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CONCERNING THE DEVELOPMENT OF A DISCHARGE IN SOLID DIELECTRICS

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EDITED TRANSLATION

CONCERNING THE DEVELOPMENT OF A DISCHARGE IN SOLID DIELECTRICS

By: V. Ya. Ushakov and N. M. Torbin

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ABSTRACT: The channels of incomplete breakdown in rock salt and organic glass are considered. It is shown that the discharge glow zone exceeds by hundreds of times the channel dimensions. It is indicated that thermo-ionization and photoionization processes can occur during the breakdown of dielectrics. Dielectrics having larger dielectric strength have larger discharge-development rates (v). Values $v = (2 \times 10^5 - 1.5 \times 10^7)$ cm/sec were obtained and were found to depend on the value of the excess voltage. English Translation: 4 pages.

CONCERNING THE DEVELOPMENT OF A DISCHARGE IN SOLID DIELECTRICS

V. Ya. Ushakov and N. M. Torbin

(The Tomsk Polytechnical Institute named after S. M. Kirov)

Experimental results recently obtained at the Tomsk Polytechnical Institute allow us to assert that the electrical breakdown of solid dielectrics starts from electron-impact ionization [1, 2]. In dielectrics 10^{-4}-10^{-3} cm thick a discharge develops as a result of the passage of several avalanches and is called a multiavalanche-streamer discharge [3]. With somewhat thicker dielectrics (about $5 \cdot 10^{-3}$ cm and thicker) the discharge develops similar to the avalanche-streamer discharge in air [4, 5].

However, the m chanism of channel formation and the characteristics of discharge development in different dielectrics have been insufficiently studied. Hippel [6] holds to the opinion that the passage of an electron avalanche of sufficiently great volume leads to fusion of the crystal within the limits of the avalanche sector due to the local high temperature. According to Fröhlich [7] electron avalanches are not oriented in crystalline dielectrics and the orientation of the channel path is caused by secondary processes. For brief times of the voltage effect (on the order of 10^{-8} s) there is a possibility of mechanical distruction of dielectrics due to the forces of the electrostatic field [9] or any other mechanisms, but not due to a high temperature [10]. Whether the paths of partial breakdown are caused by primary or secondary processes, work [8] showed that the final statement involves the presence of orientation effects up to physical destruction of the dielectrics Using the method of producing channels of incomplete breakdown in dielectrics by cutting off the voltage, we obtained certain experimental data about the development of a discharge in crystals of rock salt and organic glass in the field of the positive point opposite the plane. The glow that arises during development of the discharge was photographed with an immobile camera on a film and the obtained channels of incomplete breakdown were examined under a microscope.

Under the effect of a pulse of voltage of the breakdown magnitude and limited duration a discharge propagates from the positive point into the depth of the dielectric and its velocity varies depending upon the magnitude of the applied voltage.

Figure 1 shows photographs of a discharge in rock salt under the effect of a pulse of voltage $U = 135$ kV with a duration of $\tau = 0.4$ μs and in organic glass at $U = 143$ kV and $\tau = 0.3$ μs.

As is evident from Fig. 1, the character of the discharge depends upon the structure of the dielectric. In a crystalline dielectric the direction of the discharge is strictly oriented along one of the crystallographic directions depending upon the surge, while in organic glass the discharge more closely resembles a graphics not reproducible

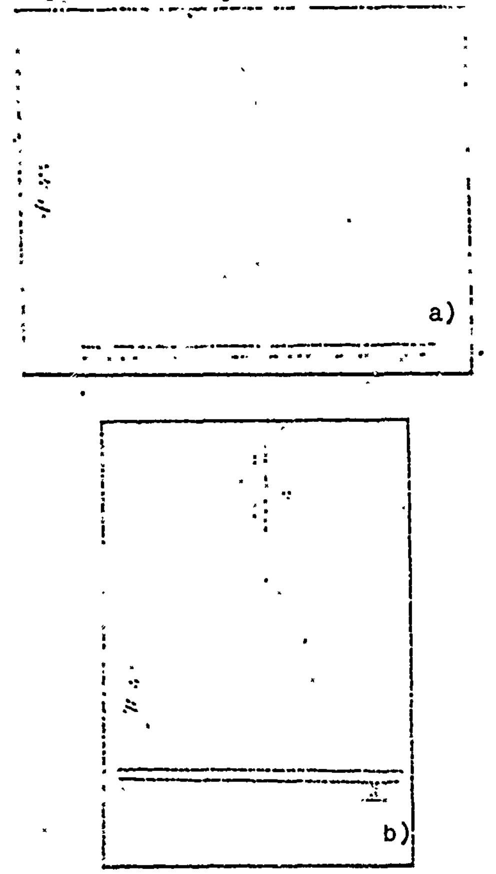

Fig. 1. Photographs of discharges of incomplete breakdown: a) in rock salt; b) in organ glass.

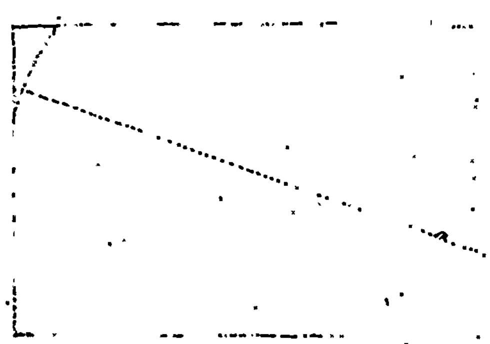

Fig. 2. Initial stage of the formation of a channel of incomplete breakdown in rock salt.

discharge in transformer oil or air with positive polarity of the point.

A comparison of the dimensions of the discharge glow zone and the channel in the dielectric shows that the discharge glow zone exceeds the dimensions of the channel of incomplete breakdown in the dielectric by a factor of one hundred. The glow is more intensive along the discharge axis, decreasing towards the periphery.

A study of the channel of incomplete breakdown in rock salt shows that in the initial stage of discharge development the channel dimensions are less than 1 μm. The channel does not have strict boundaries, but is in the form of alternating darkened sections of a "dotted line" (Fig. 2), which are also oriented along a crystallographic direction. It is possible that the presence of darkened sections is connected with the passage of electron avalanches since we did not observe visible (magnification ×90) distruction of the dielectric. However, even at this moment around the channel we observe a band that is probably due to high temperature.

Measurements of the current in the stage of discharge development showed that the current density in the channel attained 10^4-10^5 A/cm^2, and the energy liberated in the channel was sufficient to fuse the dielectric [11]. The passage of current along the channel leads to gradual widening of the channel up to 10-12 μm, which can usually be observed by the unaided eye, and to fusion of the channel walls (Fig. 3); this gives basis to assume that the glos observed during breakdown basically carries a thermal character. However, the field strength, which we calculated assuming that the voltage drop along the channel axis is small, attains 10^8 V/cm and significantly exceeds the breakdown voltage for this dielectric. Consequently, intensive ionization processes can occur in the regions adjacent to the discharge channel and part of the emission usually observed around the discharge channel can be caused by these processes. A large number of much smaller channels of incomplete breakdown can also be observed in this region. High temperatures and high gradients in the channel cause intensive thermal ionization, and also photoionization, and they increase the discharge propagation rate. A study of the breakdown of dielectrics in the presence of a barrier of metallic foil, mica or polymer films [12] showed that a barrier does not have a significant effect on the development of a discharge, and the breakdown of the dielectric occurs, as it were, in two stages: part of the sample before the breakdown of the barrier and part of the sample after the breakdown of the barrier. Consequently, for a discharge to develop in a dielectric it is necessary that the field strength attain a critical value in a certain volume of the dielectric.

In a very nonuniform field this field strength appears at the point from which the discharge begins to develop into the depth of the dielectric. Therefore, the graphic not reproducible

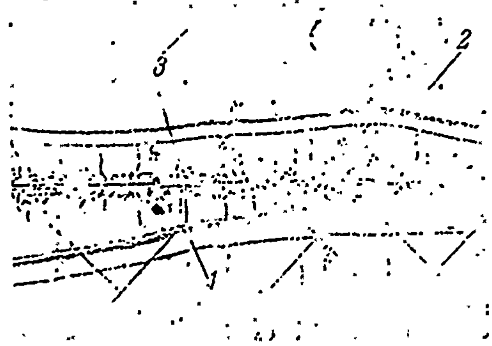

Fig. 3. Photomicrograph of the channel of incomplete breakdown in rock salt (×40): 1 – channel of incomplete breakdown; 2 – region of the dielectric adjacent to the channel; 3 – dielectric untouched by the discharge.

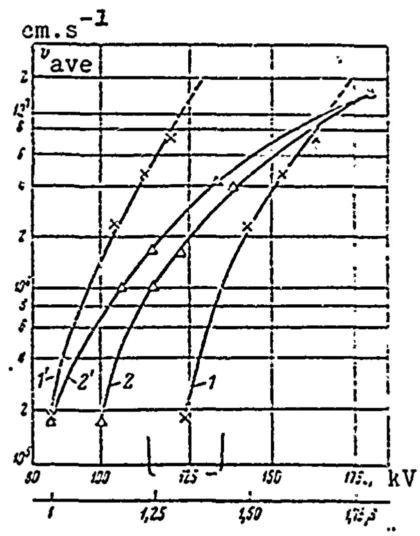

Fig. 4. Change in the discharge development rate: 1 – depending upon voltage for NaCl; 1' – depending upon overvoltage for NaCl; 2 – depending upon voltage for organic glass; 2' – depending upon overvoltage for organic glass.

sections of the channel located near the point are subject to high temperature for a longer time and have larger dimensions. Thus, in organic glass the diameter of the discharge channel varies from 32 μm at the point to 18 μm at a distance of 20 mm from the point.

The intensity of the ionization processes and, consequently, the discharge development rate significantly depend upon the magnitude of the applied voltage and can vary within wide limits. On Fig. 4 Curve 1' shows the dependence of the change in the discharge development rate upon overvoltage for rock salt (d = 35 mm), Curve 2', for organic glass (d = 20 mm). As is evident from the graph, the increase in the discharge development rate with the increase in overvoltage occurs more rapidly in organic glass than in rock salt, although the initial discharge development rates (at minimal voltages) are identical. This difference can probably be explained by the fact that the average field strength for breakdown of organic glass is higher and, consequently, conditions will be more favorable for the development of the discharge. Higher values of the rate during breakdown of polymers in comparison with crystalline dielectrics in a nonuniform field have been noted previously [13], although work [14] stated that an electrical breakdown in a nonuniform field can be propagated more slowly in amorphous materials than in crystalline dielectrics. The amorphous structure of a diaelectric probably affects only the conditions for the appearance of a discharge, which can explain the higher values of the breakdown voltages for amorphous dielectrics in comparison with crystalline dielectrics. After the discharge has begun to develop, due to the higher field strengths at the head of the discharge the structure of the dielectric does not have a significant effect on the development of the discharge and the discharge development rate is mainly determined by the magnitude of the applied voltage.

Based on the obtained data we can make the following conclusions:

1. The presence of emission during development of a discharge and the higher discharge propagation rates indicate the possibility of thermal ionization and photoionization processes during the breakdown of solid dielectrics.

2. The presence of fusion of the channels of incomplete breakdown in solid dielectrics indicate the thermal character of the formation of these channels.

3. Dielectrics with a high dielectric strength have high discharge development rates.

4. The discharge development rate in solid dielectrics varies from $2 \cdot 10^5$ to $1.5 \cdot 10^7$ cm/s and depends upon the magnitude of the overvoltage.

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