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Abstract

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Electron-Optical Observation of "Spot Fields" on Emitting Surfaces

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The regularities of thermionic, photo-, auto-, and secondary electron emission and of surface ionization are usually associated with the concept of the presence of regions with different electron work functions. Between individual surface areas a contact potential difference arises ("spot field"). With a sufficiently large number of inhomogeneities and an appreciable difference in the local work function, the interaction between spot fields becomes comparable with the external field ([1]). The concept of spot fields is a hypothesis, although a highly probable one*.

The purpose of the present work was the direct observation of spot fields in an electron mirror, which gives the shape and arrangement of the spots, establishes their relation to the crystalline structure and, what is very important, to the temperature of the emitter. We used a mirror previously employed by us for studying domains of ferromagnets and ferroelectrics ([2]).

Images formed by an emission microscope and a microprojector are also modulated by spot fields. However, the use of an electron mirror is more expedient, since: 1) the external electron beam irradiates the surface almost uniformly; 2) the temperature of the object is arbitrary; 3) the electrons move away from the object with zero velocity; 4) the contrast is additionally enhanced, since the tangential component of the spot field acts twice (during the forward and return motion of the electron). The minimal order of the contact potential expected on real cathodes, 0.01—0.1 V, is quite accessible to observation by the electron-mirror method.

Interest in the electron-optical observation of spot fields is aroused by a wide range of phenomena attributed to their influence. We shall note some of them. The presence of local coatings changes the electron work function. The processes of activation and deactivation of an oxide cathode are connected with a change in contact fields ([4]). On microprotrusions of metallic and composite emitters (for example, oxide and photocathodes) the external field reduces the work function. The interaction of the contact fields of emerging emission centers leads to an anomalous Schottky effect. The characteristics of electron-vacuum devices, upon transition from negative voltages to positive ones, do not have a sharp break

Fig. 1. “Retarding” curves at 20 and 400°; $V_p = 600$ V; the ordinate axis gives current in fractions of the maximum current

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(^{5,6}) (noticeable on a semilogarithmic scale) because of the inhomogeneity of the work function. The influence on the constant A and on the work function φ in the emission equation is attributed to local microfields (^{7}). Surface ionization on incandescent objects proceeds predominantly at places with a larger work function (^{8}). A reliably established deviation from the Maxwellian distribution, manifested in a deficiency of slow thermoelectrons from a thoriated cathode (^{9}). This deviation is attributed to the effect of spot fields (^{1}), which, however, meets with objections*.

In the “retarding” curves of secondary and photoelectrons, current saturation is often observed at a collector potential tens of volts more positive than that of the emitter (^{10}). These electrons have been called “electrons with insufficient energies.” For them, even (at accelerating potentials up to the saturation point) a distribution function is found. The data of the present work, in agreement with (^{11}, ^{12}), lead to the conclusion that this effect is imitated by spot fields. Overcoming the retarding effect of the spot fields is what gives rise to the need, for saturation, to apply positive potentials. In emission electron-optical systems, spot fields participate in the formation of image contrast. The presence of a tangential component of the spot fields reduces the resolution of a microprojector. The spot field acting on the electron trajectory also affects the structure of the beam in the electron gun. The influence of the spot fields on emission currents and on electron-optical images is substantially different. It should be expected that currents from smooth emitters are modulated by the normal component of the contact field E_{zk}. The contact field E_{zk} (for $E_{zk} > E_z$) returns slow electrons to the emitter, which causes a “stretching” of the characteristics. However, electron-optical images, even under conditions $E_z \gg E_{zk}$, will reflect, through the tangential component of the spot field E_{tk}, the presence of a microfield.

Fig. 1. “Retarding” curves at 20 and 400°; $V_p = 600$ V; on the ordinate axis, current in fractions of the maximum current.

To isolate the spot field, observation on sufficiently smooth surfaces is desirable, since the contrast of the image in an electron mirror is composed of the combined influence of the microgeometry and the local electric field. The objects of study

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* The contrast of the emission electron-optical picture, from which the presence of “spots” is usually judged (^{1}), is also caused by the influence of microgeometry, surface charge, and local space charge (^{3}).

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

—secondary-electron emitters—were carefully polished before activation. The dynodes were made of a copper-aluminum-magnesium alloy. After activation, an active film of thickness ~ 1000 Å forms on the surface. For a dynode whose electron-optical image we obtained, the "retarding" curves of the secondary-electron current are typical (Fig. 1). On the curve obtained at 20°, current saturation occurs at a considerable positive collector potential relative to the emitter (about +80 V). The curve obtained at 400° has saturation near zero potential. The course of the retarding curves was explained (^{12}) on the basis of a hypothetical assumption about the presence of spot fields ($T = 20°$). The transition to the ordinary form (at $T = 400°$) was interpreted (^{12}) as the exclusion of the influence of spot fields owing to the screening action of the surface semiconducting layer, since the electrical conductivity of the surface layer increases with increasing temperature. We monitored the polishing of the specimen by means of a metallographic microscope.

Figure 2 gives an optical photograph of the dynode surface. Only a few scratches caused by the mechanical treatment of the surface are visible. The image—

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[*] Nottingham believes (^{9}) that this effect is not caused by the spot field, since the phenomenon does not depend on the degree of activation of the cathode and occurs only in the region of slow electrons (for different specimens). In favor of the considerations of (^{1}) are our observations, since the spot fields (see below) are modulated by the crystal structure of the substrate, which does not depend on the degree of activation. In addition, on any specimens of thoriated tungsten the effect of spot fields must, naturally, under the condition $E_z \sim E_{zk}$, always appear in the region of slow electrons.

Fig. 2. Image of the dynode surface in an optical microscope (without etching the specimen), 100×

Fig. 3. **A**—structure of the "spot fields"observed in the electron mirror (without etching the specimen), 100×; **B**—image of the dynode surface in an optical microscope (after etching the specimen), 100×; **C**—defocused image of the etched dynode surface in an optical microscope, 100×

Figure 4

Figure 4: Figure 4

Fig. 4. A—surface of an L-cathode observed in the electron mirror, 100×; **B**—surface of an L-cathode in an optical microscope, 100×

after activation was the reflecting electrode of the electron mirror. In order to observe changes in the pattern of patch fields, provision was made for indirect heating and for measuring the temperature of the specimen (chromel-alumel thermocouple). The investigations were carried out at a vacuum of $3\text{-}5 \cdot 10^{-6}$ mm, when the potential of the reflecting electrode was equal to the potential of the cathode of the gun irradiating the object. Figure 3A shows the electron image of the surface of an activated cold dynode. This image differs substantially from the optical one (Fig. 2) by the presence of a distinctive structure of dark spots bounded by broad white borders. We observed on the screen that, with a slow increase in temperature, the contrast decreased and, at a temperature close to 400° (thermocouple reading error up to 10°), disappeared completely. When the heating was reduced, the spotted image appeared again, improved as the specimen cooled, and was restored when the previous temperature was reached.

We identify the observed electron image in Fig. 3A with the pattern of patch fields. What determines the sizes, shape, and contrast of the patch fields? It may be supposed that they are set by the granular structure of the substrate and by the preferential diffusion of Mg along the boundaries and, partly, the edges of the grains. On the substrate there is a thin active film of magnesium oxide, generating secondary electrons. To check this supposition and to reveal the structure of the substrate, the specimen was etched by ion bombardment ([13]). After etching, the structure was observed in an optical metallographic microscope (Fig. 3B). Figure 3C presents a defocused optical image of the same surface of the dynode etched by ion bombardment. Comparison of Figs. 3A, 3B, and 3C shows their qualitative agreement.

One should not expect identity of the electron (Fig. 3A) and optical (Figs. 3B and 3C) images for a number of reasons:

1) Regions with an altered work function, although located near grain boundaries, nevertheless, owing to Mg diffusion, cannot be strictly localized at the boundaries.

2) Patch fields extend into the vacuum and do not break off sharply at the surface. Consequently, the electron image of an unetched polished surface containing patches should be "softer" than the optical picture of the etched object. Because of the same nonsharp localization of the patch fields, the electron image also should not coincide with the optical picture of the etched polycrystalline surface. The defocused optical image (Fig. 3C) therefore imitates the patch fields better (Fig. 3A).

3) The partial blurring of the image (Fig. 3A) is connected with the fact that the refractive index in electron optics varies smoothly; for ordinary optics a sharp change of refractive index at the object-vacuum boundary is typical.

4) Visual observation of the patch field on the screen was more qualitative, since photographing (Fig. 3A) was external and was carried out at an oblique angle with respect to the tube and the screen.

In another metallic design of the electron mirror (2) we observed and photographed the surface of an L-cathode* (Fig. 4A). The electron image (Fig. 4A) reveals the granularity better than the optical one (Fig. 4B). The contrast of the electron image of the L-cathode is apparently due to the contact potential difference between grains of the sponge or larger regions surrounded by pores through which Ba or BaO had diffused. In Figs. 3A and 4A the boundaries appear as bright against the dark background of the image of the surface of a grain or of a region enclosed by pores. The sign of the contrast (Fig. 3A) permits the conclusion that, in our experiments, the boundaries are charged by the contact field posi— significant relative to the grain itself, and, consequently, at the grain boundaries the work function is smaller than on the grain itself.* Let us note that geometrical inhomogeneities on the polished object cannot modulate the contrast of the image (the conclusion is based on the observed sign of contrast at the grain boundaries). In addition, the parallel course of the delay curves (Fig. 1) and of the spot pattern with temperature, and the similarity of this pattern to the optically revealed structure of the substrate, make quite reliable both the interpretation of the nature of the "insufficient" electrons (12) and the reality of the spot fields observed by us.

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* The image was formed on the photographic plate directly by the electron beam; therefore the latter remark cannot be made.

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* This conclusion is consistent with the values of the work functions: $\varphi_{\mathrm{Cu}} = 4.5$-$5.2$ eV; $\varphi_{\mathrm{Mg}} = 3.2$-$3.8$ eV; $\varphi_{\mathrm{MgO}} \simeq 3$ eV.

Note: Figure translations are in progress. See original paper for figures.

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