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FIRST SYMPOSIUM ON AUTOELECTRONIC EMISSION

-USSR-

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[Following is the translation of an article by V. A. Gor'kov in Radiotekhnika i elektronika (Radiotechnology and Electronics), Vol V, No 12, Moscow, 1960, pages 2069-2073.]

On 10-20 May 1960, the first sumposium in the Soviet Union on autoelectronic emission (AEE) was held in Tashkent on the initiative of the Commission on Electronic Emission under the Presidium of the Academy of Sciences of the USSR.

Representatives of scientific research institutions, higher educational institutions, and designing bureaus of Moscow, Leningrad, Tashkent, and other cities participated in the work of the symposium.

Twenty-two papers and brief communications were heard and discussed concerning the autoelectronic emission of metals and semiconductors, the emission of "hot" electrons, as well as the investigation of the physical and chemical processes by means of electronic and ionic projectors.

The symposium opened with a word of welcome to the delegates by the Prorector of the Middle Asiatic State University imeni V. I. Lenin, L. N. Babushkin, who noted the remarkable progress made in the field of scientific research work on autoelectronic emission in the USSR during the last few years.

G. N. Shuppe presented to the first session a survey of the "Research in autoelectronic emission in the USSR." The speaker examined in its general features the historical chronology of the basic work devoted to the investigation of autoelectronic emission in the Soviet Union. Noting the ever growing interest in AEE investigation, the speaker briefly characterized the problems of the work and the successes of a number of the scientific research collectives working in this field which have been formed in the USSR to the present time. G. N. Shuppe concluded by attempting to analyze the present state and the interrelations of the theoretical and experimental work in the AEE field.

In the discussion of the first paper, V. B. Sandomirskiy noted a number of inaccuracies in the treatment of new theoretical calculations concerning the effect of the potential barrier form and the spatial charge upon the course of the volt-ampere characteristic curves of AEE made by A. S. Kompaneyets. It was also pointed out that the author referred to the type of experimental volt-ampere characteristic curve obtained by I. I. Gofman, G. N. Shuppe, and O. D. Protopopov in investigating the impulsive AEE of tungsten. The author considered this characteristic curve as a confirmation of the theory of A. S. Kompaneyets, while actually it contradicts this viewpoint.

A. S. Kompaneyets explained his calculations and agreed with V. B. Sandomirskiy's remark that the volt-ampere characteristic curves of AEE constructed on his own theoretical calculations on the scale: $\lg I = f\ (1/V)$, where I is the AEE current and V the anode voltage, will deviate in the area of high current densities from a straight line to the direction of smaller current. This agrees with most of the experimental work.

M. I. Yelinson pointed out that the absence from the survey of information on current foreign research impoverishes it and renders difficult a correct understanding of AEE problems; he reported briefly on the latest work in the USA on the production of stable autoelectronic cathodes suitable for practical use.

V. N. Shrednik noted the absence from the survey of information on the work being done in the USSR on ion projectors.

K. I, Krylov and V. L. Fedorov in a paper on "AEE cathodes made of small-diameter wire," reported on the investigation of autoelectronic cathodes made in the shape of fine cylindrical pivots (diameter 2-3 microns) of tungsten, which emit electrons from a rounded end. In the opinion of the authors, such a design could prevent the rapid destruction of the emitter as a result of the disintegration of its working surface due to ion bombardment. It could also insure a considerable length of service for the autoelectronic cathode, which will only be limited by the length of the cylindrical part of the cathode and the rate of pulverization of the material from the working surface of the emitter.

The participants in the discussion; G. N. Shuppe, M. I. Yelinson, V. A. Gor'kov, B. V. Smirnov, V. N. Shrednik, A. G. Zhadan, and V. A. Shishkin, expressed doubt about the value of this kind of research, because the formation of accidental irregularities arising on the emitting surface as a result of ion bombardment and local vacuum arcs does not make it possible to obtain stable cathodes with assigned and reproducible parameters.

A. P. Komar, V. P. Savchenko, and V. N. Shrednik in a paper, "Coefficients of the surface diffusion of beryllium on tungsten," reported on the determination of the coefficients of diffusion of beryllium atoms on the various crystallographic faces of tungsten from the dependence of the rate of migration upon temperature.

For a precise determination of the temperature of the point, a tantalum-tungsten microthermocouple was used. The authors believe that the process of diffusion in this case represents a displacement of the beryllium atoms over the beryllium layer on the tungsten. Also noted was the possibility of the existence of sharply differing rates of diffusion in the two mutually perpendicular directions on the face (110), which may be explained by the presence of dislocations on the large faces of the monocrystal. The values of the activation energy of the diffusion of beryllium on the various faces have been obtained.

G. N. Shuppe, who spoke in the discussion, pointed out that in his opinion, the mechanism of surface diffusion, as well as the other surface phenomena, should not be studied on the points in the projector, but on the large monocrystals. Use can be made here, of the tagged-atom, thermoemission, and photoemission methods, etc. He exhibited the emission picture of a large monocrystal of tungsten (diameter 10 mm) obtained by the thermoemission method.

A. P. Komar noted that in working with large monocrystals, one cannot obtain reliable information about the diffusion mechanism on an ideal face. This conclusion follows from the presence of various lattice imperfections (for example, dislocations) on the large surfaces of monocrystals.

In the ensuing discussion, the general opinion was expressed that it was advisable to use both methods with subsequent comparison of the experimental results obtained.

A. P. Komar, Yu. N. Talanin and N. A. Chernyavskaya gave a paper on "Effects of the distribution of admixtures on the emission picture of platinum." The authors observed an "explosive" expansion of the bright spots in the emission picture of the platinum monocrystal when the emitter is cooled rapidly. This phenomenon is to be explained on the basis of the Gibbs principle and the relation between the surface energy, the work of electron discharge, and the melting temperature.

For an unequivocal clarification of the role of admixtures in the phenomenon observed, it was proposed during the discussion of the paper that these experiments be repeated on super-pure platinum.

I. L. Sokol'skaya in a "Study of the adsorption, migration, and evaporation of cadmium on tungsten in the electron projector" (the paper was read by Yu. V. Zubenko), determined from volt-ampere characteristic curves of the AEE current, the work of electron discharge for tungsten covered with an optimal and "thick" layer of cadmium. The magnitude of the discharge work was found to be in good agreement with Anderson's data. The heat of evaporation of cadmium from tungsten was also measured.

Those who made remarks on the paper pointed out the incorrectness of the method of evaluating the degree of covering, as well as the fact that the measurements made were integral in character.

Yu. V. Zubenko read a paper on "Adsorption, migration, and evaporation of barium on carbidized tungsten W_2C."

The measurements were made in the electron projector under vacuum conditions of the order of 10^{-9} mm of mercury. Initially, the barium is adsorbed by the lateral faces of the hexagonal prism, then is accumulated in the vicinity of the basal face (1000), while the area between them remains uncovered.

With an increase in the thickness of the barium layer on the crystal surface, the AEE grows, passes through a slightly pronounced maximum, and reaches a constant value; no bright band corresponding to the discharge work minimum is observed when the cold point is covered with barium powder. In this study the heat of barium evaporation from a group of several faces of the monocrystal was measured.

The paper provoked a lively discussion, in which A. P. Komar, V. N. Shrednik, G. N. Shuppe, and others took part. The speakers noted with surprise the fact that the heats of barium evaporation from tungsten and from tungsten carbide coincided, as this does not occur in the case of thorium adsorbed on the same substances. It was also remarked that the author of the paper did not offer an explanation of the fact that barium was absent from the pyramidal faces of the W_2C monocrystal.

V. I. Veksler read a paper "On one method of evaluating the effect of a layer of ad-atoms on the work of discharge of the electrons of the substratum." On the basis of earlier developed notions of electron exchange in the interaction of the atom with the surface of a metal, the author proposed a possible interpretation of the reasons for the influence of the ad-atoms nature and the metal monocrystal's face type on the change in its discharge work.

The diminution of the discharge work is found to keep pace with the increase in the metallic radius of the ad-atom (r) and the density of the packing of the face (δ). With equal r and δ the ad-atoms of the alkaline metals should yield less electropositive layers than the ad-atoms of alkaline-earth metals. On the basis of the proposed model, the author of the paper gave a qualitative interpretation of much experimental data.

V. B. Sandomirskiy, speaking in the debate, pointed out the advisability of a multi-electron statement of this problem. He remarked that the term "radius of the atom" is becoming indefinite for the ad-atom, and expressed his feelings about the necessity of uniting the efforts of the theoreticians working in the field of catalysis and adsorption, with those of the specialists in the field of electronics for a full solution of the adsorption problem.

V. N. Shrednik noted that the concepts of the relationship between the discharge work of the adsorbate and the adsorbent also permit an explanation of the experimental results observed.

G. N. Shuppe thought that the presence of an electron exchange between the adsorbate and the adsorbent was a sufficient vindication of the hypothesis proposed in the paper. He also considered it advisable to introduce the function of neutralization of the effective charge of the ad-atom (according to Gerni).

Yu. V. Zubenko read a paper on "A study of the form of monocrystal emitters made of tungsten carbide in the electron microscope." The author exhibited photographs of the shadow images of the points' tips, in which it could be seen that the extremities of the monocrystal points of tungsten carbide W_2C were rounded, with the rounding not being a hemisphere symmetrical with respect to the axis of the point, but a surface with a more complex curvature. Upon carbidization, there is a heavy deformation of the tip of the point. With a precision corresponding to the resolving power of the electron microscope, the absence of flat sections on the extremity of the point was established.

M. I. Yelinson commented that the technique had to be changed substantially for a fuller investigation of the point form, so as to insure the observation of a large quantity of samples in different perspectives.

In a paper by I. L. Sokol'skaya and G. P. Shcherbakov, "A study of the effects of a strong field in cadmium-sulfide monocrystal emitters," it was shown that the drop in voltage in the emitter varies within broad limits depending upon temperature and illumination. It established the non-ohmic character of the conductivity, testifying to the increase in the concentration of the current carriers under the action of a strong field. It proved that the non-ohmic character of the conductivity was due to contact phenomena. It investigated the dependence of the volt-ampere characteristic curves of the AEE current in darkness and when illuminated, upon the magnitude of the drop in voltage on the emitter. This was determined from the threshold of the delay curve of the flow of AEE to the collector. Curves of the distribution of autoelectrons by energies from the cadmium sulfide were obtained.

M. I. Yelinson, joining in the discussion, noted that the work reported upon was the first investigation in the world into the distribution of autoelectrons by velocities for semiconductors, and that the original sounding technique of simultaneous determination of the dependence of the electro-conductivity and emission of CdS upon the magnitude of the electric field deserves attention. To separate the effects of an increase in the concentration of electrons from the effects of a change in the function of electron distribution by energies which occur at high values of the internal electric field in CdS, it is advisable to make investigations of the distribution curves for various densities of the autoelectron flow.

V. B. Sandomirskiy pointed out that a separation of the above-mentioned effects can also be accomplished by changing the frequency spectrum of the underlighting of the emitter of SdS.

The author of the paper (G. P. Shcherbakov) was asked a number of questions regarding the break observed in the volt-ampere characteristic curves of the AEE of CdS. In his reply, Shcherbakov noted that at present it is difficult to give a satisfactory explanation of this fact.

K. I. Krylov, A. G. Bonch-Osmolovskiy and V. L. Fedorov offered a paper on "The formation of an electron stream from an autoemission cathode by means of a strong impulsive magnetic field." Applying impulsive magnetic fields of a magnitude of several hundreds of kilo-oersteds, the authors succeeded in forming an electron stream in the impulse regime with a sectional diameter of $\sim$ 50 mk and a current magnitude of $\sim$ 1-2 A.

V. A. Shishkin, in his paper on "Investigation of emission images arising from the adsorption of diatomic molecules and molecules of inert gases," reported on an investigation in the electron projector of the adsorption of Ne, Ar, O_2, N_2 and H_2 in the pressure internal $1 \cdot 10^{-7}$ - $1 \cdot 10^{-4}$ mm of mercury with an applied electric field. The author believes that the behavior of the bright round spots in the adsorption of argon, and particularly their migration in the field in the temperature interval 300-700°K, indicates that the monatomic molecules of the inert gases are capable of replacing their outer electrons by electrons of a metal. The paper discussed the possible mechanism of the adsorption of inert gases in the field. The appearance of the bright spots in the multi-layer adsorption of molecules of diatomic gases (H_2, N_2), accompanied by the growth in emission current and the low temperature of their disappearance indicate, in the author's opinion, the possibility of adsorption of these gases in the field in molecular form.

A. P. Komar, G. N. Shuppe, V. N. Shrednik, N. B. Ayzenberg, and others took part in the discussion of the paper.

The basic idea of their remarks was that the technique employed in the work did not guarantee a high degree of purity in the gases used, which is necessary in research of this kind; therefore, the conclusions drawn by the author regarding the mechanism of the phenomena observed were doubtful.

N. A. Gorbatyy gave a brief report on "The influence of the temperature of the point of the ion projector on ionization at the surface." He observed an ion image (of the "dot" type) of the tungsten monocrystal in the ion projector with hydrogen accumulation. Experiments have shown that raising the temperature of the point from -193°C to room temperature sharply reduces the intensity of the ion image, which disappears entirely at 800°C. After heating the point in a strong electric field, the formation of spiral structures was detected. These were observed on the screen of the ion projector. The results cited, in the author's opinion, testify against the conception of the ion image as a result of surface ionization intensified by the field, and in favor of the idea of autoionization.

Participants in the discussion expressed a desire for a broadening of the work with the ion projector.

S. Z. Roginskiy and V. A. Shishkin, in a paper on "Investigation of the complex molecular pictures of a number of element-organic and organic compounds," reported on the investigation in the electron projector of a number of organic compounds containing the bonds $C = C$; $C = N$; $C - O$; $N \equiv C$; $Ge - Ge$; $N - H$; $N - N$. The authors believe that the results of their work confirm the dependence found earlier between the presence of π-electron bonds in molecules and the form of complex emission images. This is to be explained by the replacement of weekly bound electrons in the molecule by electrons issuing from the metal. The study also showed that the form of the molecular pictures does not depend upon the kind of substratum (semiconductor; metal covered with O_2; metal).

In discussing the paper, A. S. Kompaneyets noted the necessity of analyzing the possibility of explaining the observed emission pictures by means of the diffraction of electrons on the molecules adsorbed by the metal surface of the emitter, and of ascertaining the dependence of these pictures upon the properties of the symmetry of the crystal.

A. P. Komar pointed out that from the viewpoint of the ideas presented, it was difficult to explain the appearance of pictures of large dimensions on the projector screen.

As a result of the discussion of the paper, it was recommended that this work be continued in order to ascertain the fundamental possibilities of the method in the investigation on the structure of molecules.

D. N. Vasil'kovskiy read a paper on "The question of the stability of faces and the computation of the surface energy of a crystal." The analysis made by the author, within the framework of the supposition regarding the additive nature of the binding forces of the atoms and the limited radius of their activity in the crystal lattice, permitted a number of conclusions on the equiponderant form of monocrystals under different temperature conditions and in the presence of a strong electric field.

The author of the paper was asked a number of questions concerning the physical nature of his work and its relation to the preceding work by Stranskiy-Zurman and L. D. Landau.

M. I. Yelinson, A. G. Zhdan and G. F. Vasil'yev in a study "On the interpretation of the course of the volt-ampere characteristic curves of the autoelectronic emission of semiconductors and metals," presented a number of experimental volt-ampere characteristic curves obtained for the semiconductor systems $SiO_2 + C$ and $Al_2O_3 + C$, and showed that these characteristic curves must be regarded as a transition from the exponential law of emission to a slower law in the area of the removal of the surface potential barrier, i.e. with $\Theta(y) \simeq 0$ ($\Theta(y)$ being the Nordheim function.

Between the area $\Theta(y) \simeq 0$ and the area of the rectilinear course of the characteristic curves contructed on the coordinates lgj = f(1/E) (j being the density of the autoemission stream, E the electric field on the surface of the emitter) there is a transitional area for which the lack of coincidence with the theory is to be explained by the difference of the form of the potential barrier from the classic law of the forces of image formation and by the improper use of a quasi-classical method in computing the transparency of the potential barrier. The authors offered a digest of all the observed kinds of volt-ampere characteristic curves of the AEE of metals and semiconductors, and gave their interpretations.

G. N. Shuppe expressed the idea that the characteristic curves given for metals in the apper would be due to the semiconductor "casing" on their surface.

M. I. Yelinson noted that the observed emission pictures and the purity maintained in the experiments controvert this point of view.

A. S. Kompaneyets remarked that the characteristic curves presented by the authors were very interesting, especially in the area of strong electric fields in which the surface potential barrier is removed.

Yu. V. Zubenko exhibited experimental volt-ampere characteristic curves of the autoelectronic emission of tungsten at high flow densities in the impulsive regime which coincided with those given in the paper by M. I. Yelinson, A. G. Zhdan, and G. F. Vasil'yev, differing from them in certain interesting particulars only in the area of pre-breakdown flows.

M. I. Yelinson read a paper by G. F. Vasil'yev on "The effect of the form of the surface potential barrier and of the distribution of the field over the surface of the emitter upon the appearance of the volt-ampere characteristic curves of AEE." The paper examined the coefficient of transparency of the potential barrier on the solid body-- vacuum boundary --, taking into account the deviation of the potential function at small distances from the surface, from the potential of the forces of image-formation.

The author obtained a function differing from that of Nordheim in the area of strong fields. He also obtained a formula for the AEE flow density which takes into account the distribution of the electric field over the surface of the transmitter.

A. S. Kompaneyets, participating in the discussion, pointed out a certain artificiality in the form of the barrier introduced by the author.

G. A. Kudintseva reported on the Technological elaboration of the industrial manufacture of autoelectronic cathodes for certain classes of electronic instruments operating in the impulsive and stationary regimes. Her report gave data on the electric parameters of the cathodes and their length of service.

Sh. M. Kogan and V. B. Sandomirskiy gave a paper on "The emission of electrons from semiconductors under the action of strong electric fields."

The authors obtained the function of the distribution of "hot" electrons in a semiconductor, taking into account the diffusion against acoustical and optical backgrounds and inter-electron collisions. They computed the volt-ampere characteristic curve for the emission of super-heated electron gas. They examined the dependence of the volt-ampere characteristic curve upon the heating field and the temperature. They obtained the distribution of the hot emitted electrons by full energies.

A. S. Kompaneyets made a remark about the necessity of taking into account the surface phenomena in computing the emission flow of hot electrons into a vacuum, and also noted the importance of the ideas expressed in the paper about the possibility of restoring the form of the iso-energic surfaces from the character of the distribution of the emitted electrons by velocities.

M. I. Yelinson and A. G. Zhdan gave a short report on "Emission of electrons under the action of a strong electric field from cylinder-shaped cathodes on a SiO_2 + C base." The authors detected electron emission from cathodes made of tungsten wire with thin coatings of amorphous quartz or activated carbon. The cause of the emission is the strong electric field applied to the layer of SiO_2 + C. The study investigated the dependence of the emission flow upon the applied electric field, the temperature, the anode voltage, and also the distribution of the flow over the survace of the emitter.

The authors of the paper were asked a number of questions about the technique of preparing the emitters and the character of the dependences observed.

In conclusion, M. I. Yelinson reported on some results of work on the investigation of the emission of hot electrons from p--n-transitions in SiC.

O. D. Protopopov and B. G. Smirnov presented the results of their work in "The effect of silicon and germanium on electronic emission from the tungsten monocrystal." The authors believe that Si and Ge can build the tungsten crystal up to its "equiponderant" form. On the electron projector screen a characteristic ring-shaped glow was observed around the emission pictures corresponding to the faces (110), (112), (100) -- analogous to that observed in investgating the migration of tungsten over tungsten -- in the same temperature interval. The evaluation of the activation energy of the migration of Si and Ge over gunsten faces gives a magnitude close to that of the energy of activation of the migration of tungsten over tungsten. No change was detected in the mean magnitude of the discharge work of the gungsten point when covered with Si or Ge powder.

A. P. Komar and V. N. Shrednik pointed out the incorrectness of the method of powdering the tungsten point with Si and Ge, which does not allow the quantity of layers of the migrating atoms to be determined, or the front of migration to be observed. The emission picture of tungsten before being covered with Si and Ge powder, in the opinion of the speakers, attests to the conditions of insufficient cleanliness under which the experiment was conducted.

Yu. V. Zubenko and A. I. Klimin reported on a series of analogous work on the investigation of the behavior of Si and Ge on the surface of tungsten. The discussion brought out the fact that the experimental methods of this work were more perfect and the results obtained more reliable, than in the work by O. D. Protopopov and B. G. Smirnov.

A. P. Komar spoke the concluding words, expressing his satisfaction with the work of the symposium. On behalf of all those present, he thanked the heads of the Middle Asiatic State University imeni V. I. Lenin, and particularly G. N. Shuppe, for the good organization of the sumposium's work.

The resolution of the symposium noted the progress in AEE research recently attained in the USSR and outlined a number of measures aimed at the further expansion and deepening of scientific research in this very promising field of electronics.

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