ELECTRODE EROSION IN A HIGH-FREQUENCY SPARK DISCHARGE

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UDC 621.384.8

The disperse composition of the products of electrode destruction in a high-frequency vacuum breakdown and the variation of the relative degree of plasma ionization as a function of the material of the electrodes and the high-frequency voltage applied to them are investigated.

The extensive use in industry and scientific research of mass-spectral instruments with spark ion sources makes very urgent the task of increasing their metrological characteristics, permitting an improvement in the productivity and accuracy of the mass-spectral method of analysis. Therefore, the systematic study of the mechanisms of a spark breakdown and the parameters of the plasma obtained in a spark gap is of considerible interest.

The few publications devoted to such research touch mainly on the energy distribution of ions of the spark plasma [1-3] or the electrical-engineering parameters of the discharge circuit ([4, 5], for example), although it is noted that the character of the electrode destruction may have considerable influence on the results of the analysis [6]. The composition of the destruction products and their behavior in the interelectrode gap affect the processes of ion formation and, thanks to the statistical character of these phenomena, results in considerable scatter of the measured quantities.

The energy Q applied to a single spark discharge is expended on the sputtering and ionization of the electrode material. At small energy fluxes q per unit electrode surface the destruction products enter the gap in the basic form of vapor, which then, expanding adiabatically, cools and partially condenses into drops [7]. At high values of q a rapid temperature increase in the surface layer is possible, resulting in instability of the vaporization front [8] and the explosive transport of material in the form of macroscopic particles. In the spark sources of mass spectrometers a relatively low energy of 10^{-2}-10^{-3} J is released in a single breakdown in a time on the order of 10^{-8} sec, and the energy flux density can reach 10^{8}-10^{10} W/cm^2. Here both mechanisms of destruction can occur, and the disperse composition of the plasma has a broad spectrum. The energy Q released in the discharge gap is the energy $Q = CU^2/2$ of the capacitor in the secondary winding of the high-frequency transformer, while the time of energy release is $t \sim R_{ef}C$. The breakdown voltage U and the resistance of the discharge circuit depend on the width d of the interelectrode gap. Since the capacitance C (stray, concentrated, or their sum) varies little during an experiment, the characteristics of the erosion plasma depend only on the voltage between the electrodes (the gap width) and the thermophysical properties of the electrodes in a first approximation.

The investigations were carried out in the spark source of a JMS-01B mass spectrometer. To measure the disperse composition of the erosion products the material leaving the spark gap was deposited on a glass plate placed near the spark. The width of the interelectrode gap was varied from max to min [$d_{max} = (8\text{-}10)d_{min}$], simulating the variation of the microgeometry of the discharge gap and the charring of the electrodes in the process of analysis. The condensate was investigated on an optical microscope. Characteristic dispersion curves are shown in Fig. 1. The number of particles grows rapidly as their linear size decreases. Particles with sizes $l > 2.5$ μm were not counted, since they lose their shape when they strike the glass backing. This fact indicates that all the particles, even those of large size, are in the form of drops of liquid metal in the interelectrode gap. The number of finer particles and the vapor phase increase with a decrease in the width of the spark gap. The number of large particles also decreases with the transition to easily fusible materials.

Institute of Solid-State Physics, Academy of Sciences of the USSR, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 45, No. 6, pp. 992-995, December, 1983. Original article submitted July 5, 1982.

0022-0841/83/4506-1437$07.50

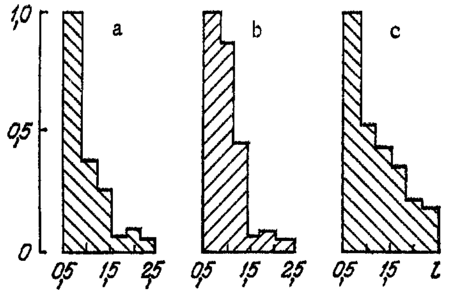

Fig. 1. Disperse composition of electrode material sputtered in a spark discharge: a) narrow gap; b) wide gap (Zn electrodes); c) Cu electrodes. *l*, μm.

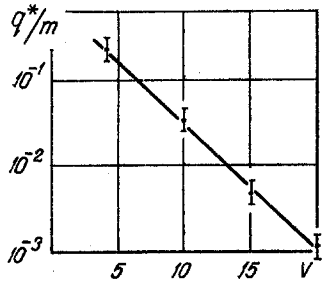

Fig. 2

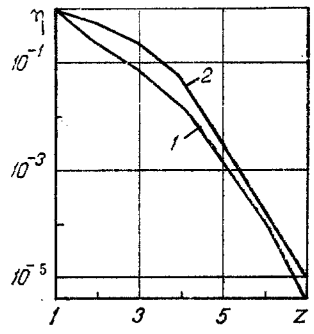

Fig. 3

Fig. 2. Relative degree of ionization q*/m as a function of the amplitude of the high-frequency voltage on the electrodes (material: Cu). V, kV.

Fig. 3. Charge ratio η of copper ions for large (curve 1) and small (2) interelectrode gaps.

The variation of the structure of the disperse composition of the material in a spark gap as the amplitude of the high-frequency voltage increases has considerable influence on the processes of ion formation in the spark, particularly on the relative degree of ionization and the effective temperature of the plasma. The relative degree of ionization was defined as q*/m, the ratio of the charge of the ions recorded by the monitor to the weight loss of the electrodes. The variation of this ratio as the high-frequency voltage on the spark electrodes (copper specimens) increases is shown in Fig. 2. Increasing the voltage from 4 to 20 kV results in a decrease in q*/m by more than 300 times. This also is evidence that the sputtering of electrode material in the form of microparticles grows with an increase in the energy applied to the spark and the inefficiency of the consumption of material increases. A higher degree of atomization of the sputtered material also corresponds to a higher effective plasma temperature, which primarily affects the charge composition of the ion beam. The charge distribution of ions of the base material ($\eta = n_Z/n$) for large and small interelectrode gaps is shown in Fig. 3. The increase in the number of multiply charged ions with a small gap means an increase, to a certain extent, in the effective temperature of the plasma of the spark discharge. In the process of analysis the size of the interelectrode gap varies arbitrarily within limits of d_{max}-d_{min}. This results in uncontrolled variation of the charge ratio and, as a result, in errors in monitoring the ion beam, and it is one of the reasons for the low reproducibility of mass-spectral analysis. Another reason is the variation of the probability of ionization of impurity elements due to fluctuations of the plasma temperature, especially those elements whose ionization potentials differ greatly from the ionization potential of the base material.

Thus, the characteristics of the erosion plasma are essentially determined by the electrical and geometrical parameters of the discharge profile of the spark generator, and their unification would promote the standardization of the conditions under which the ion beam is formed for its further analysis.

NOTATION

Q, energy; q, energy flux density; C, capacitance; U, voltage; R_{ef}, effective resistance of plasma; t, time; d, vacuum gap between electrodes; l, size of microparticles; q*, total charge of ions; m, mass; n_z, density of z-fold ionized ions; n, density of plasma atoms; η, charge ratio.

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HEAT AND MASS TRANSFER IN THE SORPTION OF HYDROGEN BY INTERMETALLIC COMPOUNDS

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UDC 536.242

The heat and mass transfer in the sorption of hydrogen by intermetallic compounds in a steady plane layer is calculated, taking account of heat liberation and filtration, by finite-difference and approximate integral methods.

Intermetallic compounds (IMC), which reversibly absorb hydrogen, are currently the subject of numerous investigations in connection with the possibility of their use in hydrogen accumulators, thermal machines, thermal pumps and accumulators, sorptional compressors, etc. The dynamics of hydrogen sorption in IMC must be investigated for the analysis and design of the above-noted devices. Trends in such investigations may now be distinguished: the study of the true chemical kinetics of sorption [1]; and the investigation of the sorption dynamics in extended IMC layers of dimensions characteristic for practical applications [2]. In the first case, attempts are made to minimize the layer thickness so that the influence of heat liberation and filtrational resistance may be neglected. In the second, as assumed in these works, the rate of sorption is completely determined by the rate of heat transfer inside the IMC layer. However, these works do not give criteria by which the experimental conditions may be chosen, and often the conditions themselves are not completely described.

In connection with this, calculations of the sorption process in which the heat liberation and filtration of hydrogen through the IMC layer are taken into account are of interest both for practical applications and for the elucidation of the conditions in which the process may be regarded as purely kinetic or controlled by the heat and mass transfer in the layer.

All-Union Scientific-Research Design, Construction, and Technological Institute of Current Sources, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 45, No. 6, pp. 995-1002, December, 1983. Original article submitted July 21, 1982.