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FIELD EMISSION INITIATION MECHANISM OF VACUUM ARC

by

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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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Page 120.

FIELD EMISSION INITIATION MECHANISM OF VACUUM ARC.

G. N. Fursey.

The phenomenon of vacuum breakdown substantially limits the use of a different kind of high-voltage vacuum devices and instruments. To this problem is devoted the very large number of works (see surveys [1-4]). However, the mechanism of this phenomenon still remains poorly understood. The fundamental reasons for this they are the probabilistic nature of the process of initiation, depending on the large number of factors, that determine real experimental conditions, and extremely short transit time to the high conductivity of gap/interval (10^{-8}-10^{-9} s).

In this connection special importance finds conducting experiment under strictly controlled/inspected conditions and formulation of problem for detection of those phenomena, which directly precede this transition/junction.

EXPERIMENTS ON AUTOCATHODES.

Purest/cleanest conditions for experimentation are realized at present for case of breakdown with needle-like auto-emitter (pressure of residual gases 10^{-9}-10^{-12} mm Hg, ideal single-crystal surface of electrode, purified of adsorptive films, retention/maintaining surface finish for elongation/extent of entire experiment with visual monitoring in terms of emissive pictures).

Beginning of investigation of processes, which lead to breakdown on emitters in the form of points, was established by works of group of Dike [5, 6]. Utilizing pulsed operation of effect and recording (0.5-2 μs), for the authors it was possible to establish that the density of emissive current, unambiguously connected with the electric intensity, is the fundamental parameter, which determines the phenomenon of breakdown. Was shown [7, 8] the nonessentiality of anodic processes and the absence of the effect of total voltage (in the range from 5 to 60 kV).

Pulse method made it possible to also reveal/detect characteristic effects, which precede transition/junction of autoelectronic emission into vacuum arc, and to demonstrate strict controllability of phenomenon of breakdown.

Appearance of bright ring around usual emissive image was one of such effects, by others - spontaneous build-up/growth of emissive current in time with constant voltage/stress in pulse. Both these phenomena were interpreted as the effects, connected with heating of emitter by their own emissive current.

Page 121.

The tentative calculation, carried out into [9], it showed the validity of this assumption. Late the fact of the heating of emitter in the prebreakdown phase was confirmed by stricter calculation [10] and straight/direct experiments in the works of our laboratory [11, 12]. We also showed [11-14] the generality of the prebreakdown laws for the wide circle of objects (W, Ta, Mo, Re, W_2C) indicated.

Photographs of effects of ring and spontaneous changes in current, obtained in our laboratory, are represented in Fig. 1 and 2.

DESTRUCTION OF THE AUTOCATHODE WHICH INITIATES BY A BREAKDOWN.

Discovered thermal effects testified about strong heating of emitter in prebreakdown phase. Relying on this fact, the authors [5, 6, 9] developed the qualitative theory of initiation.

It was assumed that upon reaching/achievement of specific current density through apex/vertex of point emitter begins to be heated by Joule heat. An increase in the temperature of emitter leads to an increase in the emissive current as a result of the transition/junction of autoelectronic emission into the autothermoelectronic. An increase in the current in turn produces an increase in the temperature and so-forth it is avalanche-like up to the melting of emitter. In the final stage the rate of the development of avalanche can increase due to the incipient evaporation of the material of cathode, ionization of the vaporized atoms and neutralization of space charge of electrons with positive ions.

We have noted [11, 13, 15, 16], that similar build-up/growth of avalanche cannot explain sharp explosion-like transition/junction to breakdown, observed experimentally. For all investigated objects of oscillogram show that with the very careful approximation/approach to a critical state it is possible to trap the quasi-stationary section (Fig. 2a, oscillograms 5, 6 and Fig. 2b, oscillogram 3), in which a spontaneous increase in the current almost completely ceases.

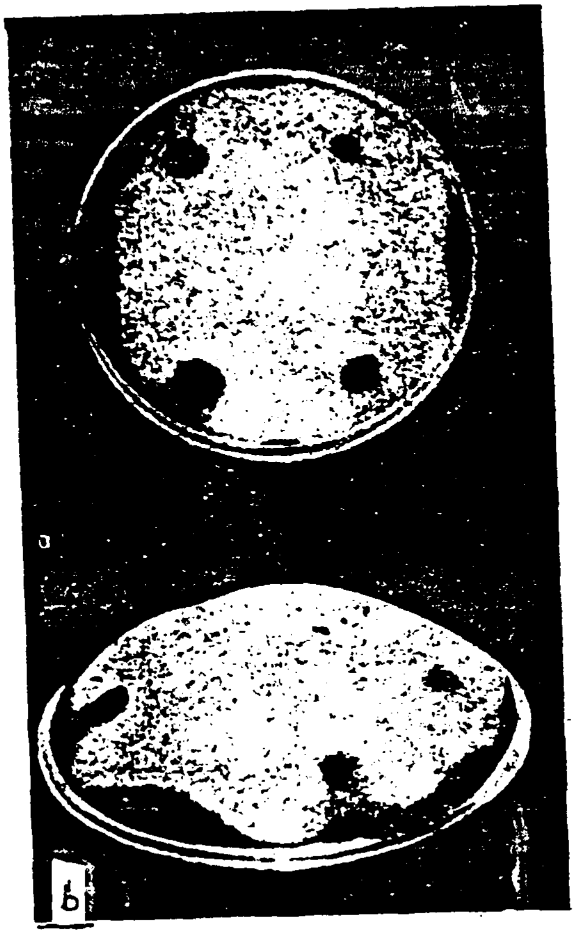

Fig. 1. Effect of ring for Ta. a) front; b) profile/airfoil.

Page 122.

Further increase in the time of the transmission of current nevertheless leads to the breakdown (Fig. 2a, oscillogram 6). This puts in doubt the destruction of the emitter as a result of the avalanche pointed out above, since current virtually does not grow.

It was assumed [11, 13] that the direct transition to the arc can be connected with process, analogous to electrical blast of thin wires [17-19].

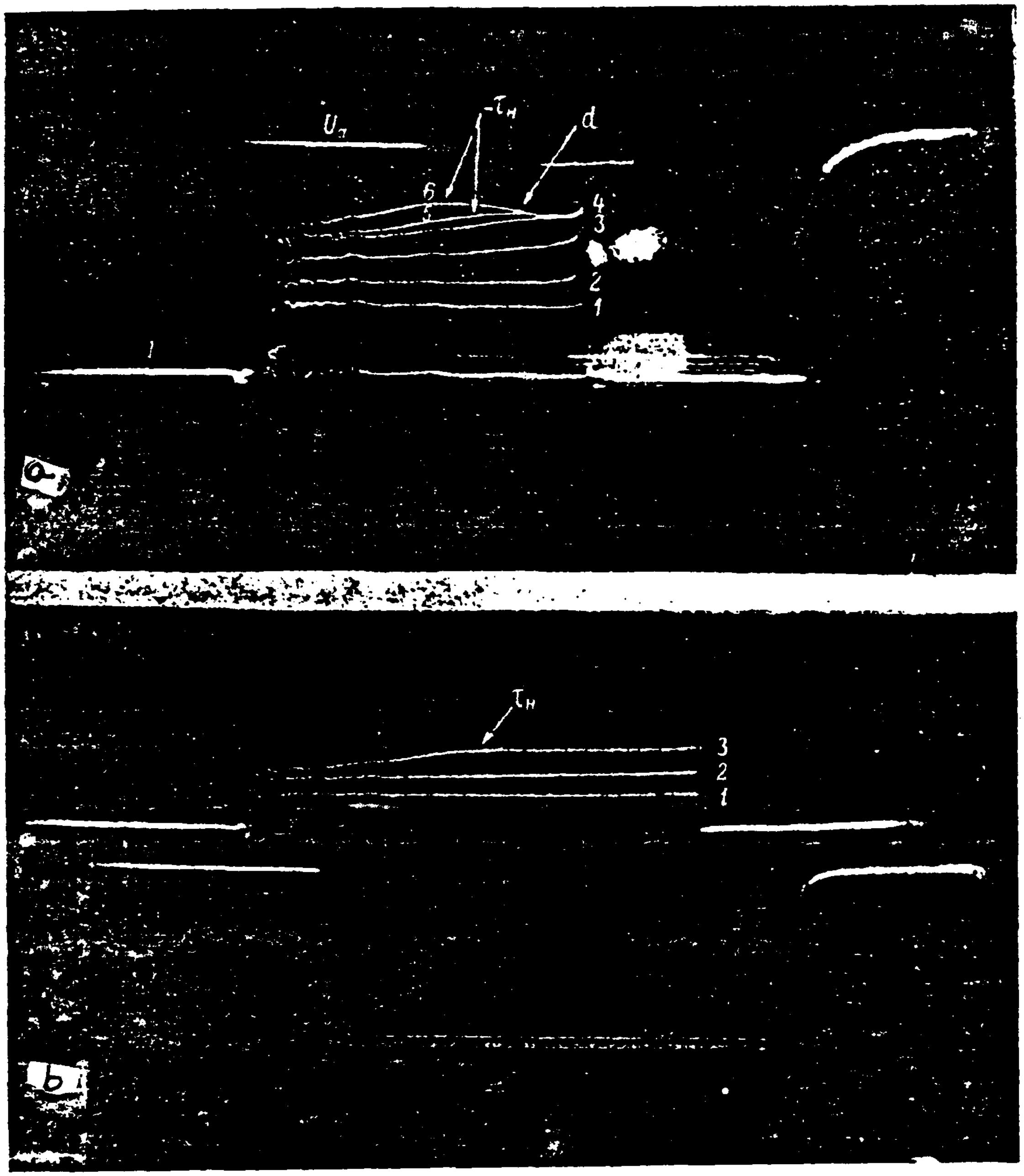

Fig. 2. Spontaneous change in current in time. a) the duration of 2 μs. 1-6 - current oscillograms, which correspond to increasing voltage/stress U_a. I - emissive current; $\tau_н$ - moment/torque of the establishment of quasi-stationary state (saturation); a) the line of the build- up/growth of current at the moment of breakdown; b)

duration of 4 μ/s.

Page 123.

In works [15, 16] it was shown that the electrical blast during the excitation of breakdown to the point is, generally speaking, by unavoidable: if blast does not occur in the initial stage (density of field emission current through the apex/vertex of point 10^8 A/cm^2, temperature it is close to the melting point), then it with the need will occur at the moment of the breakdown, when current grows by 2-3 orders for the time of 10^{-8} s [5, 6], which would correspond to immense current densities 10^{11}-10^{12} A/cm^2.

If this is so, then special features, inherent in electrical blast, must be considered in examination of mechanism of breakdown. The vast experimental material, obtained during the study of electrical blast, can give valuable information about the phenomenon of breakdown as a whole. For example, the isolation/liberation of dense plasma during the blast makes it possible to unambiguously solve the problem of the formation of medium in the vacuum gap/interval; the directed overshoot of the material of the detonated conductor (rate of 10^6 cm/s) makes the formation of rapid jets, the formation of flames and the strong erosion of the anode clear.

Entire/all sequence of development of breakdown in point can be represented as follows: strong field → critical density of field emission current → blast of point → formation of medium → discharge in vapors of exploding metal.

VACUUM BREAKDOWN IN THE CASE OF MACROSCOPIC ELECTRODES.

In whole series of works indirectly, while in works [20, 21] direct observations showed that on real surface are always microprotrusions, which have form of points. It is established also [22-24], that precisely these points are the active centers of self emission. It is possible to assume that the destruction of the given emissive centers is the fundamental reason for the breakdown (close ideas are examined in the works [24, 29]).

Let us examine consequences of blast of isolated points of cathode in the case of macroscopic surface. Above it was shown that the blast of autocathode leads to the formation of vaporous medium with the very high particle concentration. Already in the process of the blast is the partial ionization of this medium possible. Subsequently the number of charged particles in avalanche like increases as a result of the impact ionization.

Processes indicated can lead to formation of positive space charge. With so high a particle concentration the field of this charge can prove to be very strong and in a number of cases even exceed the field, created in this section of surface with external source.

Possibility of designing of strong fields on surface of cathode due to space charge was shown already by Langmuir [25], who were attempting to base field emission mechanism in arcs with cold cathode. A stricter calculation taking into account space charge of electrons was carried out later by Mackeown [26].

Page 124.

For obtaining the fields sufficient for exciting the self emission, it was necessary, however, to assume that either occurs considerable field strengthening due to the roughness or particle concentrations on the surface of cathode are extremely great. It is not difficult to see that in the model of vacuum breakdown in question both these conditions can be satisfied simultaneously: microheterogeneities lead to the considerable field strengthening, the explosive process of their destruction - to the creation of high particle concentration.

Possibility of localization of field above point of impact is most important. The local field, created with this quasi-anode, can prove to be sufficient in order to excite the critical densities of current in the sections of surface, located near the region of blast. The sections of cathode, which possess heterogeneities, will prove to the new centers of destruction with the greatest probability.

As a result of breakdown defined part of cathode, as is known, is fused. The presence of these molten sections near the places of explosive destruction can be the condition, which facilitates further functioning of discharge with the expenditure of the resources/lifetimes of initial heterogeneities. In works [27, 28] is obtained the direct proof of the extension of points from the liquid phase. The extension of these point-whiskers occurs under the action of ponderomotive forces in the presence of strong field at the moment of breakdown. Thus, field not only excites the blast of heterogeneity, but also prepares the conditions, necessary for the realization of this report/event. Congealing with breaking of arc, these not to the end/lead destroyed heterogeneities make it possible to directly observe the "frozen" picture of this extension [28]. To the fact of the extension of metal with the breakdown are indicated also in the work of Bogdanovskiy [20], for which it was possible to observe the metallic bridges which overlap discharge gap.

CONCLUSION.

It is possible to isolate the following nodal moments of the proposed model.

1. Macroscopic surface of real electrodes contains heterogeneities, which have form of points.

2. Explosive destruction of microheterogeneity is elementary report/event of excitation of breakdown for real electrodes.

3. Destruction of autoelectronic emitter under action of high

densities of emissive current is analogous with electrical blast of conductor.

4. Process of destroying heterogeneity is accompanied by creation of dense plasma in vicinity of destruction and by formation of positive space charge, which ensures onset of strong field in this section of cathode.

Page 125.

5. Under conditions of pool cathode occurs extension of points with their subsequent destruction on the reaching of critical value of current density.

Schematic sequence of process is represented in Fig. 3.

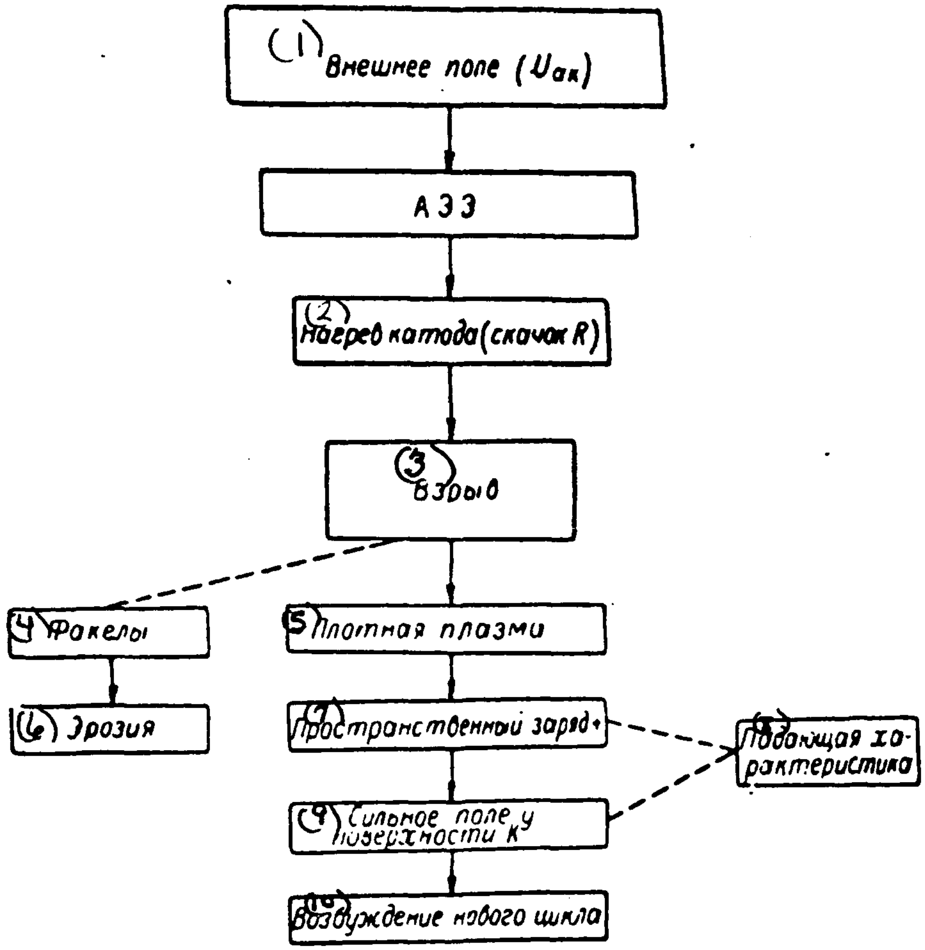

Fig. 3. Diagram of the sequence of the development of breakdown on macroscopic electrodes. K - cathode, U_{ak} - breakdown potential difference in the vacuum gap.

Key: (1). External field .... (2). Heating cathode (jump R). (3). Blast. (4). Flames. (5). Dense plasma. (6). Erosion. (7). Space charge. (8). Incident characteristic. (9). Strong field on surface K. (10). Excitation of new cycle.

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Page 126.

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