THE INFLUENCE OF AN ELECTRIC FIELD ON THE PROPERTIES OF THIN DIELECTRIC AND SEMICONDUCTING LAYERS

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Fig. 1

Figure 1: Fig. 1

Abstract

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PHYSICS

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THE INFLUENCE OF AN ELECTRIC FIELD ON THE PROPERTIES OF THIN DIELECTRIC AND SEMICONDUCTING LAYERS

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The dependence of the breakdown voltage of thin insulating layers on their thickness has been studied by a number of investigators. A detailed review of work on this question may be found in the monograph ([1]). The dependence of the conductivity of thin layers on the field strength has been investigated less thoroughly. The relation between the electrical conductivity of a thin layer and its electric strength has not been fully clarified. Experiments bearing on this question are described below.

The electrical conductivity and electric strength of thin layers of certain oxides, sulfides, and other compounds were investigated. Usually metals were coated with oxide layers electrolytically or by heating. In the case of metals whose oxides have good conductivity and whose sulfides have poor conductivity, layers of sulfides were studied. The latter were prepared by sulfidizing the surface of the corresponding metals in sulfur vapor.

Usually a pellet of Cu_2S, 3 mm thick and 0.5 cm^2 in area, was pressed against the surface of the oxide layer and served as one of the electrodes. Monovalent copper sulfide Cu_2S had a conductivity equal to 40 $cm^{-1} \cdot cm^{-1}$. The other electrode was the metallic substrate on which the oxide was formed. The test arrangement resembles that used in taking current-voltage characteristics of semiconductor rectifiers.

Fig. 1

In studying layers of MgO, Al_2O_3, ZnO, CdS, NiO, Ta_2O_5, Nb_2O_5, from 30 to 1000 Å thick, transfer of metallic ions from the substrate into Cu_2S, which has hole conductivity, was observed. The presence of transferred ions in the copper sulfide is detected in some cases—for example, for aluminum—by spectral analysis, and manifests itself in the appearance of rectifying properties in the device under investigation. The ionic current is caused by heating of the layer

Fig. 2

Figure 2: Fig. 2

by the current passing through it in certain limited regions. The compounds mentioned are arranged approximately in the order of decreasing relative share of the ionic component of conductivity.

In the case of an Nb_2O_5 layer, ion transfer is small and sometimes does not appear. Then the current-voltage characteristic has the form shown in Fig. 1. The resistance of the layer for an effective voltage below 0.2 V is high; then it decreases and the current rises sharply. The increase in current is associated with quantum-mechanical effects, and the curve of the dependence of current on voltage has a complex form that is not reflected in the photograph. Further,

a more detailed study of the current-voltage characteristic is possible and will prove useful for elucidating the nature of the processes occurring in thin films. When the voltage is reduced, the resistance of the layer again increases and assumes its former value. The current-voltage characteristic is reproducible and was photographed from the screen of a cathode-ray oscilloscope when an alternating voltage with a frequency of 50 Hz was applied to the structure. If the voltage is raised somewhat above 0.2 V, transfer of Nb into Cu_2S becomes noticeable and rectification appears. When the voltage is increased to 0.4–1.0 V, breakdown of the layer occurs.

Fig. 2

Higher voltages can be applied to the following structure. If a tablet of chemically pure tellurium is placed on the oxide layer covering aluminum and a voltage is applied, then, as a result of breakdown of the oxide layer, the tablet is welded to the electrode and a transition layer is formed. This layer has a high resistance at low voltages. When the voltage is raised to approximately 8.4 V, the resistance of the layer drops sharply and the current increases abruptly. The voltage at which the jump occurs varies only slightly from case to case. When the voltage is reduced to 6.3 V, the resistance of the layer assumes its initial value. The dynamic current-voltage characteristic at a frequency of 50 Hz is shown in Fig. 2.

The study of other films, for example the oxide layer covering tantalum, shows a smooth dependence of current on voltage. In the interval of voltage variation from $(0.3 \div 0.4)\, V_{\text{br}}$ to V_{br} (V_{br} is the breakdown voltage), the current increases with voltage according to an exponential law. Only at voltages immediately adjacent to breakdown does the current-voltage characteristic become parallel to the current axis. The permissible current strength that does not cause destruction of the layer is 0.2 A.

For a number of systems, for example for an aluminum oxide layer, the dependence of current on voltage becomes smoother as the temperature is raised.

Experience in a number of cases shows a sharp, sometimes jump-like increase of current at a certain voltage applied to the layer; this, however, is not connected with destruction of the latter. Consequently, an increase in conductivity does not always lead to breakdown. In some cases the breakdown voltage of a dielectric layer exceeds by several times the voltage at which the conductivity of the layer increases significantly.

The experimental results can be explained on the basis of the following assumptions. Breakdown of a layer is its destruction, for which a definite energy W_{br} is required. This energy is obtained as a result of heating of the layer by the current passing through it. A thin layer lowers its resistance at a small voltage; the amount of heat released per unit time is small, and heat removal is sufficiently good, so that heating of the layer and its destruction do not occur. The passage of a large current without overheating the layer does not cause its destruction, and after the voltage is removed the resistance of the layer is restored. Breakdown is connected with destruction of the layer as a result of its heating by the passing current and is a secondary phenomenon.

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CITED LITERATURE

1. A. A. Vorob' ev, E. K. Zavadovskaya, *Electrical Strength of Solid Dielectrics*, Moscow, 1956, p. 131.

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