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Letters to the Editor

NOTE ON THE THICKNESS DEPENDENCE OF THE THRESHOLD VOLTAGE OF AMORPHOUS SWITCHING DEVICES

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On the basis of thermal analysis as well as experimental results one possible explanation of the switching effect in thick amorphous switching devices was given [1]. To express I—V characteristics, the electro-thermal balance equation

$$\lambda \frac{d^2T}{dx^2} + E^2\sigma(T) = \beta(T - T_0) \tag{1}$$

which has a similar form as that in [2, 3] was solved. The important role of the conditions of heat transfer from the sample was treated elsewhere [4]. In an earlier paper [1] the heat transfer coefficient was incorporated into the constant β (reciprocal value of "thermal resistance") in the form

$$\beta = \frac{4b\lambda}{(2\lambda + bd)d} \tag{2}$$

Here d stands for the thickness and λ for thermal conductivity of the sample. Other symbols in (1) have the usual meaning.

Solving equation (1) under certain simplifying conditions (for details see [1]) one can obtain the I—V characteristics in the form

$$I = i\left[\frac{2k\lambda\sigma(T_0)\, l^2 T_0^3}{\delta E}\right]^{1/2}, \qquad V = v\left[\frac{\beta k T_0^3 d^2}{2\beta(T_0)\,\delta E}\right]^{1/2}, \tag{3}$$

where

$$i = v \int_0^{\vartheta_m} \exp(\vartheta)\, \{v^2[\exp(\vartheta_m) - \exp(\vartheta)] - (\vartheta_m^2 - \vartheta^2)\}^{-1/2}\, d\vartheta. \tag{4}$$

The shape of the I—V characteristics is determined by the value of the parameter p

$$p = \frac{h}{2}\left[\frac{4b}{(2\lambda + bd)d}\right]^{1/2}. \tag{5}$$

It is related to the maximum value of the temperature profile by the relation

$$p = \int_0^{\vartheta_m} \{v^2[\exp(\vartheta_m) - \exp(\vartheta)] - (\vartheta_m^2 - \vartheta^2)\}^{-1/2}\, d\vartheta, \tag{6}$$

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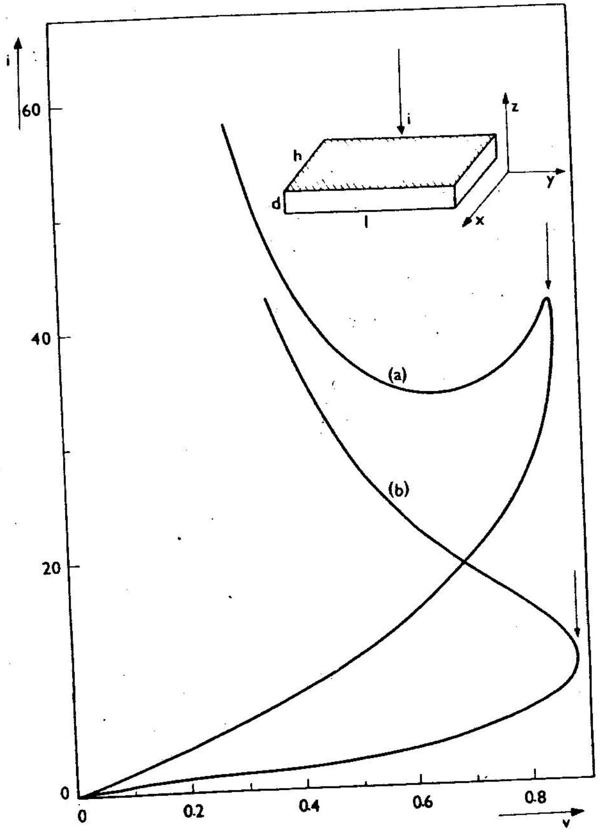

Fig. 1. The i—v characteristics calculated using the expressions (4) and (6) for $p = 5$ (curve a) and for $p = 20$ (curve b). The arrows denote the turnover points. In the insert the geometry of the sample is presented.

where

$$\vartheta_m = \frac{\delta E}{kT_0^2}(T_m - T_0)$$

(T_m and T_0 are the maximum values of the temperature in the sample and the ambient temperature, respectively).

Evaluating numerically the expressions given above for $p \gtrsim 10$ one can obtain the I—V characteristics **with a triple valued range. The element with such a characteristics acts in an electrical circuit as a** switching element with hysteresis. On the other hand, for $p < 10$, the I—V characteristics are of a thermistor s-shaped type. Two i—v characteristics (for $p = 5$ and $p = 20$) are given in Fig. 1, in which the assumed geometry of the sample is presented, too.

Let us denote the values of the parameters v, ϑ_m, V at the turnover point by v_t, ϑ_{mt}, V_t. As can be seen from Fig. 1, for p large enough the turnover point is nearly identical with the point at which the switching occurs. The dependence v_t versus p (Fig. 2) shows that v_t can be considered as a constant for $p > 10$. Then expression (3) for V can be regarded as the expression for the thickness dependence of the threshold voltage

$$V_t = C'd\,[(2\lambda + bd)d]^{1/2}, \tag{7}$$

where C' is a certain constant which depends on the experimental conditions.

One can derive the same expression using a somewhat different approach.

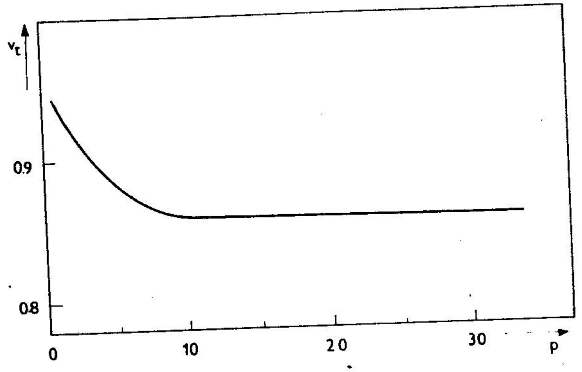

Fig. 2. The dependence of v versus p at the turnover points.

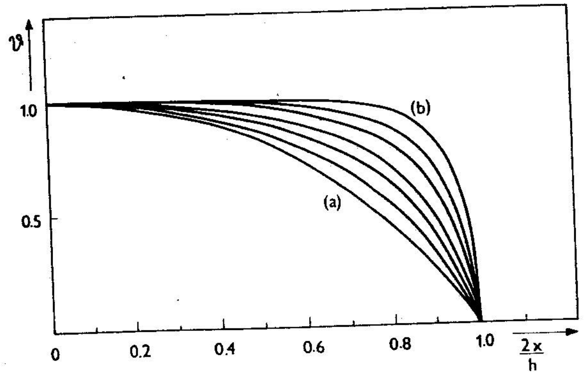

Fig. 3. The temperature profiles in the sample as a function of a normalized coordinate (the origin of the coordinate system is in the middle of the sample) for various values of the parameter p. Their sequence from a to b: $p = 5, 8, 10, 15, 20, 25, 35$.

The temperature profiles along the x-axis at the turnover points can be obtained by calculating the expression

$$\frac{2x}{h} = 1 - \frac{1}{p} \int_0^{\vartheta_x} \{v_i^2[\exp(\vartheta_{mm}) - \exp(\vartheta)] - (\vartheta_{mm}^2 - \vartheta^2)\}^{1/2} \, d\vartheta \tag{8}$$

(see [6]). They are shown in Fig. 3. The tendency of the temperature to remain constant within a
broader interval of the normalised coordinate with an increasing value of the parameter p is seen.
Moreover, the value ϑ_{mm} is constant for all p. At a first approximation one can write the electro-thermal
balance equation (1) at the turnover point the simple form

$$E_t^2 = C''[(2\lambda + bd)\, d]^{-1}. \tag{9}$$

In the model presented the temperature along the z-axis is assumed to be constant. Then equation (9)
differs from (7) by the multiplication constant only.
In paper [5] the thickness dependence of the average switching field E was experimentally studied in
more detail. The results obtained were commeted by the authors as follows: The switching field E is
proportional to $1/d$ and $1/\sqrt{d}$ for $d \geq 5.10^{-4}$ m and $10^{-5} \leq d \leq 5.10^{-4}$ m, repectively. For thinner
samples the value of E was constant.

Let us turn our attention to the expression (7) (or (9)). In the case of validity of the relation $bd > 2\lambda$,
$E_t = C/d$ holds and for $bd < 2\lambda$, $E_t = C/\sqrt{d}$. From the equality $bd \approx 2\lambda$, taking $\lambda \sim 0.5$ W/mK and
**$b \sim 10^4$ W/m^{2}K, which seem to be reasonable for usual experimental conditions, the value $\sim 10^{-4}$ m
for d follows.**

The thermal model discussed does not give any explanation for the thickness independence of the
switching field for the case of thin films. This is in accordance with the generally accepted opinion that in
these films the electronic mechanism plays a more important role than the thermal one.

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