ON SURFACE BREAKDOWN

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Corresponding Member of the USSR Academy of Sciences V. V. RZHEVSKII,
N. I. ANDRIENKO,
D. M. MIGUNOV, Yu. I. PROTASOV

ON SURFACE BREAKDOWN

It is known that if electrodes located in a gas touch a solid body (i.e., are closed by a solid body)—a dielectric or a semiconductor—then, when a voltage is applied to the electrodes, the gas breaks down, but the breakdown develops along the interface between the media. We shall call this phenomenon surface breakdown.

If the electrodes are separated by a considerable distance, greater than L_κ, then breakdown occurs through the solid body. This phenomenon seems surprising; however, it becomes understandable if one takes into account that the electric field in the solid body is spatially sharply nonuniform, since the electrodes touch the solid body at a "point"—over a very small surface; as the distance between the electrodes increases, the current in the solid body increases, since the cross section through which the current flows increases; owing to the nonuniformity of the field under the electrodes, the electrical conductivity of the solid body increases both because of the high field strength and because of an increase in temperature at the contact. The electric field in the gas is nonuniform only in the section perpendicular to the electrodes. If we assume that, as a load, the two media are connected in the electrode circuit in parallel, then the resistance of the load is equal to:

$$R^{-1} = \pi L/8\rho + (BL)^{-1}, \tag{1}$$

where the first term refers to the solid body, the second to the gas; R is the resistance of the load on the electrodes; ρ is the specific resistance of the solid body, which is a function of the field strength and temperature; $\pi/8$ accounts for the nonuniformity of the field ([1]); B is a coefficient taking into account the resistance of the gas between the electrodes and the nonuniformity of the field in the gas; L is the distance between the electrodes.

The critical distance is determined from the condition of equality of the resistances of the two media

$$L_\kappa = (8\rho/\pi B)^{1/2}. \tag{2}$$

Figure 1. Penetration of the breakdown channel h as a function of the distance between electrodes L

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For $L < L_\kappa$, breakdown occurs through the gas; for $L > L_\kappa$, through the solid body. B was determined experimentally. The nonuniform field causes the medium adjacent to the electrodes to lose its electrical strength, which also leads to breakdown. In the solid body beneath the electrodes a breakdown channel is formed, having a small resistance and being practically a conductor, through which the main share of the current flows. The channel develops from the electrodes and penetrates into the solid body. A force acts on the channel that is proportional to the field strength and to the current passing through the channel. As a result of the action of this force, the breakdown channel bends, connecting the electrodes. This picture is observed both in thermal and in electrical breakdown.

The breakdown process is described by the equation:

$$\pi c r^2 m T + \frac{U^2 t k}{R(L-2l)} - \frac{4\pi m r^3}{3}\frac{d^2 l}{dt^2} = 0, \tag{3}$$

where U is the voltage on the electrodes, t is the duration of the applied voltage; R is the resistance of the solid body between the electrodes, l is the length of the channel

breakdown; r is the radius of the breakdown channel; m is the density of the medium in the channel; k is a coefficient taking into account the inhomogeneity of the field in the solid; T is the melting temperature; c is the specific heat capacity.

The solution of equation (3) determines the length of the breakdown channel in the solid; however, of practical interest is the maximum depth of penetration of the channel into the solid. For boundary and initial conditions corresponding to the arrangement of the electrodes on the boundary of the half-space separating the solid and the gas, one obtains

$$h = E^2 L^3 t / 48 \rho m c r^2 T k, \tag{4}$$

where h is the maximum distance of the breakdown channel from the boundary of the half-space, and E is the electric strength of the solid.

Fig. 1. Penetration of the breakdown channel h as a function of the distance between electrodes L

The experimental study of surface breakdown was carried out on various dielectrics and semiconductors, with the dimensions of the specimens relative to the parameters of the channel chosen so as to satisfy the boundary conditions described above. The electrodes were placed on a plane separating half-spaces filled with the given dielectric and with air. Voltage was applied to the electrodes for various lengths of time, the voltage being increased until breakdown of one or the other medium occurred. By varying L from a minimum to the largest possible value (while preserving the boundary conditions), either breakdown through air or through the solid was obtained. By measuring h, the dependence of h on L was constructed.

A typical experimental dependence for polycrystalline NaCl is shown in Fig. 1. L_k for polycrystalline NaCl varies from 8 to 10 cm. Breakdown was produced by a voltage of frequency 50 Hz with a voltage exposure time of 1 sec. Decreasing the voltage exposure time leads to a decrease in the penetration depth of the breakdown channel into the solid. Some dielectrics with high electric strength could not be broken down from the surface in air; however, calculations show that it is possible to break down any dielectrics if L and t are increased.

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Note: Figure translations are in progress. See original paper for figures.