OPTICAL AND PHOTOELECTRIC PROPERTIES OF SILVER-OXYGEN-CESIUM CATHODES

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An issue on the role of optical factors in photoelectron emission of modern effective photocathodes is very important for elucidating the nature of this phenomenon. For this purpose, we carried out a cycle of corresponding researches at our laboratory. In our previous publications [1], we reported, in detail, the results obtained for an effective cesium-antimonide photocathode. In that series of works, making use of the photoelectric wedge technique, we determined the optical constants of this cathode, established a direct relationship between the photoeffect and the light-wave energy in immediate proximity to the emitting surface, and so on. In this work, another main representative of modern effective photocathodes—the silver-oxygen-cesium (SOC) one—was subjected to similar studies. The previous attempts [2] to elucidate the role of optical factors for this cathode failed. The results obtained in the course of this study are briefly as follows.

A wedge-like SOC cathode to be studied was fabricated in a following way. Inside a tube imbedded into liquid air, a wedge of metallic silver was deposited onto the surfaces of a glass and two lateral platinum contact strips by evaporating from a point source. Then, oxygen was introduced into the tube, and a glow discharge with minus at the silver layer was ignited. In the course of the following gradual rise of the temperature, the silver wedge became gradually oxidized, getting transparent and demonstrating a pronounced interference pattern (isopachic fringes) in reflected light. An example of such a pattern is depicted by a curve in Fig. 1. In this figure, the dependence of the relative light reflectance R' on the coordinate x reckoned from the wedge center is shown for a wedge-like layer covering a glass substrate. The dependence was measured with the help of a monochromatic light probe ($\lambda = 800$ nm). Light is weakly absorbed in this wedge. Therefore, on the basis of formulas derived earlier [1] and knowing the ratio $R'_{\max}/R'_{\min}$, we can estimate the value of the refractive index for this layer, $n' \approx 1.9$ in our case.

Afterwards, the silver oxide, Ag_2O, layer was treated by cesium vapors following the standard routine. As a result, we obtained a required SOC cathode with a typical spectral characteristic (see below). The measurement results concerning the reflection of light with the same wavelength $\lambda = 800$ nm from this SOC layer are exhibited in Fig. 1 by curve R, which evidences for an appreciable light absorption. However—e.g., at $\lambda = 1000$ nm—the given coefficient $k \approx 0.3$ is relatively small (see below). Therefore, following the indicated procedure, the ratio $R_{\max}/R_{\min}$ can be used to approximately evaluate the magnitude of the refractive index of the SOC layer as $n \approx 2.1$ in our case. Bearing in mind that $n_1 \approx 1.5$ for a glass substrate and $n_2 > 2.5$ for a platinum sublayer, the inequality $n_1 < n < n_2$ should be obeyed, which is additionally confirmed by the dependence of the R-value in the region, where the wedge, getting narrower, comes to naught on both the glass (Fig. 1) and platinum (Fig. 2) sublayers.

Having determined the magnitude of n in such a way, it is possible, by analyzing the positions of interference fringes, to find the wedge thickness d at the fixed place and, afterwards, the value of d_0. The following formula describes the distribution of layer thickness along the wedge:

$$d = \frac{d_0}{[1 + (x/a)^2]^{3/2}}, \qquad (1)$$

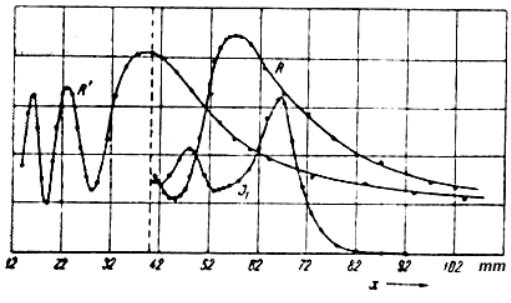

Fig. 1

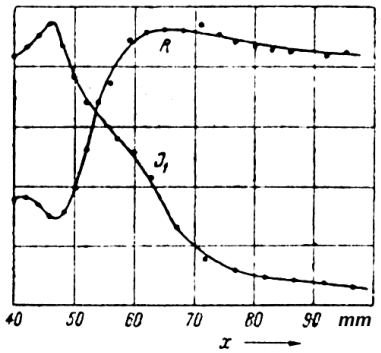

Fig. 2

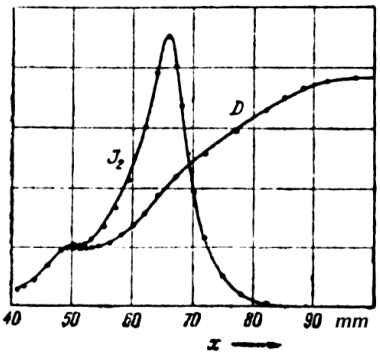

Fig. 3

and it enables one to determine the thickness of the SOC wedge at any place [1]. Carrying out the same procedure for the Ag_2O wedge, we can evaluate the swelling coefficient for the Ag_2O layer at its treatment with cesium to be of about 2.8.

Next, with the help of a monochromatic light probe, we measured the distribution of forward photocurrent along the SOC wedge, $I_1 = f(x)$. An example of those measurement results at $\lambda = 800$ nm is also shown in Fig. 1. While comparing curves R and I_1 in this figure, the following fact established by us for cesium-antimonide cathodes attracts immediate attention: the behavior of forward photocurrent is not monotonous but periodic, and its curve $I_1 = f(x)$ is almost in counterphase with the interference curve for reflected light $R = f(x)$, except for the last right maximum (see below). A similar phenomenon also takes place for the SOC wedge on the platinum strip, as Fig. 2 demonstrates (for $\lambda = 800$ nm). As was shown in our previous researches [1], this circumstance means that the forward photocurrent distribution is determined by the distribution of the energy of a light wave, ε, near the front photoelectron-emitting surface of the layer.

Owing to the inequality $n_1 < n < n_2$, the curves $R = f(x)$ in Figs. 1 and 2 have opposite behaviors in their right-hand-side sections (the influence of the half-wave loss at reflection), whereas the curves $I_1 = f(x)$ have different profiles here. Namely, in the case of a platinum sublayer, the photocurrent I_1 permanently grows up to its "optical" maximum as the layer thickness grows. In the case of a glass sublayer, it also has an additional natural "physical" maximum I_{1m} at the point, where the SOC layer thickness d_m approximately corresponds to the effective region of a photoemitter. Really, in the case of a glass sublayer with $n_1 \approx 1.5$, the relationship $n_1 < n > 1.0$ is satisfied, and the energy ε of a light wave in the right (thinnest) part of a wedge near the external surface of the layer grows, by favoring the photoemission. However, for this energy ε to be used completely, the cathode thickness has to be large enough and equal to d_m. The values of this quantity for various λ are quoted in Table 1.

Next, a similar method was used to measure the distributions of the optical transparency $D = f(x)$ and the inverse photoeffect $I_2 = f(x)$ along the wedge. An example of the results of these measurements for the SOC layer at $\lambda = 800$ nm , i.e. under the same conditions as in Fig. 1, is depicted in Fig. 3. One can easily verify that these results are quite similar to those obtained for a cesium-antimonide cathode [1]. Hence, Fig. 3 makes it possible to draw the following conclusions. The curve of transparency distribution $D = f(x)$ over our thin light-absorbing SOC film reveals a transmission interference pattern in its left-hand side section. The curve of inverse photocurrent distribution $I_2 = f(x)$ has, of course, a sharp physical maximum I_{2m} followed by a little additional maximum-plateau. The latter is in phase with the interference maximum in the transparency distribution curve, which is known [1] to testify that the distribution of inverse photocurrent is governed by the distribution of light-wave energy ε at the back—photoelectron-emitting, in our case—surface of the SOC layer. Moreover, as the results of our measurements demonstrate, the

Table 1

λ, nm	d_m, nm	k	$1/\mu$, nm	$1/\sigma$, nm
420	45	0.8	42	63
500	47	1.3	29	75
600	55	1.3	34	85
700	62	1.2	48	81
800	67	0.8	83	50
900	62	0.5	132	33
1000	88	–	–	–
1100	97	–	–	–

position of the main "physical" maximum of the inverse photocurrent I_{2m} accurately coincides with the position of the "physical" maximum of the forward photocurrent I_{1m} and corresponds to the same wedge thicknesses listed in Table 1 at every wavelength λ. However, in all cases, $I_{2m} > I_{1m}$, with their ratio ranging from 1.5 to 1.8.

All the measurements at $\lambda = 800$ nm, the results of which are shown in Figs. 1–3, were carried out in the spectral interval 420–1100 nm. Here, the results can differ a little, because the optical constants of a SOC layer change with the wavelength λ (see below); this fact was established for a cesium-antimonide layer as well [1]. To give a certain characteristic to the measurements fulfilled, Fig. 4 demonstrates the spectral distributions—normalized to the unit of incident energy—of the forward photocurrent I_1 and the optical transparency D at a point, where the layer thickness equals 62 nm. It also exhibits the maximal values of inverse photocurrent I_{2m} at points, where the layer thickness is equal to d_m listed in Table 1. Figure 4 makes it evident that the spectral distribution curves for both photocurrents are equivalent to the known distributions, typical of a normal SOC photocathode [3], by the presence and positions of both maxima, and by the photoemission threshold.

Therefore, in our case of SOC cathodes, similarly to cesium-antimonide ones [1]—and, probably, for all effective photocathodes—it is necessary to recognize the energy of light wave in the immediate proximity to the photoelectron-emitting surface of a cathode as one of the major factors governing the photoemission process. In experiments, this fact often becomes hidden by other complicating phenomena. In the case of SOC cathodes, the following thing is of special interest. If the cathode is treated with cesium, a huge amount of deoxidized metallic silver should be separated out in the cathode bulk in the course of the reaction $Ag_2O + 2Cs \rightarrow Cs_2O + 2Ag$. Therefore, either the separated silver has to become uniformly distributed over the cathode volume in the form of extremely fine particles with dimensions $l \ll \lambda/n$, or a homogeneous system is to be formed. It is so, because a pronounced interference pattern in the layer can be obtained only provided that either of those two cases is realized.

Besides the optical factors, the kinetics of motion of excited photoelectrons in the cathode in the course of photoemission is also of great importance. Earlier, we considered this issue in the case of cesium-antimonide cathodes. We intend to elaborate it for the case of SOC cathodes as well. However, some preliminary evaluating

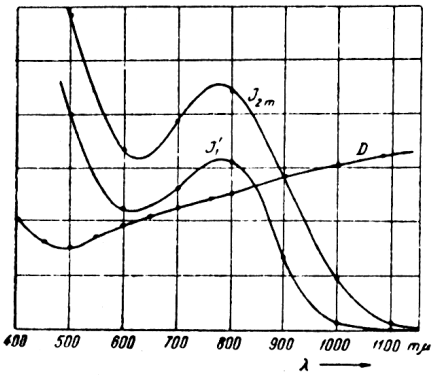

Fig. 4

calculations can be carried out just now. Taking advantage of the monochromatic transparency curve $D = f(x)$, or $D = f(d)$, in the range of large thicknesses and the formula

$$D = A\exp(-\mu d) = A\exp\left(-4\pi\frac{k}{\lambda}d\right), \qquad (2)$$

one can evaluate the reduced absorption coefficient k and the effective path length of light quanta in the cathode $1/\mu$. Then, knowing the layer thickness d_m (see Table 1) in the maximum of inverse photoeffect and making use of the formula

$$d_m = \frac{\ln(\mu/\sigma)}{\mu - \sigma}, \qquad (3)$$

it is possible to evaluate the effective path length $1/\sigma$ of a photoelectron in the material of a SOC cathode. The corresponding results obtained for k, $1/\mu$, and $1/\sigma$ for various light wavelengths λ are quoted in Table 1. By comparing the relevant values for SOC and cesium-antimonide [1] cathodes, one can see that they are similar—in general, of course. This circumstance allows one to hope that a unified theory could be developed not only concerning the role of optical factors but the kinetics of electron motion and so on in the general physical problem dealing with modern efficient photocathodes.

1. N.D. Morgulis, P.G. Borzyak, and B.I. Dyatlovitskaya, Dokl. Akad. Nauk SSSR **52**, 681 (1946); **56**, 925 (1947); Izv. Akad. Nauk SSSR, Ser. Fiz. **12**, 126 (1948).
2. W. Kluge, Phys. Z. **34**, 465 (1933); H. Ives and A. Olpin, J. Opt. Soc. Am. **24**, 198 (1934).
3. See, e.g., S.Yu. Lukyanov, *Photoelectric Cells* (Academy of Sciences of the USSR Publ. House, Moscow–Leningrad, 1948) (in Russian), Figs. 27–29.

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BORZYAK PETRO GRYGOROVYCH (03.09.1903–15.08.2000)

Corresponding Member of the Nat. Acad. of Sci. of Ukraine P.G. Borzyak was the famous scientist in the field of emission electronics and nanophysics. He studied the physical mechanisms of photoelectron emission from cathodes of various types. P.G. Borzyak proved experimentally that the most efficient photoemitters are semiconductors; proposed the idea of photoelectron spectroscopy which became one of the basic methods of studies of the electron structure of surfaces of solids; revealed the particular electronic properties of metals in the state of colloidal (nano-sized) particles; and discovered (together with O.G. Sarbey and R.D. Fedorovych) the phenomenon of electron emission from fine-dispersed (island) metallic films. This discovery allowed one to produce cathodes of new types and underlay many subsequent studies of the inequilibrium heating of an electron gas in nanoparticles. The detailed theory of these processes was developed by P.M. Tomchuk and his colleagues.

P.G. Borzyak trained many highly qualified experts in the field of emission electronics and nanoelectronics and made the weighty contribution to the development of this scientific trend in Ukraine.

MORGULIS NAUM DAVYDOVYCH (14.05.1904–01.09.1976)

Corresponding Member of the Acad. of Sci. of UkrSSR N.D. Morgulis was the famous scientist in the field of physical electronics, surface physics, and plasma physics. He studied the mechanisms of electron and ion emissions from solids, as well as the processes running in electron emitters of various types; constructed the first ion microscope-projector; founded the Department of Physical Electronics at the Institute of Physics of the Acad. of Sci. of UkrSSR and the corresponding chair at Taras Shevchenko Kyiv National University. After the war, N.D. Morgulis initiated the studies of surface phenomena under superhigh vacuum, the development and mastering of new methods for the diagnostics of surfaces. Together with P.M. Marchuk, he proposed an efficient method for the direct transformation of heat energy to electric one with the use of thermoemission transducers filled with Ce vapor. A number of important works of N.D. Morgulis are devoted to the physics of low-temperature plasma.

N.D. Morgulis trained many highly qualified experts on physical electronics and founded the Kyiv school in this field recognized over the world. The National Academy of Sciences of Ukraine established the Morgulis' Prize awarded for the outstanding works on surface physics and physical and nanoelectronics.