CATHODE SPUTTERING WITH ELECTRICAL DISCHARGE THROUGH A HEAVY WATER–SATURATED VAPOR INTERFACE

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An experimental study of electrical discharge in an atmosphere of heavy-water vapor was conducted. The heavy-water surface served as the cathode. Under specific discharge conditions, intense neutron radiation induced by the discharge was observed. The dependence of the intensity of neutron generation on the discharge current was measured.

Introduction. During the last decades, cathode sputtering has taken on scientific and technical significance in connection with its widespread use in semiconductor technology, the fabrication of various thin films of metals, semiconductors, dielectrics, and hard alloys, as well as in the etching of these materials. In glow discharge, the cathode is subjected to intense bombardment by ions of the gas in which the discharge occurs. In this case, the energy of the bombarding ions and their flow depend on a number of factors, such as of the the shape and material of the discharge electrodes (especially the cathode), the voltage across them, the medium in which the discharge occurs, the discharge current, the gas pressure in the discharge gap, the distance between the electrodes, and the cathode potential drop [1]. In glow discharge, electron emission is due to bombardment of the cathode by positive ions. Such emission is characterized by the surface ionization coefficient γ, which is the ratio of the number of multiplier electrons that have escaped from the cathode to the number of positive ions that have impacted the cathode [2, 3]. The phenomenon of secondary electron emission furnishes an explanation of the mechanism of self-sustaining gas discharge. The bombarding ions can knock out not only electrons but also individual atoms or ions. A characteristic of the cathode sputtering process is the coefficient of sputtering s, which is the average number of atoms knocked out of the cathode per bombarding ion. If the gas in the space between the electrodes is chemically active with respect to the cathode material, corresponding chemical reactions will be observed on the cathode surface during discharge. When the cathode is a heavy-water surface and the gas in the space between the electrodes is saturated heavy-water vapor (as well as electrolysis products D_2, T_2, and O_2), the cathode surface is subjected to bombardment by D^+ and T^+ ions. If the energy of the bombarding ions is sufficiently high, fusion is possible in collisions of ionized deuterium and tritium atoms with the heavy-water surface. If the colliding nuclei have sufficiently high relative velocities, they can escape the potential barrier of electrostatic repulsion, and, coming very close together, they can react with each other. In order for fusion to occur, the nuclei must be at a distance of the order of 10^{-11} cm, after which fusion occurs, with appreciable probability due to the tunnel effect. Thus the first signs of nuclear interactions in a substance can be observed experimentally only by heating above 10^6 K, or when the energy of relative motion of the colliding nuclei is in excess of 10^2 eV [4]. The effective thermonuclear-reaction cross-section increases rapidly with an increase in the enery of relative motion of the colliding nuclei. But even under optimum conditions the cross-section remains considerably smaller than the effective cross-section of atomic collisions; because of this, fusion in gas discharge is possible by ion bombardment of the surface of a deuterium- or tritium-containing cathode and is highly improbable in ion-neutral collisions in the plasma of the gas discharge.

An experimental study of high-voltage discharge in a D_2 atmosphere has been described [5]. A deuterium-saturated palladium electrode was used as the cathode. In spite of the gamma radiation recorded by the authors, no neutron radiation was recorded in the course of the discharge. It seems likely that in these experiments the

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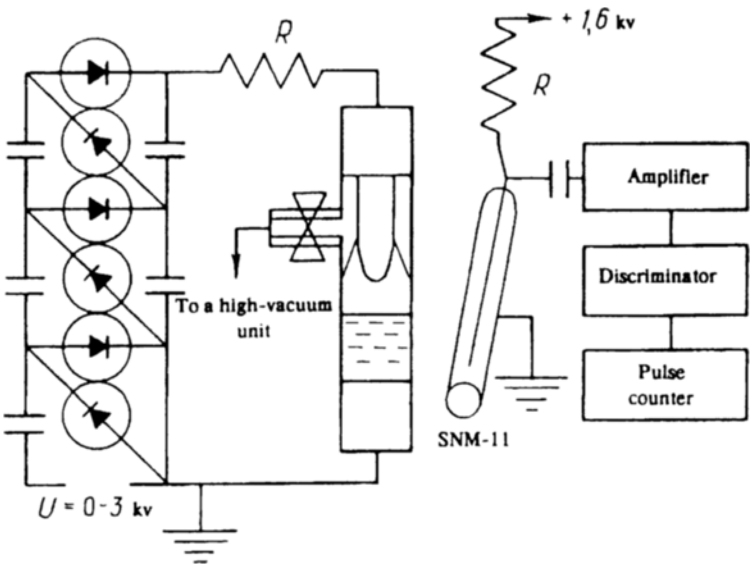

Fig. 1. Block diagram of the experimental setup.

crystalline structure of palladium inhibited the direct deuteron-deuteron collisions at the cathode. Moreover, the authors used a periodically pulsed spark discharge, in which a high potential difference between the electrodes persists in initial stage only. In [6], spark or ozonizing discharge induced by an inductance coil in a deuterium atmosphere is described. A metal that formed a metal hydride was used as the material for one of the electrodes. In the course of the study, the authors detected a stable reproducible excess of thermal energy generated in the discharge chamber. The authors used high-precision colorimetric methods that eliminated practically all systematic measurement errors.

A series of experiments to study electrical discharge in tubes filled with deuterium using palladium electrodes is described in [7, 8]. The papers point out abnormal bursts of neutron radiation (up to $\sim 10^6$ neutrons per burst) in a discharge tube with a palladium cathode and a tungsten anode. Papers [9, 10] point out some conditions for reproducing such an abnormal neutron yield: 1) the formation of palladium thin film on the discharge-chambers surface, 2) the passage of gaseous deuterium through the discharge chamber at low pressure, and 3) an ac voltage between the two electrodes in a certain range (6000–17,000 V). It is an easy matter to observe that conditions 2) and 3) are those for the formation of cathode sputtering and condition 1) is a result of that process. Evidently, during cathode sputtering of deuterium-saturated palladium, the deuterium ions, which bombard the cathode with an energy of $\sim 1-10$ keV, could enter into a fusion reaction with the deuterium contained in the cathode at certain stages of decomposition of the palladium crystall lattice.

Thus, in electrical discharge on a heavy-water surface used as a cathode when the interelectrode space is filled with heavy-water vapor (as well as, perhaps, with electrolysis products D_2, T_2, and O_2), realization of physical conditions under which fusion can occur as a result of bombardment of the cathode by deuterium and tritium ions is possibile at the cathode.

The purpose of the present work was an experimental study of the electrical discharge between a tungsten anode and a heavy-water surface used as a cathode in an atmosphere of heavy-water vapor and electrolysis products to record possible neutron radiation and to investigate the dependence of neutron generation on the discharge parameters.

Experimental Setup and Equipment. A block diagram of the experimental setup is shown in Fig. 1. The setup is a glass flask filled with heavy water. A copper electrode with a thin silver coating is mounted in flask's base. This electrode is in direct contact with the heavy water, whose surface is used as the cathode. An insulated tungsten rod is used as the anode. The flask is connected to a high-vacuum unit and is evacuated to the saturation pressure at room temperature. Intense heavy-water boiling is observed during the pumping process. The discharge gap is supplied by a cascade generator through a ballast resistor R. During an experiment, the electrode voltage

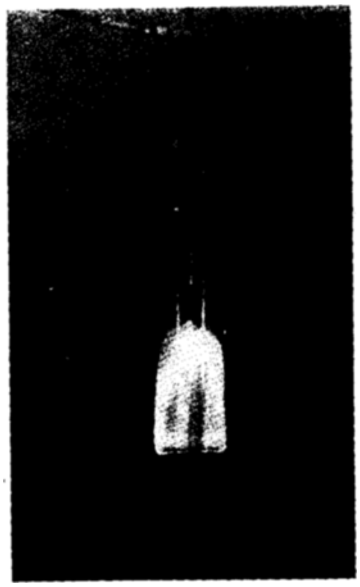

Fig. 2. Photograph of discharge and selected elements of experimental setup.

could be varied within $U_d = 0-12$ kV, and the discharge current, within $I_c = 0-300$ mA. A neutron radiation sensor was installed at a distance of 1–2 cm from the cathode, an SNM-11 neutron counter of Russian manufacture was connected to an SPU-1-1M unit, which contained an amplifier, a discriminator, and a pulse counter. The attenuation and discrimination levels of the sensor were such that the observed background neutron flux was in the range of 1 to 15 neutrons/min. During gas discharge, electrolysis of the heavy water at the cathode, which increased somewhat the pressure inside of discharge tube, was observed. Discharge conditions were maintained that ensured, to the extent possible, both homogeneity of the combustion zone and the absence of any contraction of the discharge. A photograph of the experimental setup is presented in Fig. 2. The discharge begins to contract and to degenerate into an arc as the discharge current increases in excess of 300 mA, when the voltage across the electrodes drops sharply as a result of the decreased of the resistance of the discharge gap. The neutron radiation sensor recorded a neutron flux that exceeded the background by a factor of tens starting with an electrode potential difference $U_d = 2$ kV, at a discharge current of 80–100 mA.

Results of Experimental Measurements and Discussion. The most probable reaction in the present experiment is

$$d + d \begin{array}{l} \rightarrow He^3 + n + 3.25 \text{ Mev}, \\ \rightarrow T + p + 4.0 \text{ Mev}. \end{array} \quad (1)$$

Here the probabilities of both processes are practically equal. For $W_d \ll 0.15$ MeV, the dependence of the total effective cross-section of the dd reaction on the deuteron energy W_d is expressed with rather high accuracy by the formula [4]

$$\sigma = 2.4 \cdot 10^{-19} \frac{1}{W_d} \exp\left(-\frac{1.4 \cdot 10^3}{\sqrt{W_d}}\right). \quad (2)$$

With the dependence of effective cross-sections for elementary interaction acts on particle energy known, one can calculate the rate of a fusion reaction in a substance. The number of nuclear reactions occurring in a unit volume per 1 sec is determined by the expression

$$g = n_1 n_2 \langle \sigma V \rangle. \quad (3)$$

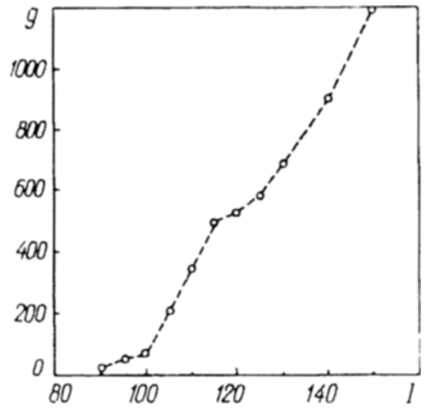

Fig. 3. Dependence of neutron flux produced by the setup g, neutron/sec, on the discharge current I, mA, for electrode voltage $U_d \sim 4$ kV.

Here n_1 and n_2 are the concentrations of nuclei of the both reacting components of the substance and $<\sigma V>$ is the product of the relative velocity of nuclei multiplied by the effective cross-section of the reaction averaged over the velocity distribution. The cathode current in discharge is determined by the expression

$$j_c = en_i V_i (1 + \gamma_i) S , \tag{4}$$

where γ_i is the coefficient of secondary electron emission, and S is the area of the cathode spot. If we assume that the ion component of the discharge current is mainly caused by D^+ ions, and the ion energy amounts to tens of percent of eU_d, then the rate of a fusion reaction in the above described experimental setup can be estimated by the formula

$$g = n_1 \frac{j_c}{e} \sigma l , \tag{5}$$

where n_1 is the concentration of deuterons in the heavy water and l is the characteristic size of the region occupied by the heavy water. As is seen from relation (5), the intensivity of the neutron flux generated by the setup is a linear function of the cathode current when the voltage at the electrodes and, consequently, the mean energy of the particles bombarding the cathode remain constant.

Figure 3 presents a graph of the dependence of the neutron flux generated by the setup on the discharge current for electrode voltage $U_d \sim 4$ kV. As is seen from the graph, an approximately linear dependence of the neutron flux on the cathode current is observed. Estimation of the total neutron radiation by formula (5) for discharge current j_c = 140 mA and electrode voltage U_d = 4 kV gives $\sim 5 \cdot 10^3$ neutron/sec, which exceeds by severalfold the actually registered values. The divergence is explained by the fact that far from all deuterons bombarding the cathode participate in fusion. This is also explained by the approximate character of relation (5).

Conclusions. The experimental investigation showed that when the cathode is heavy-water surface and the space between electrodes is filled by saturated vapors of heavy water as well as with its electrolysis products, at the cathode in glow discharge, conditions can be realized under which a fusion reaction of type (1) can occur as a result of the bombardment of the cathode by deuterium and tritium ions. During this process, the recorded neutron flux exceeds the background by a factor of tens, and a linear dependence of the neutron flux generated on the discharge current is observed. On the whole, the intensity of neutron generation in the setup must be nonlinear as a result of the change in potential difference between the electrodes as well as the cathode potential drop and, consequently, the change in the energy spectrum of the particles bombarding the cathode. However, the investigated range of current variation is so insignificant that the dependence appears approximately linear. The observed phenomenon could be of practical interest in the development of new energy sources as well as in the production of controlled neutron sources.

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