THE ELECTRO-THERMAL MODEL OF SWITCH EFFECT IN THE CHALCOGENIDE GLASSES

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Abstract
The paper presents modelling of a volt-ampere characteristic of semiconductor chalcogenide glasses, which demonstrates so-called switch effect showing hysteresis behaviour during increasing and subsequent decreasing of current or voltage in the sample. Conductivity of the material is temperature depend. In this model, the cylindrical sample is divided into two parts and the Joule heat is created in both of them. The model assumes that the heat transfers between these parts can be described Newton's law of cooling.

INTRODUCTION

Switch effect

Chalcogenide glasses present an important subgroup of non-crystalline materials with several possibilities of technical applications in the area of electronics and optoelectronics [1-3]. Their electrical properties were explored first time by Kolomijec with colleagues around 1960 [4]. Switch effect as the memory effect in these materials discovered Owshinski in 1968 [5]. Another perspective application of these materials is the photo (current) induced phase structural change [6], which can bring the use in data (incl. holographic) record.

The paper presents electro-thermal model of the switch effect. The aim is to show that the switch effect (by which the volt-ampere characteristic shows strong hysteresis) may be induced also by the electro-thermal mechanism.

SINGLE-LAYER MODEL

Electrical conductivity

The volt-ampere characteristic I(U) of chalcogenide glasses is linear for very small currents. The influence of temperature T on its characteristic is given by

$$I = const\,.\,U \exp(-\frac{W}{kT})$$

where W is the activation energy of the corresponding chalcogenide glass and k is the Boltzman constant. In our case, the temperature of sample T is equal to room temperature T_o.

The higher currents may develop self-heating of the sample, which can be incorporated into the volt-ampere relation through the temperature change induced by current. At the same time a simplified assumption is applied that the sample is isothermal (temperature is equal in whole volume) and the heat release out of the sample is govern by the Newton law for the thermal release. For the mentioned assumptions, the temperature correction is continual proportional to the electric power of the sample UI, so the $T = T_o + \beta UI$, where β is constant. The volt-ampere characteristic of the single-layer sample may be written as follows

$$I = const\,.U.\exp(-\frac{W}{k(T_0 + \beta\, UI)})$$

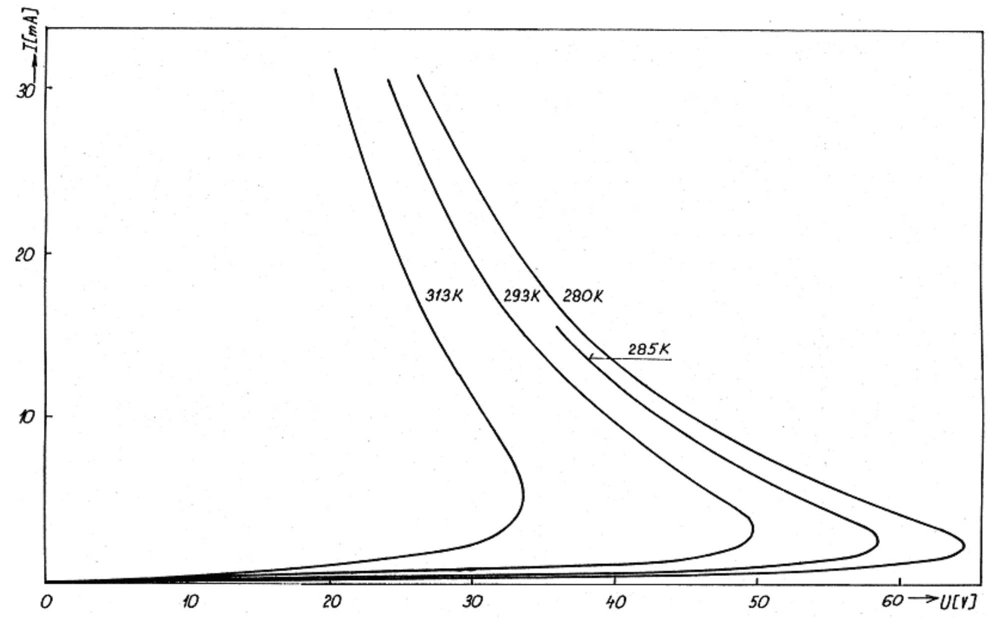

Figure 1

For higher currents are the corresponding volt-ampere characteristics markedly non-linear. The situation with several volt-ampere characteristics at different temperatures of surrounding environment is shown on Figure 1. The characteristics show also the field with negative differential resistance. One has to note, that the whole process is reversible by the rise and decline of the current. The volt-ampere characteristic of single-layer model does not show any hysteresis behaviour.

TWO-LAYER MODEL

This part describes the two-layer model and proves that the corresponding volt-ampere characteristics show hysteresis behaviour, so called switch effect. The entire geometry of the two-layer sample together with an appropriate thermal profile is given on the Figures 2 and 3.

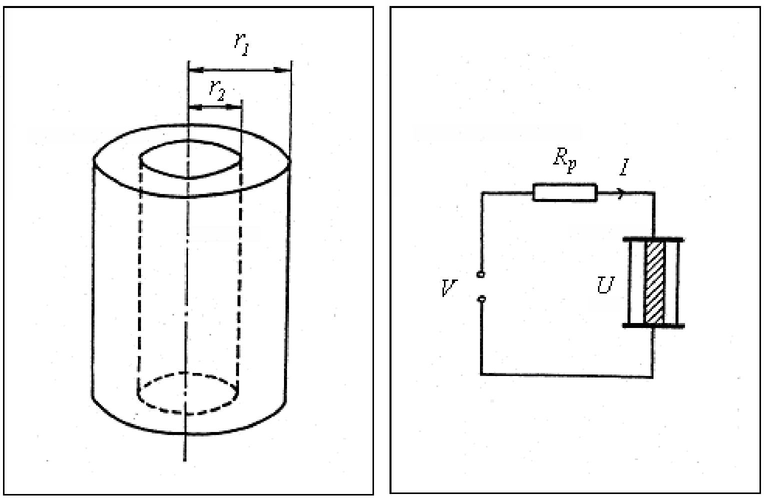

Figure 2.

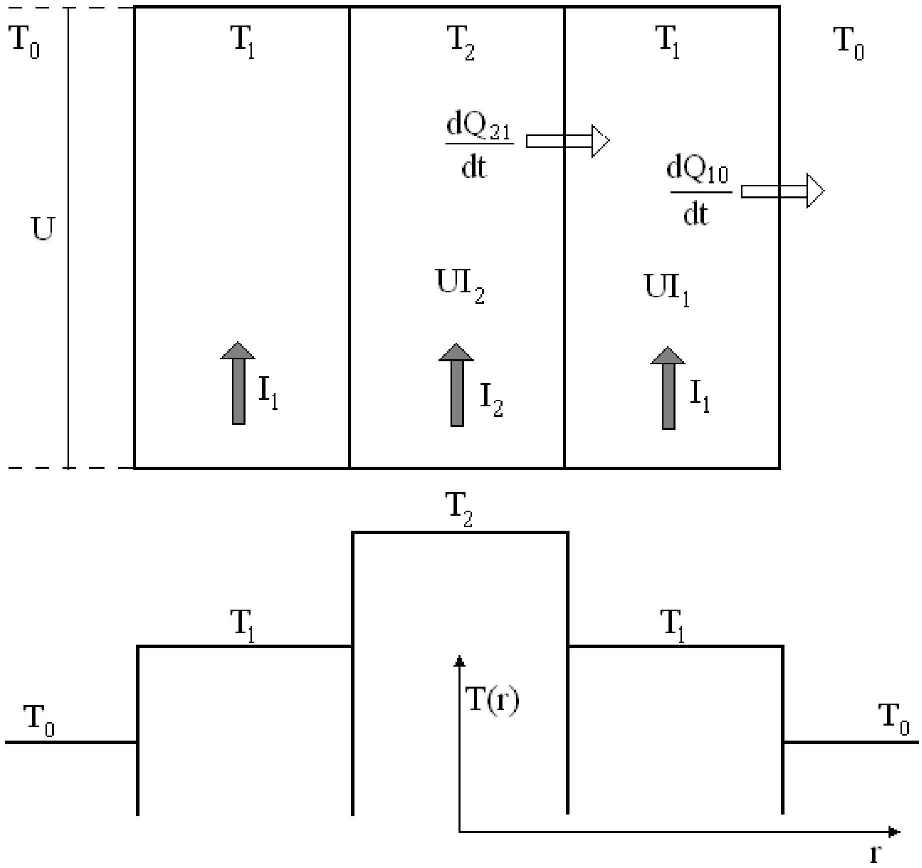

Figure 3.

At the first stage we will investigate the thermal balance in particular sample layers.

In stationary state, the heat rate UI_2 induced by the current I_2 is in the middle (the second) part of the sample in equilibrium with the heat outlet dQ_{21}/dt from the layer 2 to layer 1 per unit of time, and so

$$\frac{dQ_{21}}{dt} = UI_2$$

In respect with the assumption of validity of the Newton's relation, the heat outlet will be given by the equation

$$\frac{dQ_{21}}{dt} = \gamma_{21}(T_2 - T_1)$$

where γ_{12} is a constant.

The thermal balance of the outside layer in equilibrium is given by equation

$$\frac{dQ_{01}}{dt} = \frac{dQ_{21}}{dt} + UI_1 = UI_2 + UI_1 = UI$$

where

$$I = I_1 + I_2$$

is the total current passing through the sample (the both layers). The heat released into the surrounding environment is described by the equation

$$\frac{dQ_{10}}{dt} = \gamma_{10}(T_1 - T_0)$$

From the mentioned follows that

$$\gamma_{10}(T_1 - T_0) = UI$$

$$\gamma_{21}(T_2 - T_1) = UI_1$$

All these relations serve to express the temperatures T_1 and T_2 in particular layers of the sample for the stationary state

$$T_1 = T_0 + \beta_{10}UI$$

$$T_2 = T_0 + \beta_{10}\,UI + \beta_{21}\,UI_2$$

where

$$\beta_{21} = \frac{1}{\gamma_{21}}$$

$$\beta_{10} = \frac{1}{\gamma_{10}}$$

are the corresponding constants. The currents, which are passed through particular layers are described by the analogous relations like in the case of single-layer sample, so

$$I_1 = const\,.U \exp(-\frac{W}{k(T_0 + \beta_{10}UI)})$$

$$I_2 = const\,.U \exp(-\frac{W}{k(T_0 + \beta_{10}UI + \beta_{21}UI_2)})$$

$$I_1 + I_2 = I$$

By the numerical solving of the above mentioned equations is possible to obtain a graph of corresponding volt-ampere characteristics of the two-layer's sample. The characteristics show hysteresis behaviour already during the corresponding rundown.

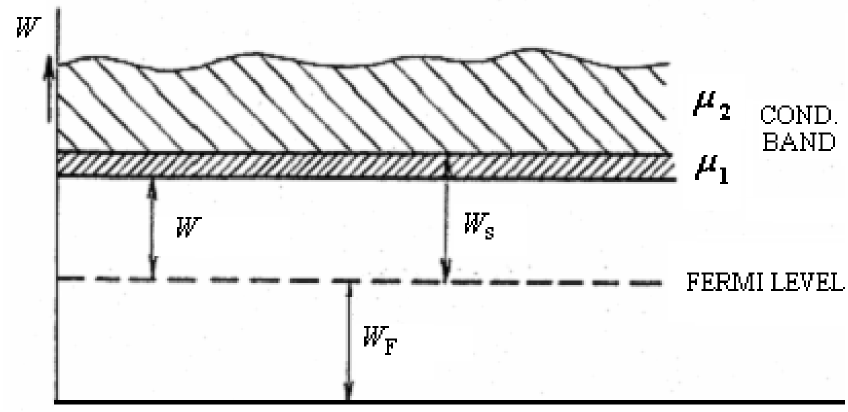

Figure 4.

Another improvement of the volt-ampere characteristics model of the chalcogenide glass can be achieved by the implementing of two sub-bands of carrier mobility (Figure 4).

TWO SUB-BANDS OF MOBILITY IN NON-CRYSTALLIC SEMICONDUCTORS

Electronic spectrum of the chalcogenide glasses features with an existence of low mobility sub-band situated on the bottom of conduction band (like on the top of valence band). The sub-band of high mobility is situated above it (see Figure 4).

The explanation is following: an occurrence of the low mobility sub-band may be conditional to the existence of potential barriers which make the transport of unbound electrons with low energy harder (see Figure 5). The mobility of unbound electrons with sufficiently high energy (situated at the layers above the top of potential barriers) will be much higher.

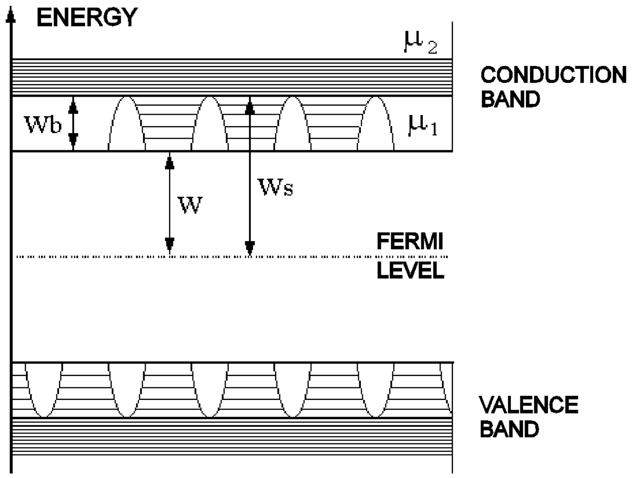

Figure 5

Single- and two-layer sample with two sub-bands of mobility

If the initiated two sub-bands are assigned simply to two different values of mobility μ_1 and μ_2 (see Figures 4, 5), the entire transport in the glass (considering the two-layer sample) can be described by the following three relations

$$I_1 = const\,.\,U\left[\mu_1\exp(-\frac{W}{k(T_0+\beta_{10}UI)}) + (\mu_2-\mu_1)\exp(-\frac{W_{O1}(1-cU)}{k(T_0+\beta_{10}UI)})\right]$$

$$I_2 = const\,.\,U\left[\mu_1\exp(-\frac{W}{k(T_0+\beta_{10}UI+\beta_{21}UI_2)}) + (\mu_2-\mu_1)\exp(-\frac{W_{O1}(1-cU)}{k(T_0+\beta_{10}UI+\beta_{21}UI_2)})\right]$$

$$I_1 + I_2 = I$$

In addition, the mentioned equations involve a fact that the electric field decreases the mobility gap width W_s, and so $W_s = W_{so} - cU$, where U is the electric tension on the sample and c is constant.

Numerical solution of the three above relations can produces a graph of particular volt-ampere characteristics of the two-layers sample. Illustrative examples are shown on Figures 6 and 7. The characteristics show hysteresis behaviour. Sample is changing its state from the high- to low-resistance and vice versa what is just the principle of the switch effect.

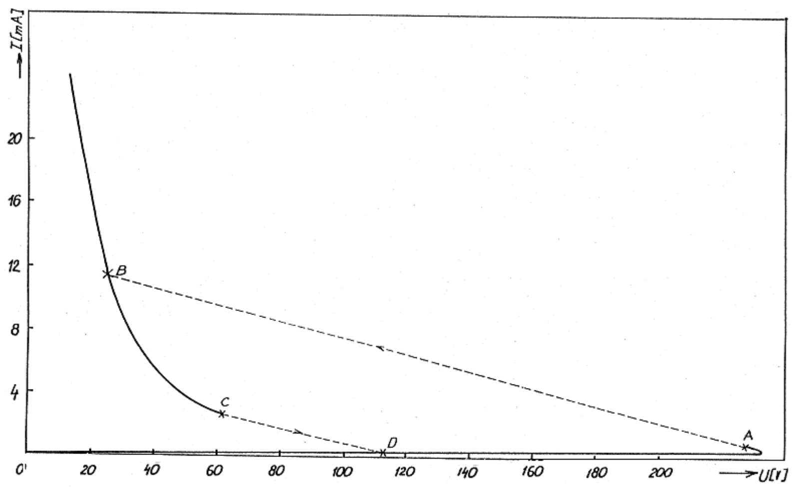

Figure. 6

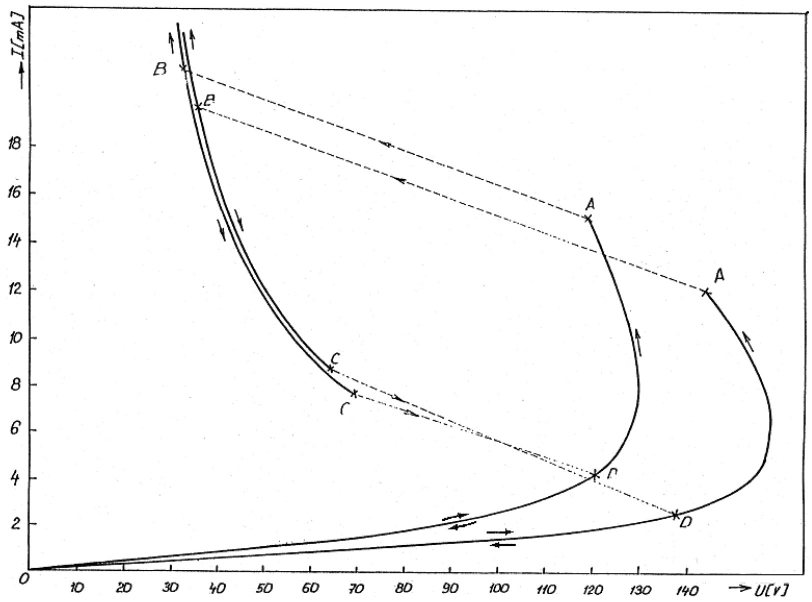

Figure 7

ACKNOWLEDGEMENT:

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