c_m, ρ_m, b, resistivity, thermal conductivity, heat capacity, density, and temperature coeffient of the resistivity; I, current; M, c_p, flow rate and heat capacity of the cooling gas; α, heat-transfer coefficient. The indices are: 0, l correspond to quantities referring to the cold and warm ends of the current lead; res indicates residual, and ef indicates effective.

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GETTERING EFFICIENCY DURING MASS TRANSFER IN A VACUUM

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The results of an investigation of the composition of the residual atmosphere in an "open" vacuum and inside a quasiclosed volume during electron-beam vaporization of molybdenum and niobium are presented.

The comparison of the efficiencies of gettering gas particles caused by the vaporization of a substance in an "open" vacuum and inside a quasiclosed volume located in a vacuum [1] is of great practical interest. Here it is important to note the presence of two simultaneously occurring processes of mass transfer: the transfer of the substance being vaporized and the transfer of the residual atmospheric gas.

The experiments were carried out on a vacuum installation, from the working chamber of which air was evacuated by a VN-2 roughing pump and a VA-2-3 diffusion pump in series. The working chamber of the vacuum installation, made of stainless steel, consisted of a hollow cube 600 mm on a side with a wall thickness of 10 mm. The chamber was equipped with a U-530M electron-beam gun operating jointly with a U-250A apparatus. The vauum was measured with standard PMT-2 and PMI-2 gauges connected to a VIT-1 vacuum meter. The partial pressures of the residual gases were determined on an APDM-1 monopolar mass spectometer with an MMS-2A sensor. The quasiclosed volume, made of niobium or molybdenum foil 0.5 mm thick, consisted of a cylinder 100 mm in diameter and 350 mm long. This cylinder and the MMS-2A sensor were fastened to an interchangeable flange so that the target being vaporized was on the opposite

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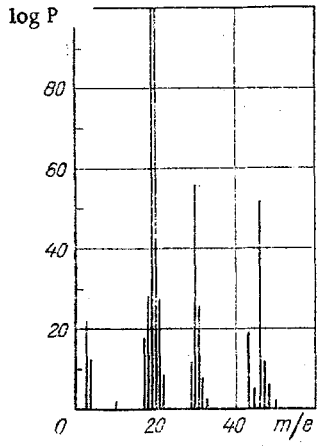

Fig. 1

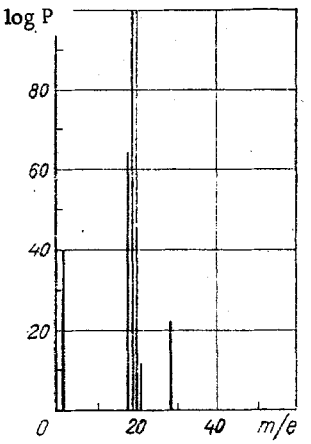

Fig. 2

Fig. 1. Mass spectrogram obtained during heating of the molybdenum target by an electron beam with an energy U_{acc} = 18 kV at a beam current I_b = 30 mA in an "open" vacuum. Limit of variation of ion current $\delta I_i = 3 \cdot 10^{-11}$ A, scanning band $\Delta(m/e)$ = 100 amu, ionizing electric current (emission current of sensor cathode I_e = 0.25 mA, scanning time t_{scan} = 10 sec. log P, arb. units; m/e, amu.

Fig. 2. Mass spectrogram characterizing the efficiency of gettering residual gases during molybdenum vaporization in an "open" vacuum: U_{acc} = 18 kV; I_b = 100 mA; $\Delta(m/e)$ = 100 amu; I_e = 0.25 mA; t_{scan} = 10 sec; $\delta I_i = 3 \cdot 10^{-12}$ A; total pressure measured by the vacuum meter $p = 1 \cdot 10^{-3}$ Pa.

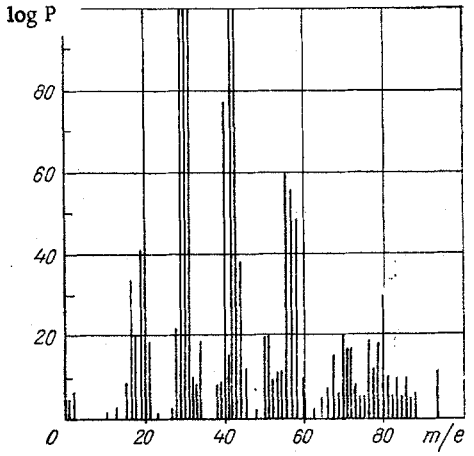

Fig. 3. Mass spectrogram obtained during heating of a molybdenum target in a quasi-closed volume: U_{acc} = 18 kV; I_b = 10 mA; $\Delta(m/e)$ = 100 amu; I_e = 0.25 mA; T_{scan} = 10 sec; $\delta I_i = 1 \cdot 10^{-11}$ A.

end of the cylinder. Before taking mass spectra in the "open" vacuum the flange with the sensor was released from the cylinder.

In all the experiments a screen was mounted in front of the electrode system of the sensor on the target side at a distance of 50 mm from its cut. This screen protected the sensor electrodes from charged particles and metal vapors. A standard needle leak valve was used to admit gases into the working chamber.

The mass spectrometer was calibrated before the start of the experiments. As the reference gas we used argon Ar^{40}, admitted into the working chamber preliminarily evacuated to a pressure of $1.3 \cdot 10^{-3}$ Pa. The sensitivity of the mass spectrometer was determined by admitting nitrogen into the process chamber and comprised $2 \cdot 10^{-7}$ A/Pa. Then the mass spectrum of the residual gases in the working chamber was taken under the conditions of an "open" vacuum, with the chamber not preheated. The pressure of the residual gases was measured simultaneously with

several PMI-2, and their readings were averaged. Then the electron-beam gun was turned on, preliminary stepwise heating of the molybdenum target was performed, and the mass spectrogram of the residual gases was taken (Fig. 1). The accelerating voltage in the electron gun was 18 kV, while the current was established in the heating mode at 10, 20, and 30 mA for several minutes. The power in the beam was subsequently increased through the current to 1.8 kW and the mass spectrogram of the residual gases was taken again in the established vaporization mode (Fig. 2).

After the above-described experiments were run in an "open" vacuum, the working chamber was resealed and a quasiclosed volume in the form of a cylinder of molybdenum foil was mounted on the interchangeable flange with the sensor. Then the procedure of measuring mass spectra was repeated and readings were taken at the same times: upon admission of the reference gas, after evacuation of the reference gas, during heating to outgas the target and walls of the quasiclosed volume (Fig. 3), and during vaporization of the target and condensation of its vapors on the walls of the quasiclosed volume. Such experiments were also run with niobium, with the target material and the construction elements of the quasiclosed volume being made of niobium. The mass spectrograms obtained in this case are identical to those presented in Figs. 1-3. The mass spectrograms taken in all cases before heating of the target are practically identical with each other and indicate that the residual atmosphere of the working chamber contains the usual gases in such cases, which can be arranged in order of increasing mass as follows: hydrogen, atomic nitrogen N^{14}, atomic oxygen O^{16} and methane CH_4^{16}, hydroxyl groups OH^{17}, water vapor H_2O^{18}, nitrogen N_2^{28} and carbon monoxide CO^{28}, oxygen O_2^{32}, carbon dioxide CO_2^{44}, and a number of hydrocarbons of the types C_2H_n, C_3H_n, C_4H_n. In this case the pressure in the chamber is determined mainly by water vapor, hydroxyls, nitrogen, carbon dioxide, and hydrocarbons.

An analysis of mass spectrograms obtained in the period of heating of the target (see Figs. 1 and 3) showed that the heating of molybdenum and niobium takes place in completely identical fashion and is accompanied by the intensive release into the quasiclosed volume of atomic and molecular oxygen, OH^{17} groups, water vapor, nitrogen N_2^{28} and carbon monoxide, carbon dioxide, and especially hydrocarbons, i.e., the effective outgassing of the target and the construction walls takes place in 10-15 sec. In the process, the vacuum in the working chamber recorded by the PMI-2 is hardly able to vary with time. But in an "open" vacuum the outgassing processes proceeds for an order of magnitude longer and is accompanied by an increase in pressure in the chamber by about an order of magnitude.

It is seen from Fig. 2 that hydrogen (possibly atomic), water vapor, several peaks in the region of m/e = 20 difficult to identify, nitrogen, and carbon monoxide are present in the "open" vacuum during vaporization. The complete suppression of the peaks of all residual gases, except for the hydrogen peak, is observed during vaporization of the investigated materials in the quasiclosed volume. The partial pressure of hydrogen, which evidently also determines the total pressure of residual gases in the quasiclosed volume, is $2 \cdot 10^{-6}$ Pa, which agrees well with the results of calculations made in [2]. We note that the value of the hydrogen pressure measured by us may be somewhat higher than that in the region of action of the vapor-plasma phase within the quasiclosed vlume, since the electrode system of the senor is hidden from the gettering region by a screen and is remote from it. For the same reason, peaks from niobium (m/e = 93) and molybdenum (m/e = 96) vapors are not observed in the mass spectra.

The results obtained indicate that gettering of the vapor-plasma phase of vaporized material and the surface of a freshly deposited coating takes place far more efficiently in a quasiclosed volume than in an "open" vacuum. In this case the density of residual gases in the closed volume is a minimum of three orders of magnitude lower than the density in the surrounding vacuum and two orders of magnitude lower than the density which exists in an "open" vacuum under the same vaporization conditions.

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