

Ecton Erosion Model of Low-Power Contacts

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Abstract. The justified erosion model of low-power contacts according to which the ecton is a driver of erosive mass-transfer switching current. The height of the threshold is inversely proportional to the ion average charge of the cathode flame and is directly proportional to the product of the number of electrons in ecton on the sum of the values of the sublimation and ionization specific energy which is the criterion for the erosion resistance of materials

I. INTRODUCTION

One of the main reasons of the reed switch contacts erosion is considered to be the formation of liquid metal bridge during opening a current 1 - 10 mA [1]. However, according to the G.A. Mesyatz hypothesis [2] only the ecton is a driver of mass transfer at closing and opening contacts. To date work on the erosion of low-power contacts are not fully considered the processes and mechanisms of formation of the prominences and recess holes on the electrode surface.

The aim of this work is an experimental study ecton model erosion contacts when switching electrical current circuits, based on the study of these processes and mechanisms. The morphology and elemental composition of the surface are studied by SEM, AFM and EPMA methods.

The direct current switching mode was 24 V for 0.04; 0.1; 0.2; 0.3; 0.4 and 0.8 A with a resistive load and the operations numbers were from 0 to 1 million times.

II. RESULTS

The electrical discharge machining of the anode and the mass transfer of the anode material to the cathode under conditions of arc discharge caused by the thermo mechanical action of the electron package (about 10^{11} electron) named as ecton emitted normal to the cathode surface jointly with the molten metal, steam and the plasma (cathode flame) with speeds of up to 10^6 cm/s in the direction of the anode. It occurs during the electrode convergence on the switching current. Its interelectrode gap reaches the distance about $d = 0.1 - 1$ microns. As a result of the cathode surface roughness the field increases (from 10^5 to 10^8 V/cm) and the autoelectronic emission and combination with thermionic are exited.

If the threshold density ($\sim 10^8$ A/cm²) exceeded then it leads to explosive electron emission [3], the microexplosion transform the cathode material in liquid, steam and plasma phases: the spark stage of the discharge starts. The liquid metal drops fly out with the speed $v \approx 10^4$ cm/s. The cathode plasma flame moves to the anode with velocity $v \approx 10^6$ cm/s. The secondary electron current flows in the ecton form which in the cathode flame has a zero work function and injects in the direction of

the anode. The ecton formation time is about $t_e \approx 10^{-8}$ s. The number of electrons in ecton is about $N_e \approx 10^{11}$ [2]. The secondary electron emission single act (from one of the surface tip) lasting 10^{-8} s is terminated as a result of dissipation, emission of molten metal and reduce the current density. The spark temperature reaches 10000°C in the breakdown channel. The cathode ecton localization energy (spark discharge) in the anode microvolume surface causes to its explosion due to the formation of several states: liquid, gaseous, plasma. The crater at the blast site is appeared. The anode crater exceeds the cathode one size because of the electrons from the anode flame is returned back to the anode increasing its temperature and the anode ions to compensate for electron space charge.

It leads to more heating of the anode. The polar portion mass transfer is from the anode to the cathode for the same electrode materials. The anode plasma flame, vapors and droplets move to meet the cathode ones. On the cathode surface are formed a large number (10^5 - 10^6) approximately the same geometrical size and shape of a saucer-like disc, and on the anode surface appear the same number of the small craters on the deepening inner surface.

By opening current due to the surface roughness of the contact divergence occurs simultaneously. Through a separate spot will be leaking all the current in the circuit. Therefore, the area of the retraction current is melted. It forms a molten metal bridge which exploding in the constriction zone creates the ecton giving the surface erosion.

The ecton erosion model foundation bases on the analysis of the SEM, AFM images and AFM profiles of the contact surface after switching the currents of 0.04; 0.4 and 0.8 A at a different number with 10^3 to 10^6 operations.

1. On SEM and AFM images of the anode and cathode surface of the samples after the operations the peak erosion on the cathode protrusions and corresponding recesses on the anode crater form are observed. The areas of cathode and anode new structures are approximately $1.3 \cdot 10^4$ mc².

The cathode structures are flat protrusions or peak shape consisting of similar shape and diameter of the saucer-micron sized disks (2.8 and 5.4 micrometer diameter for 0.4 and 0.8 A currents accordingly). At the anode opposite the cathode protrusions formed the deepening which as well as the anode has a fine surface structure in the form of multiple approximately identical in shape and diameter (3 and 6 microns at currents of 0.4 and 0.8 A accordingly) microscopic craters.

2. The form and dimensions of microscopic craters anode and cathode discs is not dependent on the number of the operations and their diameters vary in direct proportion to the magnitude of current. The cumulative effect of the contact erosion during

switching is the sum of the effects of erosion from individual operations.

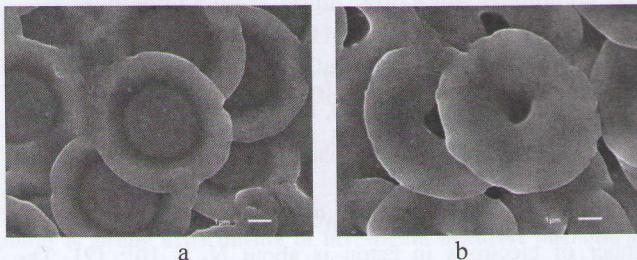


Figure 1. SEM image at a current of 0.8A: a - cathode discs, b - anode craters .

3. The volume of the anode craters (0.36 and 9.42 mc^3) and volume of the corresponding cathode disks (0.4 and 8.5 mc^3 accordingly) from AFM profiles are defined for the current 0.4 and 0.8A . These volumes are approximately equal to each other in pairs. Consequently, the cathode disks are formed mainly from the material transferred to the cathode from the anode craters formed microexplosions. As we suppose that it is caused by mechanical shock bursts of the ectons (electron package) on the anode surface.

4. The formation of ecton energy impact on the cathode surface is mostly on the sublimation and ionization of matter. It is not difficult (considering the average ion charge, specific energy of sublimation and ionization energy consistent iron atom) to assess the threshold energy for the formation of one ecton ($N_e = 10^{11}$). It is inversely proportional to the mean ion charge of the cathode flame and it is directly proportional to the product of the number of the ecton electrons on the amount of the sublimation and ionization energy density values and approximately equals 10^{-8} J .

As the ecton formation time is $t_e \approx 10^{-8} \text{ s}$ the threshold current source of power should be at 1 W and a current of 0.04 A . Indeed, SEM images of the contact surface erosion after switching current 0.04A is practically not observed.

Thus, it can be argued that the higher the specific energy of the material sublimation and ionization increase the erosion resistance. Then the criterion of the erosion resistance Z can be represented by the following expression:

$$Z = \gamma (E_r + E_i), \quad (1)$$

where $\gamma = 1$ is the universal proportionality factor for any solids, mol / kcal , E_r is the specific energy sublimation kcal / mol , E_i is the ionization energy (first ionization potential) kcal / mol . The evaluation of the metal or alloy workability experimentally found in [3]. To simplify the analysis of the electrical discharge machinability materials [3] used the relative ratio of machinability

$$M = V_{ez} / V_{steel45}, \quad (2)$$

where V_{ez} , V_{steel} are the linear metal material removal rate with the test material and the electrode made of steel45, $\text{mm} / \text{minute}$.

Table 1
The experimental values of the coefficient workability M for different metals and steel 45 (English classification as 34CrNiMo6) [3].

Substance	M	substance	M
steel45	1	Ni	0,9
Cu	1,3	Mo	0,8
Al	1,5-1,7	W	0,7

The proposed criterion erosion resistance Z confirmed experimentally according to data presented in Table 2.

Table 2
Comparison criteria Z erosion resistance of materials with coefficients experimentally established workability M .

substance	E_r , kcal / mol	E_i , eV	E_i , kcal / mol	Z	Z / Z_w	M_w / M exper. [3]
Al	55	5.95	136.85	191.85	0.49	0.47
Cu	81,2	7,69	176,87	258,07	0,66	0,54
Fe	94	7.83	180.09	274.09	0.7	0.78
Mo	160	169.05	329.05	7.35	0.84	0.88
W	210	7.98	183.54	393.54	1	1

III. SUMMARY

Thus, these presented data support a model ecton erosion by means of the mass transfer in the closing and opening of the contacts.

REFERENCES

- [1]. S.M. Karabanov, R.M. Mayzels, V.N. Shoffa, Magnetically contacts (reed switches) and products based on them, Dolgoprudny "Intellect" Publishing House, 408, 2011 (in Russian).
- [2]. G.A. Mesyatz "Metal Acton-electron avalanche", "Advances of Physical Sciences", V. 165 (1995) 601(in Russian).
- [3]. A.L. Livshits, A.T. Kravets, I.S. Rogachev, Electropulse metal processing, Moscow: Engineering, 1967.