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DYNAMIC TEMPERATURE STATES IN THICK – FILM MICROELECTRONICS ELEMENTS

Описано теоретичний аналіз (порівняний з екмпериментальними дослідженнями) динамічних температурних станів багатошарових мікросхем (виготовлених за технологіями низько- і високотемпературної кераміки). Температура має важливе значення в безвідмовній роботі електронних пристроїв (для прикладу, в газових сенсорах, виготовлених за товстоплівковою технологією, температура визначає основні параметри, такі як чутливість і селективність) і значно підвищує ризик появи дефектів у структурах. Наведено базові моделі та процедуру розв'язання системи рівнянь. Розв'язок для типової товстоплівкової структури порівнювали з експериментальними даними. Розглянуто багато факторів, які впливають на точність отриманих результатів.

The theoretical analysis (compared with experimental investigations) of dynamic temperature states in layer microcircuits (made in LTCC or HTC technology) has been described in the paper. Temperature plays a very important role in proper operation of microelectronic devices (for example in gas sensors – made in thick-film technology – it determines the basic parameters like sensitivity and selectivity) and significantly increases the risk of various defects. The basic models and solution procedures of analytical equations system have been presented. The solution for the typical thick-film structure (active layer placed on alumina substrate) has been compared with the experimental results. The many factors which have influence on accuracy of obtained results have been taken into consideration and discussed. The results of analysis can be used in researches with reliability and tolerance aspect of microsystems (intensity of degradation processes) as well as in determination of thermal properties of the designed systems.

1. Introduction

The intensive development of modern electronics, especially the significant extension of miniaturization is causing the high values of thermal power density generated in particular elements of microcircuit. Moreover, the bigger numbers of microcircuits operate in pulse regime. The emitted heat in such conditions (as a result of current flow) has not only substantial value of amplitude (especially in power system), but it is also characterized by huge dynamic changes in time and the big temperature gradients [1]. The identification and analysis of heat processes play a very important role in determination of intensity of degradation processes (reliability aspect and microsystem tolerance) [2–5] as well as in determination of thermal properties of the designed systems (for example micro-heaters of gas sensors, controlled IR sources) [6, 7].

2. Reliability investigations of thick-film resistors

The product reliability is defined as ability to proper operation with determined tasks [5]. According to the probability theory one of the coefficients of the electronic element reliability R is the defect intensity λ in the specified time interval:

$$R(t) = \exp\left[-\int_0^t \varphi(t)dt\right]. \tag{1}$$

As the investigations show, the reliability of elements made in thick-film technology is very high but the fast development of contemporary microelectronics caused the more frequent designing of devices which operate with very high dynamic input functions [8]. From those reasons it is necessary to introduce dynamic temperature coefficient (π_{Td}) into φ(t) function:

$$\pi_{Td} = \exp\left(b \cdot q^n \frac{T_M - T_O}{T_O}\right), \tag{2}$$

where b = 4290 is coefficient of intensity of degradation processes, n = – 0,696 – constant, T_0 – ambient temperature, T_M – maximum temperature on the surface of layer, q – power density.

3. Modelling

The analytical solution of thermal transient problem is possible after making suitable simplifications in the theoretical model. These assumptions should fulfil to the real–world conditions. The all factors which can have an influence on this problem have been considered and analyzed during researches.

3.1. Characteristic of object

The main component of thick-film circuit is ceramic substrate, which is carrying element with high resistivity, good thermal conductivity and thickness about 0,5 mm. The particular layer (resisitive, conductive or dielectric) are screen-printed on the substrate and fired in special burning process. The transverse dimensions of layers (i.e. 5×5mm) are much bigger than their thickness (about 20μm). It should be note that the one from the main heat sources are resistive elements which are the most flexible to failures. Thermal phenomena in the conductive and dielectric layers are less significant in temperature distribution [9, 10].

3.2. Object model

In the dynamic states (single thermal pulse excitation) each fragment of circuit (important from thermal point of view) can be approximated by model (Fig. 1) consists of infinity plate (active layer made from material with properties: λ_R – thermal conductivity, ρ_R – density, c_{PR} – specific heat, a_R – thermal diffusivity, L – thickness) and half-infinity area (ceramic substrate with properties λ_P, ρ_P, c_{PP}, a_P) [11, 12]. It can be described by equations:

$$a_R \frac{\partial^2 T_R(x,t)}{\partial x^2} + \frac{q_V(t)}{\rho_R c_{PR}} = \frac{\partial T_R(x,t)}{\partial t} \quad for \quad -L < x < 0, \tag{3a}$$

$$a_P \frac{\partial^2 T_P(x,t)}{\partial x^2} = \frac{\partial T_P(x,t)}{\partial t} \quad for \quad 0 < x < \infty. \tag{3b}$$

Such model is determined by object construction (p.3.1) and short duration time of thermal excitation. In dynamic states the heat losses from lateral areas can be negligible and problem can be considered as 1D.

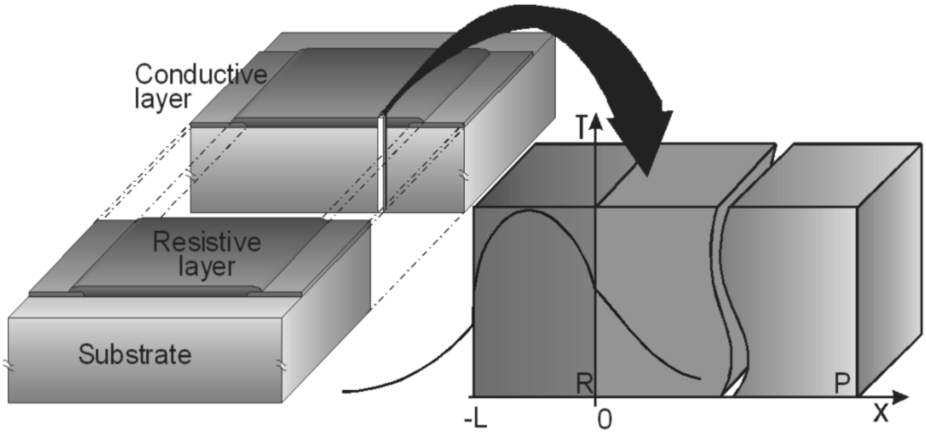


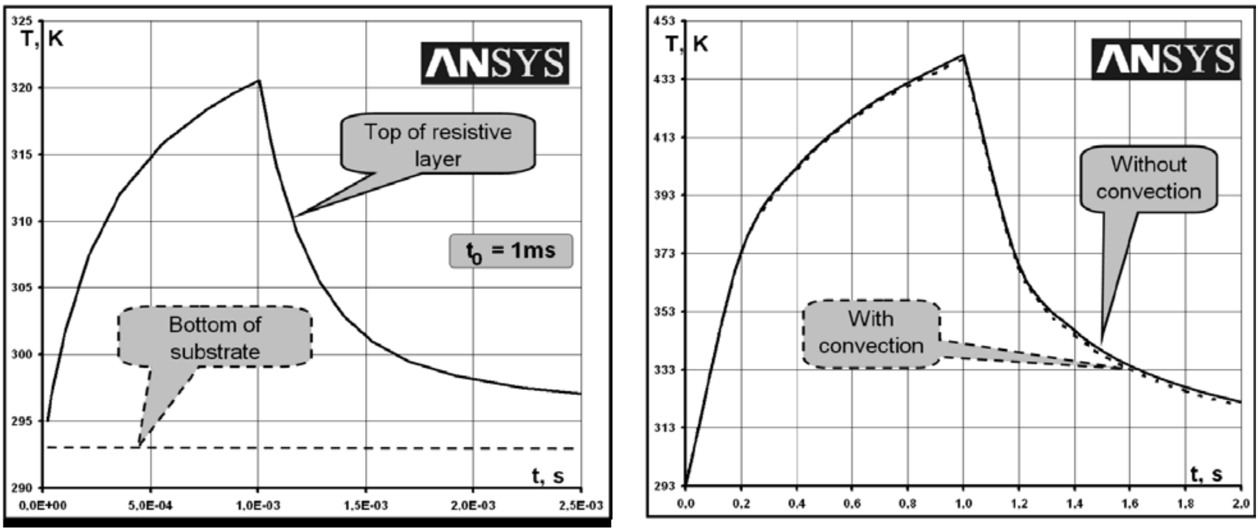
Fig.1. Model of layer circuit in transient thermal behaviour

3.3. Boundary conditions

If the duration of exciting pulse is very short it is possible to make assumption about infinity thickness of substrate, described by formula:

$$\lim_{x\to\infty}\frac{\partial T_P(x,t)}{\partial x}=0 \qquad for \quad x\to\infty\,. \tag{4}$$

Taking into account the above-mentioned aspects it is necessary to restrict of considerations to thermal excitations with short time duration (for adequate thermo-physical parameters of substrate and active layer materials it can be estimated the boundary value of this time – for example 1 μs). The proposed model is adequate to the considered object when thermal wave doesn't reach the opposite part of substrate (Fig. 2 a).



a) *b)*

Fig. 2. Simulation in ANSYS program: a) comparison of temperature values on the outside areas of layer circuit for excitation t_0 = 1 ms; b) convection influence on temperature changes on the surface of resistive layer – time excitation equals 1s

The very important problem is heat exchange with environment by radiation, conduction and convection [13, 14]. For the sake of very short duration time of excitation the heat exchange with environment from area excited by thermal pulse is negligible in relation to conduction on the contact layer-substrate (even for significant temperature increasing) – Fig. 2 b).

In this connection it can be described:

$$\left.\frac{\partial T_R(x,t)}{\partial x}\right|_{x=-L} = 0 \qquad for \quad x=-L. \tag{5}$$

The continuity of heat exchange on the medium contact (active layer and substrate) is guaranteed by penetration phenomena of fused phases of substrate and layer (occurred in technological process):

$$\begin{aligned} &\lambda_R \left.\frac{\partial T_R(x,t)}{\partial x}\right|_{x=0} = \lambda_P \left.\frac{\partial T_P(x,t)}{\partial x}\right|_{x=0} && for \quad x=0 \\ &T_R(0,t) = T_P(0,t) && for \quad x=0 \end{aligned} \tag{6}$$

In this connection that initial conditions fulfil the thermodynamic equilibrium of object in given temperature:

$$\begin{aligned} &T_R(x,0) = T_0(x,0) = T_A && for \quad t=0 \\ &T_P(x,0) = T_0(x,0) = T_A && for \quad t=0 \end{aligned} \tag{7}$$

so further considerations can be made for temperature surpluses θ. It simplified of solution considerably.

Because the heat pulse is generated in whole volume of active layer by short time t_0 so it can be assumed its rectangle shape, dependent on time only:

$$q_V(t) = q_V\left[1(t) - 1(t-t_0)\right]. \tag{8}$$

4. Calculations

Solution of boundary problem determined in p.3.3 was obtained based on Laplace transform. Equations (depended on time t and x coordinate) have a form:

$$\begin{aligned} &\theta_R(x,t) = \theta_R'(x,t) && for \quad t \le t_0 \\ &\theta_R(x,t) = \theta_R'(x,t) - \theta_R'(x,t-t_0) && for \quad t > t_0 \end{aligned} \tag{9a}$$

$$\begin{aligned} &\theta_P(x,t) = \theta_P'(x,t) && for \quad t \le t_0 \\ &\theta_P(x,t) = \theta_P'(x,t) - \theta_P'(x,t-t_0) && for \quad t > t_0 \end{aligned} \tag{9b}$$

where:

$$\begin{aligned} \theta_R'(x,t) = {} & \frac{q_V a_R}{\lambda_R} t - \frac{q_V a_R}{\lambda_R (K+1)} \sum_{m=0}^{\infty} H^m \times \\ & \times \left\{ \left(t + \frac{(2mL-x)^2}{2a_R} \right) erfc\left(\frac{2mL-x}{2\sqrt{a_R t}} \right) + \sqrt{\frac{t}{\pi a_R}} \times \right. \\ & \times \left[-(2mL-x) e^{-\frac{(2mL-x)^2}{4a_R t}} - [x+2(m+1)L] e^{-\frac{[x+2(m+1)L]^2}{4a_R t}} \right] + \\ & \left. + \left(t + \frac{[x+2(m+1)L]^2}{2a_R} \right) erfc\left(\frac{x+2(m+1)L}{2\sqrt{a_R t}} \right) \right\} \end{aligned} \tag{10}$$

$$K = \sqrt{\frac{\lambda_R \rho_R c_{PR}}{\lambda_P \rho_P c_{PP}}}, \qquad h = \frac{\sqrt{a_R}}{\sqrt{a_P}}, \qquad H = \frac{K-1}{K+1}. \tag{11}$$

The obtained solution was compared with results of simulations in ANSYS program (Fig. 3).

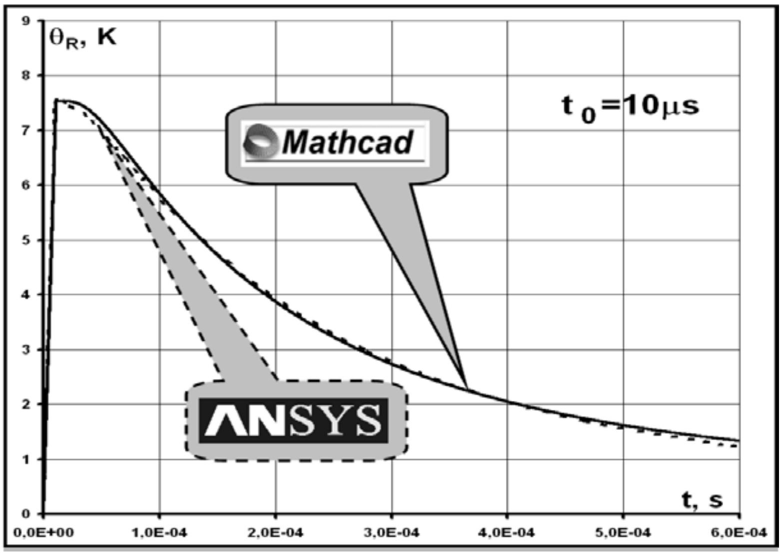
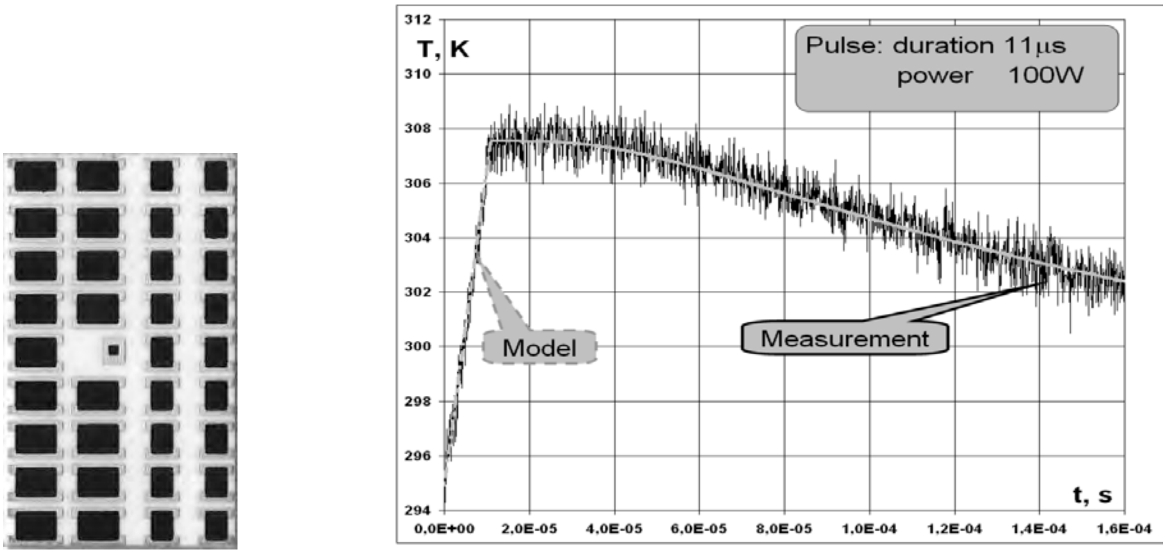


Fig. 3. Calculations comparison of analytical method (analytical solution of simplified model – eq. (9 – 11) and numerical method (ANSYS program) for time duration 10μs

The results confirmed the calculations convergence obtained using analytical and numerical methods (correctness of the created model). The difference between particular curses of temperature surplus versus ambient temperature is the biggest for finally cooling stage.

5. Experimental Investigations

The obtained results (based on eq. 9 – 11) were compared with results of measurements made using infra-red detector on the surface of tested samples (Fig. 4).



a) *b)*

Fig. 4. Experiment: a) test circuits, b) comparison of temperature courses on resistive layer surface determined on the basis of the mathematical model and measurement made with using IR detector (pulse excitation 11 μs)

The example temperature course is presented in Fig. 4 (pulse excitation 11 μs, power – 780 W, dimensions of resistive layer - 2,85 mm× 2,15 mm× 0,027 mm).

The investigations have been made with the used resistors prepared on the basis of resistive paste (sheet resistance – 10Ω). The control of the maximum pulse voltage of input function in the goal of keeping the stable power and consequently the stable energy was required because the resistors were not functionally corrected (their resistance values). The tested resistor used to be find damaged when a break has become in the circuit (in case of entire burn up of the resistive layer). The beginning of damage appeared by spark-over in the resistor. The degradation process of tested layers – in the most cases – start on the sample edge. The full damage took place in the course of generating subsequent stimulations.

During the measurements (except the resistance value) the temperature distribution on the object surface with use of ultra fast infrared detector was registered. The pulse generator allowed the stimulation of tested resistive layer by high energetic pulses with power exceeding 10 kW and pulse duration in the range from 125 ns to 2,5 ms. The generator was equipped in suitable control unit which allows the pulse duration change, the time duration control of the break between successive pulses and the pulse number choice.

6. Conclusions

The presented method of the thermal modelling of substrate can be also applied for other thick-film components but the very good knowledge about their thermal parameters is required.

The big heat accumulation in active layer is observed for short time of pulse excitations. It causes the temporary (but very fast) temperature increasing which can lead to mechanical damages or parameter changes.

Pulse activation of the active layer structure significantly increases the risk of various defects. The phenomena connected with electric field (breakdowns) as well as with thermal processes (i.e. high maximum temperature values, big values of temperature gradients) cause quicker structure degradation. The frequency and rapidity of occurring changes of structure are also significant.

The elaborated model can be used in other researches, i.e. measurements of thermal properties of different materials [15], simulation of quasi-stationary and non-stationary temperature fields [6, 7], investigations in EMC area and parametric correction of the resistive elements [4].

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CANCAN-PROGRAM FOR DETERMINATION OF CONFIGURATION PARAMETERS OF CAN- BUS CONTROLLER

Досліджено методи розроблення, які забезпечують правильну конфігурацію CAN-шини. Результати досліджень підтверджують можливість розрахунку параметрів, які необхідні для вибору правильної конфігурації CANконтролера. Розроблена CANCANпрограма дає змогу розраховувати матриці R, L, C, G параметрів, що необхідно під час розрахунку часу проходження сигналу і падіння напруги в лініях. Програма дає змогу перевіряти коректність прийнятих припущень і повідомляє про області, де необхідно здійснити модифікацію, зокрема в критичних випадках.

The researches for elaboration of the method allowed to correct configuration of CAN-bus have been presented in the paper. The results of investigations have proofed the possibilities of parameter's calculation, required to choose relevant CAN controller configuration during the design. Elaborated CANCAN-program allow to calculate matrices R, L, C, G parameters, used at next step for time of the signal propagation and voltage drops in the lines, etc. in relation to wire types and their configuration. It allows checking the correctness of applied assumptions and indicates the modification areas, especially in critical cases of application.

1. Introduction

It is generally assumed that the designers of CAN-bus based systems should have sufficient experience and an intuition. Owing to them the designers can properly determine final parameters of the systems like the highest transmission speed, transmission medium type, achievable transmission range etc. at given environment conditions and specify EMC requirements. It would be therefore strongly desired to develop a method of the selection of CAN-bus operational or functional parameters on the base of mathematical line model.

The above-mentioned problems were considered as a base of the investigations aims, directed to synthesis and practical application of the method, allowing determination of configuration parameters of CAN-bus by the analysis of its structure, topology conditions and transmission properties characteristics of CAN-bus, in relation to application and disturbing signals.