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Research methods of reliability indicators of rectifier diode in tablet execution

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Abstract. A new forecast approach for the reliability of power semiconductor devices in cyclic operation on the basis of numerical analysis of nonuniform temperature fields is offered. We compared the failure rates of semiconductor power devices in real thermal regime with the thermal conductivity of the statistical data.

1. Introduction

The modern power semiconductor devices can be formally divided into two groups. The first group of devices used primarily for conversion of very high power includes diodes and thyristors. The second group of devices using low and mid-range power represents metal-oxide-semiconductor field effect transistor (MOSFET) and Insulated-gate bipolar transistor (IGBT).

Diode D123-500 in tablet execution is intended for use in DC and AC frequency to 500 Hz different power plants. Main Features: sealed metal-housing, clamping internal terminal connections, providing high resistance to cyclic loads, supplied forward and reverse polarity.

Model of low-frequency diode type D123-500 presented in Fig. 1. Areas of application: in vehicles,uncontrolled and half-controlled rectifier bridges,welding, galvanic.

The aim of this work – analysis of the failure intensities of a power semiconductor device based on the numerical simulation of unsteady non-uniform temperature field with the internal heat source in the range of operating temperatures.

2. Analysis of thermal regime of device

Analysis of the thermal regime typical diode in tablet executions conducted in one-dimensional setting. The transition temperature was taken see point $T_{tr} = 190\,^{\circ}C$. The geometry of the solution domain is shown in Fig. 2.

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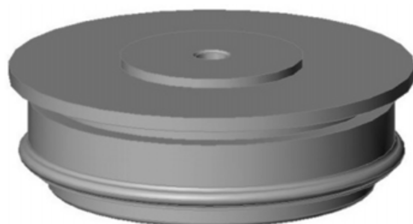

Figure 1. Rectifier Diode type D123-500 in tablet execution.

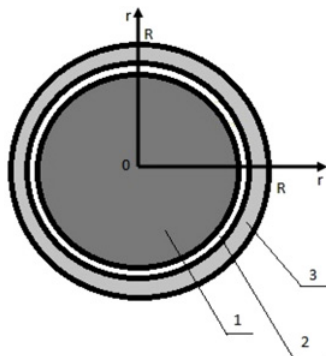

Figure 2. The geometry of the field solution (1,2,3 – areas with a different thermophysical characteristics).

The mathematical solution of the problem would be:

$$\begin{cases} \rho_1 c_1 \dfrac{\partial T_1}{\partial t} = \lambda_1 \dfrac{\partial^2 T_1}{\partial r^2}, & 0 < r < R_1 \\ \rho_2 c_2 \dfrac{\partial T_2}{\partial t} = \lambda_2 \dfrac{\partial^2 T_2}{\partial r^2}, & R_1 < r < R_2; \\ \rho_3 c_3 \dfrac{\partial T_3}{\partial t} = \lambda_3 \dfrac{\partial^2 T_3}{\partial r^2}, & R_2 < r < R_3. \end{cases} \tag{1}$$

Initial and boundary conditions can be written as follows:

$$\begin{aligned} & t = 0 : T = T_0, 0 \le r \le R; & & \\ & r = 0 : \frac{\partial T}{\partial r} = 0, t > 0; & & -\lambda_1 \frac{\partial T_1}{\partial r}|_{r=R_1} = -\lambda_2 \frac{\partial T_2}{\partial r}|_{r=R_1}, \\ & r = R : T = T_h, t > 0; & & T_2(t, R_2) = T_3(t, R_2), \\ & T_1(t, R_1) = T_2(t, R_1), & & -\lambda_2 \frac{\partial T_2}{\partial r}|_{r=R_2} = -\lambda_3 \frac{\partial T_3}{\partial r}|_{r=R_2}. \end{aligned} \tag{2}$$

Numerical simulation of the temperature field in a non-uniform circular plate with dimensions on the X-axis equal to R1, R2, R3.

It was assumed that the model includes areas with different thermophysical characteristics (Table 1). In an area of radius R1 (Fig. 2) heating of the material occurred. On the boundary r = R of the boundary conditions of the first kind (prescribed temperature), the point of contact 1 and 2 environments, as well as 2 and 3 environments were considered conditions the fourth kind (reflect the equality of temperatures and heat fluxes passing through the contact surface of two bodies) [1].

Table 1. Thermophysical properties of model elements.

Material	λ, W/m*K	C, kJ/kg*K	ρ, kg /m3
Silicon	149	714	2330
Aluminum	210	903	2700
Ceramics	1,8	680	1800

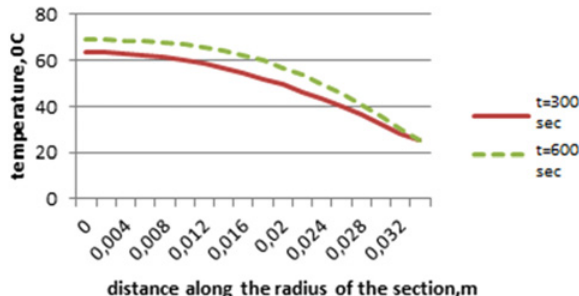

Figure 3. Distribution of temperature along the radius of the cross section.

The main assumptions used in the formulation of the problem:

1) The thermal characteristics of the materials does not depend on temperature.
2) Thermal contact at the boundaries between the areas (1,2) and (2,3) is considered ideal.
3) A characteristic distribution of temperature of the simulated object (diode) at ambient temperature T = 25 °C at time t1 = 300 sec, t2 = 600 sec shown in Fig. 3 [2].

3. Method of numerical solution

The thermal conductivity Eq. (2) with appropriate initial and boundary conditions is solved by the finite difference method [5–7]. The diagram of splitting by coordinates was applied for the solution of difference analogues of a three-dimensional equation.

4. Forecasting the indicators reliability of the power semiconductor device

To analyze the reliability indicators of the diode selected mathematical models - Arrhenius and multiplicative model [3].

Multiplicative mathematical models for evaluating the reliability of the diode:

$$\lambda_e = \lambda_{bfr} \cdot K_m \cdot K_{dn} \cdot K_f \cdot K_{s1} \cdot K_q \cdot K_e \tag{3}$$

where: λ_{bfr}– base failure rate of the power device; K_m– rate mode depending on the electric load and temperature; K_{dn} – value of rate depending on the maximum set in the specifications, the electrical load; K_f – rate of functional specificity of the operating mode of the device; K_{s1} – value of the rate as a function of the operating voltage relatively the ximum allowed by specifications; K_q – rate of level of quality of the device; K_e – rate of severity of service conditions.

Arrhenius model for evaluating the reliability of the diode:

$$\lambda_A(T) = C \cdot \exp\left(\frac{-E}{kT}\right) \tag{4}$$

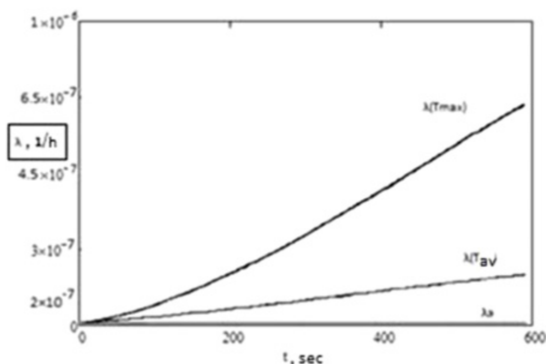

Figure 4. Failure rate of device at an ambient temperature T = 25 °C, t = 600 sec (λ e - multiplicative model (3); $\lambda\,(T_{cp})$ – Arrhenius model (with T_{cp}); $\lambda\,(T_{max})$ – Arrhenius model (at T_{max})).

where: C– constant, E – is the activation energy, k– Boltzmann constant.

The numerical values of $\lambda_A(T_{max})$, calculated according to the Arrhenius model (4), 4.5 times higher than those obtained by the multiplicative model (3) for running time 600 sec. And the ambient temperature of 25°C. The intensity ratio of denials by the Arrhenius model $\lambda_A(T_{max})$ and $\lambda_A(T_{cp})$ was 2 ceteris paribus.

5. Conclusion

Using the multiplicative model (3) in the estimates of the failure rate of devices leads to a significant overestimation of the service life of devices ($\lambda_e = 1.447 * 10^{-7}$, 1/h) [4].

Prediction of reliability indices of device should be carried out on the basis of analysis of the real non-stationary non-uniform thermal regime of the device.

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