torches, whose radiation has a sufficiently complex nature. The question is in the mechanism of its registration and total contribution to the fixed radiation. As the results of investigations [4] have shown, appearance of such radiation is inevitable when using EB with power density in the range from units W/cm^2 to tens kW/cm^2.

Similar visual glowing effects of target surface were observed in the experiments of measuring the static parameters of intensive axially-symmetric beams by transition radiation described in the work [5]. Copper target with the surface quality of 9-10 finish class of the material (mirror polishing) was treated by electron bombardment during the experiments. Pressure in the vacuum chamber of analyzer was 10^{-8}-10^{-9} mm Hg, power density of continuous axially-symmetric EB was equal to 1,3-17,3 kW/cm^2 (electron energy was varied in the range of 2,5-4,5 keV depending on the operation mode of an electron gun). We have to note that in connection with the features of investigation technique of the EB microstructure, a flow of electrons fell down on the target at the angle of $\alpha = 5°$ distributing power over the surface of the area of 4,7 mm^2 (area of a semi-ellips formed by the glowing trace of EB of the diameter of 1 mm in the place of contact with the surface).

It was established that radiation arising at angular incidence of a charge on the interface of two mediums possesses a number of important properties different from normal incidence: it is polarized in two mutually perpendicular directions, and total radiation density is determined by the sum of its longitudinal and transverse components. At the same time, when considering non-relativistic particles (the given approximation is applicable in our case since at accelerating potentials $U = 10^3$-10^4 V relativistic root gives only 0,196-1,965 % deviation), transition radiation is found to be polarized as well as at normal incidence. The mentioned property is very important at detecting of transition radiation, since allows to separate it from various noises and side effects.

Moreover, also other properties of transition radiation were experimentally established in [4]: direct proportionality between radiation intensity and energy of bombarding electrons in the energy range from 30 eV to 100 keV; structure uniformity over the whole metal surface which undergoes electron bombardment; radiation spectrum is continuous in the observed wavelength region from 350 nm to 600 nm; radiation is localized on the metal surface in the region of electron incidence and its intensity does not depend on the pressure of residual gases in the working pressure range of device; distribution of radiation intensity is defined by the current density in the transverse section of an incident beam.

As an example, in Fig. 2 we illustrate the photographs of the traces of EB glowing obtained at bombardment of metal targets by pulse (Fig. 2a,b) [3] and continuous (Fig. 2c,d) EB. In the last case, for radiation registration we have used photocamera with effective amount of points over EB cross-section of $N = 10^4$-10^5 (effective amount of points which form EB glowing, as a

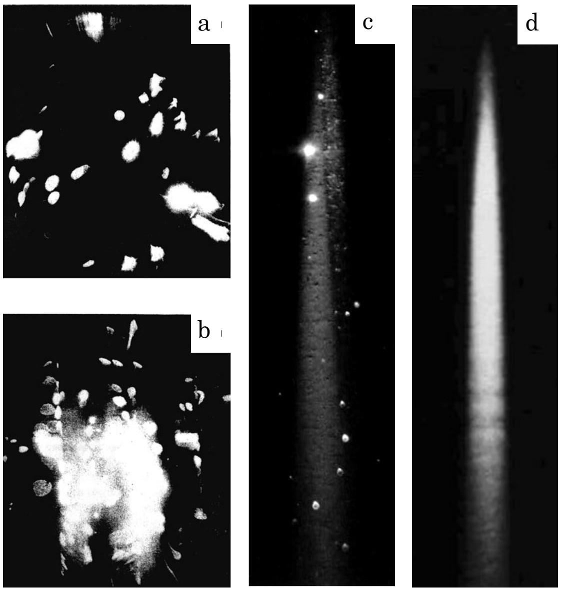

Fig. 2 – Glowing of the metal surface during electron bombardment: a, b – photographs obtained by the authors of [3] (molybdenum and copper-tungsten targets, respectively); c, d – photographs of the glowing trace of axially-symmetric EB on copper target at the values of beam power of 17,3 and 1,6 kW/cm^2, respectively

rule, does not exceed 25% of a number of camera pixels). If energy characteristics of the flow and power density on the metal surface corresponded to the operation mode of pulse EB with pulse duration of $\tau = 1\text{-}10^2$ s [3], formation of local sources of plasma radiation took place on the metal surface. In Fig. 2c, on the background of experimentally registered beam trace formed by transition radiation, microtorches distributed over the contact area of EB with surface are well observed. Considerable non-uniformities appeared in the detected radiation that led to the significant measurement inaccuracies. However, with the decrease in the EB power to units of kW/cm^2, plasma torches disappeared and just transition radiation was observed (Fig. 2d).

3. CONCLUSIONS

Different initiation mechanisms of surface glowing of metals during electron bombardment were considered in the comparative analysis of the results of works [3] and [1, 4-6]. It is established that phenomena of stable transformation of the EB energy on metal surface to the plasma energy [3] cannot be classified as “new physical phenomenon”, since they find explanation within classical representations of transition radiation and its variety – transition scattering that confirms fundamentality of the conclusions stated in work [1].

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