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ALGORITHM FOR REPRESENTATIONS OF THE POLYSWITCH FUSE CHARACTERISTICS IN THE MODELING PROBLEMS

Abstract. Approximations of the temperature dependences of the resistance and current-voltage characteristics of the PolySwitch fuses are proposed. These approximation dependences would have sufficiently well-posedness and stability for use in problems of modeling electronic units using these PolySwitch fuses. In particular, it is established that the equation based on the Curie-Weiss law (known in physics of ferroelectrics and ferromagnets) is applicable for such approximation of the temperature dependence of resistance, and the algorithm based on the use of the dependence of the indicated resistance on voltage was tested for the N-shaped current-voltage characteristic.

Keywords: algorithm, approximation, modeling of experimental characteristics, PolySwitch fuse.

Introduction

Resettable fuses of the PolySwitch type or PPTC (polymeric positive temperature coefficient) fuses are structures based on technical nanocarbon dispersed in a polymer (polyethylene). They have a non-linear posistor dependence of resistance on temperature with a high value of positive temperature coefficient. That is, their resistance has a jump-like increase in a narrow temperature range corresponding to the phase transition [1, 2]. They are of particular interest in the development of protection against electrical and thermal overloads in the photovoltaic system of solar arrays [3].

Problem statement

The main parameters important for the application of fuses of the PolySwitch type are their electrical resistance in the low resistance state *RFul* and the tripping current I_{tr}, i.e. minimum current through the PPTC fuse of the PolySwitch type at which the transition from its conducting state to the non-conducting state occurs. However, these data are not sufficient for their effective use in solving increasingly complex problems of functional electronics and electrical engineering.

Information is needed about their behavior and the effect on the operation of various fuses in wider ranges of currents and voltages.

In this regard, one of the actual tasks is the development of mathematical models describing the electrical characteristics of PPTC fuses. These models should be based on experimental data, and they should allow their use in the design and engineering of electronic fuses and units. However, at the stage of the computer simulation, developers have to deal with difficulties related to the influence of representation of the functional characteristics of such devices on the well-posedness and stability f solved computing applied tasks. First of all, this is refers to jump-like temperature dependence of the resistance and the N-shaped current-voltage characteristic.

The objective of this work was to find an approximation of the temperature dependences of the resistance and current-voltage (I-V) characteristics of the nanocomposite posistor PolySwitch fuses. In this case, the approximations should have been sufficiently well-posedness and stability for use in the tasks of modeling electronic unit using PPTC fuses.

Main part

1. Temperature dependence of electrical resistance

PPTC fuses have a temperature dependence of the resistance *RFu*(*T*) that increases with increasing temperature. The dependence has three characteristic sections (Fig. 1).

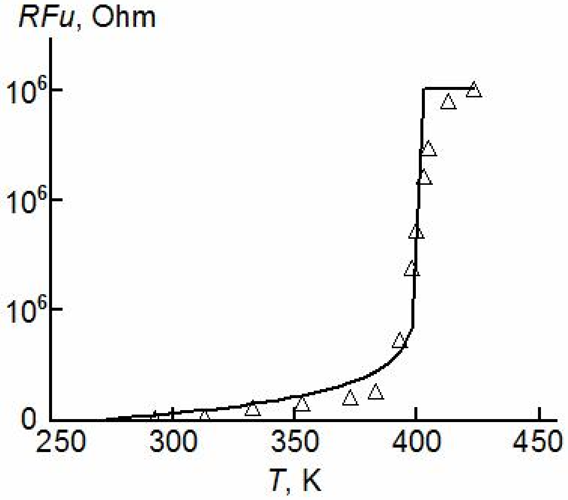

Figure 1 – Typical temperature dependence of the electrical resistance *RFu*(*T*) of LR4 type PPTC fuse [4]. The points are the experiment, the solid line is the approximation (T_{tr} = 398 K; *RFul* = 1 Ohm; *RFuh* = 10^6 Ohm)

At relatively small temperatures (section 1) there is a gradual increase in PPTC fuses resistance with increasing temperature. In a narrow temperature range at about 398 K, a sharp increase (by several orders of magnitude) in the resistance of the PPTC fuses is observed (section 2). With a further increase in temperature, their dependence of resistance on temperature also has a smooth character (section 3) [1].

The physical mechanism of such posistor jump-like dependence is determined by the structural features of the current conductive nanocomposite. Due to carbon channels in the cold state, the nanocomposite is a conductor with low intrinsic resistance. When heated above a certain temperature (T_{tr} is the transition temperature), carbon channels are broken due to the volume expansion of the polymer matrix and the transformation of the crystal structure of the matrix into amorphous one. In this case, the electrical resistance of the nanocomposite increases sharply [1, 2].

The temperature dependence of the electrical resistance $RFu(T)$ of the considered posistor fuse can be approximated by an equation that is similar to the Curie-Weiss law known in physics of ferroelectrics and ferromagnets [5, 6]:

$$RFu(T)=\begin{cases} A/(T_{tr}-T), \ if \ \ T<T_{tr}; \\ RFuh, \ if \ \ T\geq T_{tr}, \end{cases} \tag{1}$$

where $A = RFul\cdot(T_{tr} - 273)$; $RFul$ is the electrical resistance of PPTC fuse in conductive state (determined by the passport values: R_{min} is the minimum fuse resistance at 23°C or R_{1max} is the maximum fuse resistance at 23°C measured one hour after tripping); $RFuh$ is the selectable constant defined by values of $RFu(T)$ in the temperature range corresponding to high resistance state.

2. Current-voltage characteristic

The I-V characteristic of a PPTC fuse, like of any posistor element, is an N-shaped dependence [7, 8] (Fig. 2).

Parametric equations (where temperature is used as a parameter) can be used to describe the current-voltage characteristics of the posistors under consideration (as thermistors) [8, 9]. These equations are obtained on the basis of the heat balance equation $I(T)^2\, RFu(T) = V(T)^2/RFu(T) = (T - T_0)/RT$:

$$I(T)=\sqrt{\frac{T-T_0}{RT\cdot RFu(T)}}\,; \tag{2}$$

$$V(T)=\sqrt{\frac{RFu(T)\cdot(T-T_0)}{RT}}\,, \tag{3}$$

where V is the applied voltage; I and RT are the value of electric current and thermal resistance of the structure; T and T_0 are the temperatures of the structure and the environment.

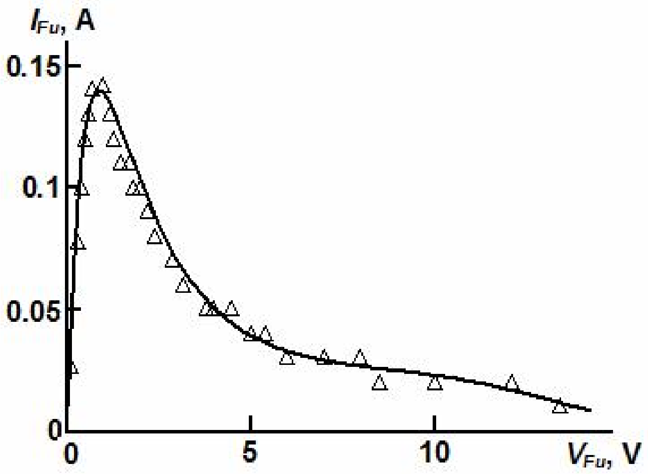

Figure 2 – Typical current-voltage characteristic of the PPTC fuse (FRH120–250UF [10]). The points are the experiment, the solid line is the approximation

However, the traditional parametric form of the posistor I-V characteristic considered above is often not acceptable for PPTC fuses of the PolySwitch type. Firstly, this is due to the jump-like temperature dependence (Fig. 1), which can lead to various types of "overflows" and loss of stability of the results obtained when applying iterative solution methods. Secondly, a relatively simple non-parametric analytical equation is required in some cases, since the input of additional parameters leads to ambiguities. In particular, as can be seen from Fig. 2, one value of current I corresponds to two values of voltage V, which leads to difficulties approximation of such dependence.

Using the value of electric voltage as an argument allows to avoid such ambiguity, that is, to take:

$$RFu(V) = V/I(V). \tag{4}$$

The experimental dependence $RFu(V)$ obtained in accordance with (4) is shown in Fig. 3, and as can be seen, it has no ambiguities.

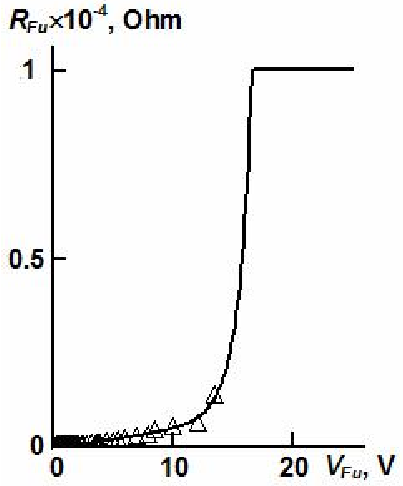

Figure 3 – The dependence of the electrical resistance on the voltage of the FRH120–250UF PPTC fuse. The points are the experiment, the solid line is the approximation. The accepted limit of *RFuh* corresponds to the range of resistances for commercial types of PPTC fuses from Fuzetec Technology company [10]

The following approximation equation was used for its analytical representation:

$$\log[RFu(V)] = P_K(V), \tag{5}$$

where $P_K(V) = \sum_{k=0}^{K} a_k \cdot V^k$ is *K*-th degree polynomial function.

The parameters a_k (k=0…3) were determined by the least squares method on the basis of the experimental dependence *RFu*(*V*) calculated from the current-voltage characteristic of a specific PPTC fuse assumed to be used. The obtained values $K=3$; $a_0=0.717$; $a_1=0.251$; $a_2=-3.807\cdot10^{-3}$; $a_3=2.111\cdot10^{-5}$ provided a satisfactory approximation accuracy (Fig. 3, the solid curve) for the I-V characteristic shown in Fig. 2.

Conclusions

It was shown that the well-known analytical equation (known as the Curie-Weiss law in the physics of ferroelectrics and ferromagnets) can be applied to approximate the temperature dependence of the electrical resistance of a posistor fuse of the PolySwitch type.

In the analytical description of the *N*-shaped I-V characteristic of such a fuse, an algorithm is proposed that includes calculation of the dependence of its electrical resistance on the applied voltage based on experimental data, approximation by the exponential function of the obtained tabular dependence. The exponent is a third degree polynomial of value electrical voltage. The analytical equation for

the I-V characteristic obtained on this basis provides satisfactory accordance with the experimental data used.

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