THE DESTRUCTION OF A DIELECTRIC WITH A PULSED ELECTRIC DISCHARGE IN CHANNELS WITH ABLATING WALLS

Yu. F. Tainov

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We present experimental data with respect to the ablation of the walls of a cylindrical channel made of a dielectric material under the action of a pulsed electric discharge. We have found the relationship between the mass removed from the walls of the channel and the geometry of the channel and the physical constants of the dielectric materials.

A number of papers have been devoted to an investigation of the properties of electric discharges in cylindrical channels with ablating walls, the purpose of these studies being either the development of high-speed plasma jets [1], or the creation of a bright glowing plasma cloud [2], ejected from a capillary channel. The manner in which the dielectric enters the discharge zone, as well as the effect of channel geometry and the form of the dielectric on the ablation process was not considered in the cited communications and represents the subject of the present paper. Moreover, the quantitative description of the process of plasma interaction with the ablating wall is of independent interest.

The experiments were performed on a discharge unit fabricated in accordance with the schematic diagram shown in Fig. 1. The discharger is housed in a vacuum chamber evacuated to a pressure of 10^{-5} mm Hg. The discharge of the capacitor C occurs between copper electrodes 1 and 2 within a channel with a diameter $d = 16$ mm and a length $l = 30$-165 mm, formed by the walls of dielectric 3. During the discharge, the dielectric is vaporized, ionized, and ejected in the form of a plasma jet into the vacuum through an axial orifice in electrode 2. The discharge is initiated from a Bostik low-power plasma injector positioned inside electrode 1. The following materials were used as the dielectric: Teflon, polypropylene, and calomel Hg_2Cl_2, derived by cold pressing from a powder. The dielectric insert was weighed before the tests and after 100-200 discharges. The capacity C varied between 90 and 7200 μF at a working voltage of 1 kV. The products of dielectric decomposition predominate in the discharge plasma, and the rate of electrode loss represents no more than 4% of the dielectric loss.

It was found in most of the experiments that the discharge current is aperiodic. A voltage of 100-300 V remains at the capacitor on conclusion of the discharge, and this voltage increases as the channel length is increased. The graphical processing of the current and voltage oscillograms for the discharge interval shows that approximately 90% of the energy W_0 stored in the capacitor is liberated in the discharge channel. With increasing discharge energy, there is but a slight increase in current strength; it is primarily the duration of the current pulse that increases.

Figure 2 shows the results from the determination of the yield of ablated material per single discharge event for various dielectrics and a variable channel length as a function of the applied energy. We can draw the entirely justified conclusion that a linear relationship exists between the quantity of ablated material and the energy generated by the discharge. The following empirical relationship has been noted between the mass of the vaporized dielectric and the geometric dimensions of the channel when $W_0 = \text{const}$:

$$m = k_1 \frac{\sqrt{l}}{d}. \tag{1}$$

This relationship is satisfied with sufficient accuracy within the limits of the following geometric channel dimensions: $d = 16$-50 mm, $l = -30$-165 mm.

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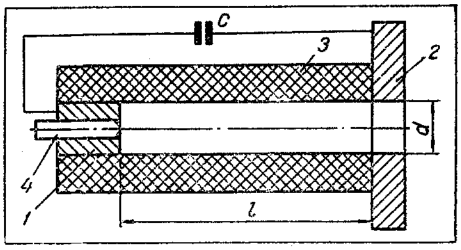

Fig. 1

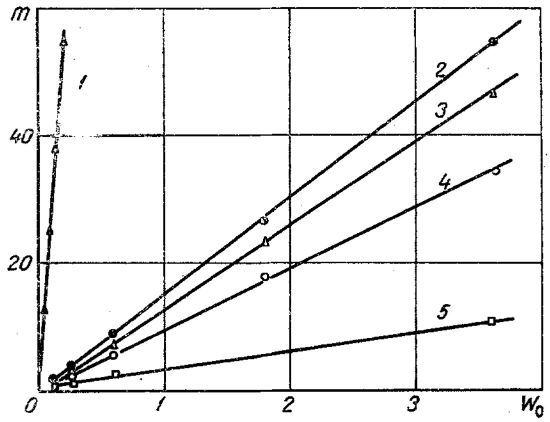

Fig. 2

Fig. 1. Basic circuit of the discharge unit: C) accumulating capacitor; 1 and 2) electrodes; 3) dielectric; 4) initiating injector.

Fig. 2. Dielectric mass yield m (mg/discharge) as a function of the energy W_0 in the discharge (kJ) for a channel with d = 16 mm: 1) Hg_2Cl_2; 2) Teflon, l = 165 mm; 3) Teflon, l = 115 mm; 4) Teflon, l = 60 mm; 5) polypropylene, l = 60 mm.

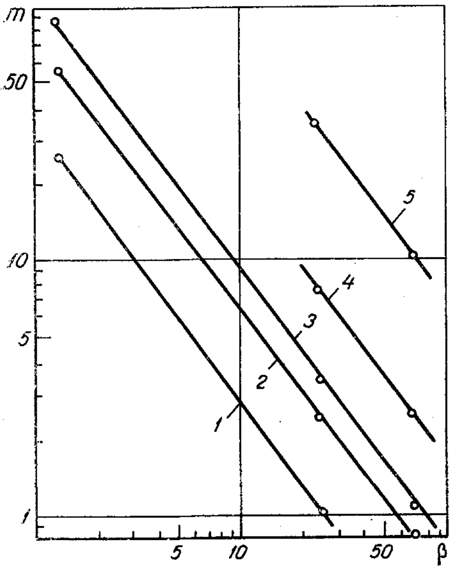

Fig. 3. Yield of dielectric mass m (mg/discharge) as a function of the specific heat of ablation β (kJ/g) for a channel with l = 60 mm: 1) W_0 = 100 J; 2) 200; 3) 315; 4) 600 J; 5) 3.6 kJ. For Hg_2Cl_2, Teflon, and polypropylene we have β = 1.33, 24, and 70 kJ/g, respectively.

To compare the data on the mass yield of vaporization products from various materials we have to establish the constant characterizing the ablation resistance of the dielectrics. We have taken the specific heat of ablation β as such a quantity: it is defined as the quantity of energy required to break all chemical molecular bonds per unit weight of material. The specific heats of ablation were determined from the known magnitudes of the chemical molecular bonds [3]. The energy spent on the heating of atomic products of material decomposition to plasma-discharge temperatures and the ionization losses were not taken into consideration in the specific heat of ablation.

It develops that the dielectric mass vaporized from the walls per single discharge is uniquely defined by the specific heat of the dielectric ablation, all other conditions being equal, and namely

$$m = \frac{k_2}{\beta}. \tag{2}$$

The coefficient k_2 is defined by the channel geometry and the circuit discharge parameters. The single-valued relationship between the dielectric loss of material and the value of β demonstrates the mutual parallelism of the curves in Fig. 3, illustrating formula (2) on a logarithmic scale. When we use substances with a low specific heat of ablation it is possible to increase the mass yield from the walls during the discharge; however, in the overall balance the fraction of energy expended on the destruction of the molecules remains constant, i.e., in a specific experiment the chemical composition of the substance has no effect on the magnitude of energy spent on the destruction of the chemical bonds. Thus, if we know the ablation resistance of a given material, we can predict the mass yield for other dielectrics in the same experiment. The overall expenditures on the destruction of the bonds increase as the channel is lengthened, as its diameter is reduced, as the inductance and stray resistance of the discharge circuits are reduced, i.e., when we encounter all the changes which correspond to an increase in m. In particular, when l changes from 30 to 165 mm, the energy expenditures on destruction of the molecular bonds increase from 20 to 55% of W_0. We should take note of the fact that substances with a limited range of sublimation temperatures from 400 to 600°C were used in the experiments. However, the difference in sublimation temperatures may have no significant effect, since the plasma temperature at the instant of maximum current is estimated at a level of 10^4°K for a Teflon channel. The estimate is based on the theoretical conductivity $\sigma = 250\ \Omega^{-1} \cdot m^{-1}$ of the plasma channel. The conductivity was calculated from the known resistance of the discharge gap at the instant of maximum current, on the assumption that the current is uniformly distributed through the channel diameter.

The validity of the temperature estimate at this level is confirmed by spectroscopic measurements. In the plasma jet being discharged from the channel, against the background of a continuous spectrum, we note primarily the lines of neutral and singly ionized fluorine and carbon atoms. The upper bound of the plasma temperature can be derived from the following considerations. At a temperature of $1.5 \cdot 10^4$°K, in accordance with the Sakh equation, we should find virtually total ionization, in which even the energy spent on ionization will, alone, be greater than all of the stored energy.

NOTATION

C	is the accumulating capacitor;
l	is the channel length;
d	is the inside channel diameter;
m	is the dielectric mass loss per discharge;
k_1 and k_2	are proportionality factors;
W_0	is the energy stored in the capacitor;
β	is the specific heat of ablation;
σ	is the plasma conductivity of the channel.

LITERATURE CITED

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3. Concise Handbook of Physicochemical Quantities [in Russian], Izd. Khimiya (1967).