PARAMETERS OF HIGH-FREQUENCY VACUUM BREAKDOWN IN A MASS-SPECTROMETER ION SOURCE

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The electrical and optical characteristics of hf vacuum breakdown are experimentally investigated. It is shown that the breakdown current amplitude can reach 20 A with a voltage of up to 30 kV on the electrodes and a discharge duration of 20-25 nsec.

The use of a spark mass spectrometer to determine impurities in solids is limited by the poor reproducibility and accuracy of the analysis. Most mass-spectrometrists agree with the view that the errors of analysis are mainly due to processes occurring in the spark source during vaporization and ionization of the investigated material and the formation of the ion beam. In this connection it was of interest to investigate the electrical parameters of vacuum breakdown (current amplitude and duration, discharge voltage, etc.) in conjunction with the parameters characterizing the spark plasma, particularly the ionization processes occurring in it. The conduction of such investigations can enlarge our knowledge of the kind of effects occurring in a spark source, and can lead to an improvement in the qualitative characteristics of the analysis.

The parameters of the hf vacuum discharge used in spark mass spectrometry have been the subject of a few studies. In [1-3] the ion energy spectrum was investigated, but this spectrum, however, is not related to the hf spark parameters. The amplitude of the spark discharge current has only been estimated and, in the opinion of the authors of [1, 2], is measured in milliamperes.

In [4-7] the shape of the hf discharge current was investigated and it was shown that the discharge current can reach several amperes.

Below we give the results of an investigation of the electrical and optical characteristics of a vacuum spark, which are required for identification of the parameters of ion sources of different mass spectrometers. The measurements were made on a JMS-01B mass spectrometer, which has an ion source typical of such instruments. In the experiments we determined the current shape and the voltage in the spark discharge, and also the time course of the intensity of individual emission lines of different ions in the obtained plasma. The measurement setup is shown in Fig. 1.

The voltage was measured with a capacitive divider C_1, C_2, the current with a noninductive resistor R, and the spectral characteristics with an SPM-2 monochromator. The measured signals were fed to an S1-42 two-beam storage oscillograph, which could record simultaneously any pair of parameters of interest, and the

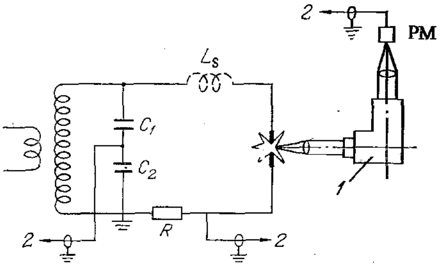

Fig. 1. Ion source circuit and measurement setup: 1) Monochromator; 2) leads to oscillograph.

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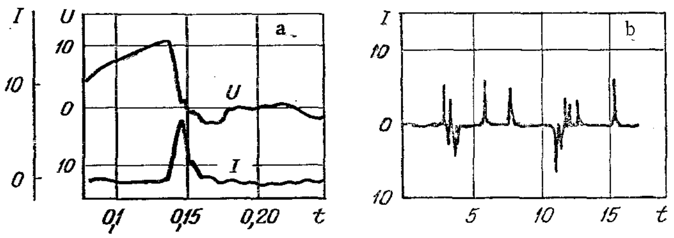

Fig. 2. Breakdown voltage and current oscillograms. I, A; U, kV; t, μsec.

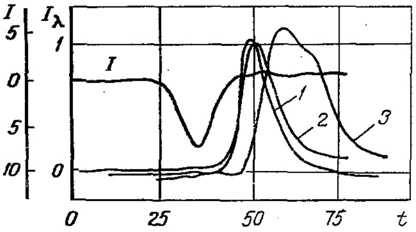

Fig. 3. Oscillograms of intensities of individual lines (I, A; I_λ, rel. units): 1) CIII (2296 Å); 2) CII (2837 Å; 3) CI (2478 Å).

signals were then photographed from the screen. The hf transformer was tuned to resonance frequency 1 mHz; the discharge capacitance $C_1 = 50$ pF ($C_2 \gg C_1$).

Typical oscillograms of the electrical parameters of the spark discharge are shown in Fig. 2. Figure 2a shows current and voltage oscillograms for a single breakdown. The decaying hf oscillations, previously reported by Franzen [2], are clearly seen. The frequency of these oscillations is 10^8 Hz, which is much greater than the basic frequency of the generator. Their decay can be attributed to the loss of energy on dissipative processes in the spark and on the electrodes and can be very pronounced [4], while the frequency depends on the electrode circuit parameters (the capacitance C_1 and the stray inductance L_S due to the presence of the vacuum lead-ins and conducting wires). The frequency of these oscillations varied with change in capacitance C_1.*

Since the duration of the voltage pulse of the spark generator is 10-80 μsec, several breakdowns between the electrodes can occur in this time (Fig. 2b). With a short pulse duration a single breakdown can be obtained. With a sufficient number of generator pulses the breakdown for metal electrodes can occur equally probably on either electrode, irrespective of its material, although predominant breakdown in one direction is possible during an individual pulse. In the case where one of the electrodes is an ionic crystal (NaCl, KCl) breakdown occurs exclusively on the metal electrode side, i.e., when the ionic crystal is at a positive potential.

The current oscillograms for individual breakdowns were similar in shape but they showed a large spread of amplitude, which could reach 20 A when the electrode voltage was 30 kV. It should be noted, however, that the amplitudes of the first breakdowns of different pulses had a much smaller spread.

Figure 3 shows typical oscillograms of the discharge current and intensities of individual lines of neutral, singly- and doubly-charged carbon. An analysis of a large number of oscillograms of the breakdown current and the emission lines showed that when the amplitude and shape of the discharge current were the same, the amplitude and shape of the emission curves of equally charged ions were also the same. This indicates satisfactory reproducibility of the plasma characteristics when the energy input is the same. In all cases the emission of the individual lines lagged behind the discharge current peak by up to 10-20 nsec: We can conclude from this that the vaporization of the analyte takes place mainly at the discharge current peak and the vapor is subsequently ionized. The variation of the line intensities with time shows that the more highly ionized states are present from the very start, whereas the states with a lower degree of ionization appear later.

Thus, we can conclude from the conducted experiments that the amplitude of the hf discharge current of

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*In spark circuits the concentrated capacitance C_1 is often absent and its role is taken by the stray capacitance, whose value is usually of the same order, i.e., several tens of pF.

a vacuum spark can reach several tens of amperes with a discharge duration of 20-50 nsec; during the discharge there is intense vaporization of the electrode material, whose vapor is subsequently ionized. The main reason for the irreproducibility is the spread of the electrical parameters of the discharge, which determine the energy input to the spark and, consequently, the characteristics of the plasma produced: Stabilization of the discharge current and voltage of individual breakdowns should lead to an improvement in the metrological characteristics of instruments.

NOTATION

C, capacitance; R, resistance; L_s, stray inductance; I, current; U, voltage; L_λ, emission intensity.

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THEORY OF THE POSITIVE COLUMN OF A NONSTEADY ELECTRIC ARC IN A CHANNEL CONTAINING A GAS STREAM

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The problem of a nonsteady arc column in a channel containing a gas stream is solved for an arbitrary law of variation of the current with allowance for the variability of the gas density, flow velocity, and flow rate.

Theoretical investigations of the interaction of the positive column of a nonsteady electric arc in a channel containing a gas stream are associated with considerable difficulties. Analytical solutions of the problem can be obtained only by adopting a number of simplifying assumptions. In [1], for example, the problem was solved when convective energy losses can be neglected, while in [2] the gas flow rate was constant. As a result of the heating of the gas in the electric arc, however, its velocity and flow rate can vary considerably along the channel [3, 4]. Therefore, for a fuller understanding of processes of interaction of an arc discharge with a gas stream, one must allow for the variability of its velocity and flow rate.

It is assumed that the entire channel is filled with an electrically conducting gas, while the main role in the energy balance of the arc is played by processes of Joule dissipation of the energy of the electric field, heat transfer in the radial direction due to heat conduction, convective energy transfer along the channel axis, and emission, and the properties of the positive column of a nonsteady arc in a gas stream can be described by the equations

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