Bimetallic Effect and Structure of Valence Shells of Cathode Metal Atoms

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Abstract - Previously we have shown that in arc discharges with one-element cathodes there is a relation of physical parameters of the cathode metals as well as discharge characteristics with the number of electrons in the valence shell of cathode metal atoms. In arc discharges with cathodes made of two or more number of metals there was found a phenomenon of selective erosion of the cathode surface (bimetallic effect). The authors that have revealed and studied this phenomenon failed to find the relation of the bimetallic effect with physical parameters of the cathode metals. The paper shows that the bimetallic effect is related not with physical parameters of metals but with characteristics of the cathode metal atoms.

By present time, at least two of the most important discharge characteristics are known for arc discharges with cathodes made of the majority of simple metals. It is shown in Ref. [1] that physical parameters of the cathode metal and discharge characteristics are related to the number of electrons in the valence shell of metal atoms N_{VE}. Results of investigations of erosion and mass-discharge composition of plasma produced in the cathode spot are known for arc discharges with cathodes made of two or more number of elements of a periodic table. The authors [2] investigated erosion of electrodes having the form of rectangular bars and made of different metals squeezed in pairs up to beginning of plastic deformation of one of the metals.

Table 1

Bimetall: A/B	S_A/S_B	T_m	T_{boil}	ΔH_f	ΔH_{evap}	γ [3]	I_0 [4]	U_c [4]	N_A/N_B
Mg/Ni	37/63	650/1455	1095/2900	0,61/2,66	2,25/56,24	2,73/1,21	0,2/2,1	12/17	6 / 8
Mg/Fe	30/70	650/1539	1095/3200	0,61/1,93	2,25/49,35	2,73/1,25	0,2/2	12/16,5	6 / 10
Mg/Cu	32/68	650/1084	1095/2940	0,61/1,2	2,25/42,58	2,73/1,0	0,2/1,8	12/18,5	6 / 7
Mg/Al	72/28	650/660,4	1095/2500	0,61/1,08	2,25/29,3	2,73/2,42	0,2/1,2	12/18	6 / 5
Mg/Sn	80/20	650/231,9	1095/2620	0,61/0,44	2,25/18,5	2,73/7,45	0,2/0,7	12/12	6 / 4
Mg/Zn	60/40	650/419,5	1095/906	0,61/0,79	2,25/12,53	2,73/2,8	0,2/0,4	12/10	6 / 6
Mg/Pb	70/30	650/237,4	1095/1745	0,61/0,26	2,25/9,78		0,2/0,35	12/9	6 / 4
Pb/Fe	23/77	237.4/1539	1745/3200	0,26/1,93	9,78/49,35	There	0,35/2	9/16,5	4 / 10
Pb/Cu	27/73	237,4/1084	1745/2940	0,26/1,2	9,78/42,58	are no	0,35/1,8	9/18,5	4 / 7
Pb/Al	39/61	237,4/660,4	1745/2500	0,26/1,08	9,78/29,3	data for	0,35/1,2	9/18	4 / 5
Pb/Sn	39/61	237,4/231,9	1745/2620	0,26/0,44	9,78/18,5	Pb	0,35/0,7	9/12	4 / 4
Pb/Zn	34/66	237,4/419,5	1745/906	0,26/0,79	9,78/12/53		0,35/0,4	9/10	4 / 6
Zn/Ni	28/72	419,5/1455	906/2900	0,79/2,66	12,53/56,24	2,8/1,21	0,4/2,1	10/17	6 / 8
Zn/Fe	19/81	419,5/1539	906/3200	0,79/1,93	12,53/49,35	2,8/1,25	0,4/2	10/16,5	6 / 10
Zn/Cu	43/57	419,5/1084	906/2940	0,79/1,2	12,53/42,58	2,8/1,0	0,4/1,8	10/18,5	6 / 7
Zn/Al	72/28	419,5/660,4	906/2500	0,79/1,08	12,53/29,3	2,8/2,42	0,4/1,2	10/18	6 / 5
Zn/Sn	62/38	419,5/231,9	906/2620	0,79/0,44	12,53/18,5	2,8/7,45	0,4/0,7	10/12	6 / 4
Sn/Ni	32/68	231,9/1455	2620/2900	0,44/2,66	18,5/56,24	7,45/1,21	0,7/2,1	12/17	4 / 8
Sn/Fe	27/73	231,9/1539	2620/3200	0,44/1,93	18,5/49,35	7,45/1,25	0,7/2	12/16,5	4 / 10
Sn/Cu	54/46	231,9/1084	2620/2940	0,44/1,2	18,5/42,58	7,45/1,0	0,7/1,8	12/18,5	4 / 7
Sn/Al	68/32	231,9/660,4	2620/2500	0,44/1,08	18,5/29,3	7,45/2,42	0,7/1,2	12/18	4 / 5
Al/Ni	14/86	660,4/1455	2500/2900	1,08/2,66	29,3/56,24	2,42/1,21	1,2/2,1	18/17	5 / 8
Al/Fe	11/89	660,4/1539	2500/3200	1,08/1,95	29,3/49,35	2,42/1,25	1,2/2	18/16,5	5 / 10
Al/Cu	12/88	660,4/1084	2500/2940	1,08/1,2	29,3/42,58	2,42/1,0	1,2/1,8	18/18,5	5 / 7
Cu/Ni	35/65	1084/1455	2940/2900	1,2/2,66	42,58/56,24	1,0/1,21	1,8/2,1	18,5/17	7 / 8
Cu/Fe	23/77	1084/1539	2940/3200	1,2/1,93	42,58/49,35	1,0/1,25	1,8/2	18,5/16,5	7 / 10
Fe/Ni	63/37	1539/1455	3200/2900	1,93/2,66	49,35/56,24	1,25/1,21	2/2,1	16,5/17	10 / 8

Selective erosion phenomenon of cathode metals has been found out in the discharge moving along the metal boundary line. The authors called this phenomenon a bimetallic effect. Selectivity is that the discharge is developed preferably at one of the metals (Table 1).

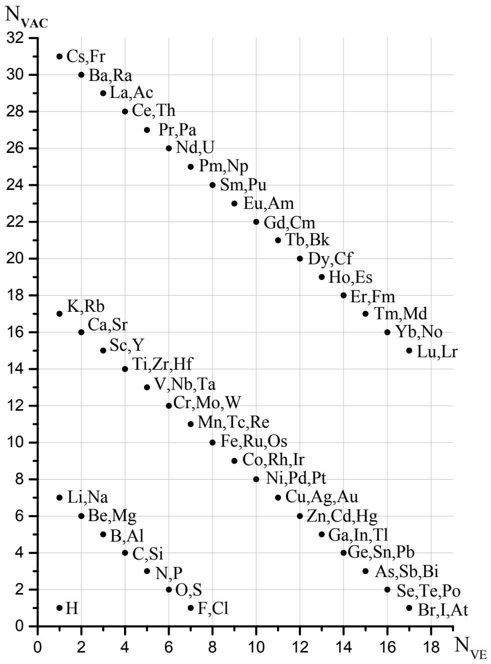

Fig.1

Fig.(1) shows N_{VAC} and N_{VE}, of elements in the periodic table

Table 2

I	II	III	IV
Mg	$3s^2$	$3p^6$	Fe,Cu,Ni
Al	$3s^23p^1$	$3p^5$	Fe,Cu,Ni,Mg,Zn,Sn
Fe	$4s^23d^6$	$3d^44p^6$	------------------------
Ni	$4s^23d^8$	$3d^24p^6$	Fe
Cu	$4s^13d^{10}$	$4s^14p^6$	Fe,Ni,Sn
Zn	$4s^23d^{10}$	$4p^6$	Fe,Cu,Ni,Mg
Sn	$5s^24d^{10}5p^2$	$5p^4$	Fe,Ni,Mg,Zn
Pb	$6s^25d^{10}6p^2$	$6p^4$	Fe,Cu,Mg,Zn,Al,Sn

The first column presents cathode materials (A/B). The second column presents the ratios of erosion areas of bimetallic cathodes S_A/S_B (%). The following are the melting temperatures T_m (˚C) and boiling temperatures T_{boil} (˚C), fusion heat ΔH_f (kJ/cm^3) and evaporation heat ΔH_{evap} (kJ/cm^3), specific erosion of one-element cathodes $\gamma\times10^5$(cm^3/C), threshold currents of one-element cathodes I_0 (A), cathode voltage drops in the arc discharges with one-element cathodes U_c (V). As it is seen from the Table, as a rule, metals with high T_m, T_{boil}, ΔH_f, ΔH_{evap} are more exposed to erosion. In case of a bimetallic cathode, the metals having in case of one-element cathodes less γ, higher I_0 and U_c are exposed to higher erosion. Exceptions are shown at a light background. The last column of Table 1 presents the number of vacant placed N_{VAC} in valence shells of the cathode substance atoms.

Table 3. Composition cathodes

Pb-Ti				
Pb	90%	$6p^4$	4	23,8%
Ti	10%	$3d^84p^6$	14	74,6%
Pb-Cu				
Pb	50%	$6p^4$	4	31,7%
Cu	50%	$4s^14p^6$	7	60,3%
Cu-Mo				
Cu	90%	$4s^14p^6$	7	16,1%
Mo	10%	$4d^55s^15p^6$	12	53,8%
Cu-C-Pb				
Cu	60%	$4s^14p^6$	7	48,6%
C	30%	$2p^4$	4	8,8%
Pb	10%	$6p^4$	4	39,1%

Table 2 presents metals of bimetallic cathodes (I), distribution of electrons by orbitals of valence shells (II), availability of vacant places at the orbitals of valence shells (III), metals with erosion trace area exceeding the erosion trace area on the metals of the first column of Table 2 (IV). Sn and Pb have the least N_{VAC}. Erosion of Pb in combination with any metal used in [2] is the least. Fe has the highest N_{VAC}. There is no one metal that being combined with Fe would be exposed to larger erosion than Fe itself. We see from Table 2 that Mg and Zn have equal N_{VAC} but Mg is exposed to larger erosion. Sn and Pb also have equal N_{VAC} but Sn is exposed to larger erosion than Pb. Mg has the main quantum number n = 3 and Zn has n = 4. Sn has n = 5 and Pb has n = 6. And at last, Mg has N_{VAC} = 6 and Al has N_{VAC} = 5. Both Mg and Al have n = 3. Mg has lager erosion than Al. As it follows from the above-said, *in a bimetallic cathode the metal with atoms having larger number of vacant places in a valence shell is exposed to larger erosion and at equal N_{VAC} the metal having the less n is exposed to larger erosion.* Relation of a bimetallic effect with the structure of valence shells of metal atoms (and not only metals) is verified as well by the results of investigations of mass composition of ion beams extracted from plasma of composition cathodes made of mechanical mixture of powders by the "shift-under-squeeze" method (Table 3) and of plasma of chemical compounds (Table 4).

Table 4 [5]

Chemical compounds			
SiC			
Si	$3p^4 3d^{10}$	4	67%
C	$2p^4$	4	33%
TiC			
Ti	$3d^8 4p^6$	14	60%
C	$2p^4$	4	40%
TiN			
Ti	$3d^8 4p^6$	14	75%
N	$2p^3$	3	25%
TiO			
Ti	$3d^8 4p^6$	14	85%
O	$2p^2$	2	15%
LaB_6			
La	$4f^{14} 5d^9 6p^6$	29	75%
B	$2p^5$	5	25%
UN			
U	$5f^{11} 6d^9 7p^6$	26	50%
N	$2p^3$	3	50%
UC-ZrC			
U	$5f^{11} 6d^9 7p^6$	26	15%
Zr	$4d^8 5p^6$	14	45%
C	$2p^4$	4	40%

It is seen from Table 3 that the substance content in the cathode body (second column) doesn't correspond to the ion content in the beam (fifth column) extracted from the cathode spot plasma. Moreover, the sum in the fifth column is less than 100%. This is due to the availability of C^+, CH_4^+ in the beam and in the beam from the Cu-Mo cathode there is 26,2% of $Cu_2MoO_5^+$ - products of plasma chemical reactions. Ref. [6] shows that Cu-Al cathode spots at a bimetallic cathode appear both at each of the metals and at the metal boundary line that affects the U_C change having place in the limits of (25-32) V characteristic for the arc at the aluminum and copper cathodes.

Tables 1, 3, 4 present totally 38 different cathodes. Only 4 cathodes (Sn-Cu, Sn-Al, SiC, UN) do not correspond to the formulated rule and 2 cathodes (Cu-C-Pb, UC-ZrC) correspond them only partially. One circumstance is common here, and namely: in their composition all these cathodes have materials with a specific type of a crystal lattice (Sn, C, U).

References.

[1] E.N.Abdullin, G.P.Bazhenov, Yu.P.Bazhenov, A.V.Morosov, in Proc. of 13th Int. Symp. on High Current Electronics, Tomsk, 2004, pp.105-108.

[2] Electroerosion machining of metals. M.K. Mitskevitch, A.I. Bushik, I.A. Bakuto, etc.; Edited by I.G.Nekrashevich. – Minsk, «Nauka i Tekhnika», 1988, p.87.

[3] A.I. Vasin, V.A. Petrosov, Characterization of erosion characteristics of cathode materials in a stationary vacuum arc with cold cathode, In Proc. Low-Temperature Plasma Generators (abstracts of papers of XI All-Union Conf.), Novosibirsk, 20-23 June 1989, p. II, pp. 56-57.

[4] S.A. Krat'ko, Investigation of processes in a transition region between glowing and arc electric discharges, Abstract of Ph. D. Thesis (Phys.-Math.), Minsk, 1988, p. 9.

[5] Sasaki J., Brown I.G., Rev. Sci. Instr., 1990, V.61, №1, pp. 586-588. (Cited by A.I. Ryabchikov, Physics, Izv. VUZov, №3, 1994, pp. 34-52).

[6] M.K. Mitskevitch, A.I. Bushik, I.A. Bakuto, P.S. Zachepilo, in Proc. V All-Union Conf. on Plasma Accelerators and Ion Injectors (abstracts of papers), «Nauka», M., 1982, pp. 136-137.