MODELING OF TEMPERATURE REGIMES OF THIN FILM GAS SENSITIVE DEVICES

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Abstract

This paper presents results of the modeling of the temperature distribution in a chip of thin film gas sensor, operating at high temperatures (150-1000^{o}C), required to provide high sensitivity and selectivity to target gases. Analysis of thermal regimes of such chip was carried out on the base of model of plate with local source of heat. It was found that substrate heat conductivity is most influencing parameter, determining both temperature distribution in chip and also the electrical power consumption decreasing. The example of realized chips designed in accordance with results of modeling is presented. The results of modeling are compared with experimental data.

Introduction

For the normal functioning of a thin film gas sensor (TFGS) its construction should include heating element, providing the warming of the film up to required working temperature. The latter, in its turn, influences the choice of topology of TFGS chip, substrate material and TFGS construction, in general. As a result, it is needed for TFGS construction optimization with a purpose of increasing of TFGS reliability and durability and decreasing of the power consumption.

In practice, the task of optimization of TFGS construction requires the knowledge of temperature regimes and, in particular, temperature field distribution in a chip of gas sensor on dependence on material substrate, geometry of chip, temperatures in working zone of sensors, etc. In this connection, there was carried out investigation of the given problem through the numerical computer modeling of temperature distribution in a chip of TFGS and experimental testing of the results of modeling on developed structures of TFGS chip.

1. Modeling of the temperature fields in chip of gas sensor

The task of modeling of the temperature regimes of TFGS is sufficiently complicated and for its simplification there was considered the chip of TFGS “isolated” in space. The given approach allows us already at the stage of selection of material of substrate, geometrical sizes and topology of chip to estimate the influence of all the mentioned above factors on temperature distribution in chip.

In our case chip of TFGS represents a thin plate (with thickness δ=400-500 μm) of dielectric substrate with linear dimensions L_x and L_y, on the surface of which resistive heater (RH) is formed through the group technology methods. Linear sizes of RH are: $2\Delta\xi$, $2\Delta\xi$ and coordinates of center of RH - (ξ,η).

Analysis of the thermal regime of such gas sensitive element can be carried out on the base of model of plate (Fig.1) with local source of heat and heat exchange from surface [1].

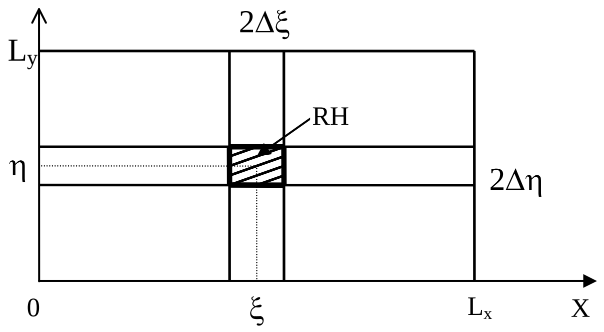

Fig.1. Plate with local source of heat – the model of chip of TFGS

In the frame of the given model it is supposed:

1) the sources of heat of power P are distributed uniformly in the field of RH, surface density of heat flow from local sources with power P is equal to zero out of RH and is constant in its limits;

2) the heat exchange from plate ends is negligible in comparison with heat exchange from basic surfaces;

3) the heat exchange with environment is realized only through irradiation and convection from two basic surfaces;

4) the coefficients of heat exchange from basis surfaces do not depend on temperature and are equal α_1 and α_2 correspondingly.

Then the stationary field of temperatures of such plate can be described by the following differential expression [2]:

$$\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} - a^2\theta = -g_s, \qquad 1\{U\} \tag{1}$$

where $g_s = \frac{P}{4\Delta\xi\Delta\eta\delta\lambda}$, $a = -\frac{\alpha_1+\alpha_2}{\lambda\delta}$, 1{U}=1 in the field of U and 1{U}=0 out of this field U; $\theta=T-T_s$ is temperature head, T is temperature of plate in given point, T_E is environment temperature; λ is specific heat conductivity of plate, α_1 and α_2 are coefficients of heat emission. Border conditions for the given equation with account of assumption 2 have the following form:

$$\left.\frac{\partial\theta}{\partial i}\right|_{i=0} = \left.\frac{\partial\theta}{\partial i}\right|_{i=L_i} = 0, \quad (i=x,y) \tag{2}$$

$$\theta = \frac{P}{(\alpha_1+\alpha_2)S_u}\varphi_x\varphi_y \tag{3}$$

where $S_u=4\Delta\xi\Delta\eta$ is surface area of RH (U), a φ_x and φ_y are non-dimensional coordinate functions having bulky form and so will not be presented here.

2. Numerical calculation of temperature distribution in chip

The computer calculation of the temperature fields in TFGS chip by Eq.(3) was carried out for different values of λ , and L_i (i=x,y), coordinates of the field of heating up, environment temperature T_E and average surface temperature T_S.

There were used the following values: λ = 1; 10; 100 W/(м· K); L_x , L_y= 5·10^{-3}; 1·10^{-2}; 1,5·10^{-2}; 2·10^{-2} (m); δ = 4^{-4} м; 2Δξ =7,5^{-4} м; 2Δη = 2,5^{-4} м; ξ,η= 0; L_i/4; L_i/2; T_E = 20°C; T_S = 200; 250; 300; 350; 400°C. Coordinates x and y were changed with a step 0,1L_i.

Proceeding from the dependence of the coefficient of heat irradiation on temperature the calculations were carried out in the following order: 1). assignment of average surface temperature of substrate T_S and finding of the coefficients of heat emission α_1 and α_2; 2). finding of the value of dissipating power P; 3). calculation of the temperature as function of coordinate by formula (3).

The value of total dissipated power was estimated by equation:

$$P=\alpha\cdot(T_{П}-T_c)\cdot L_x \cdot L_y \qquad (4)$$

3. Results of modeling of temperature distribution in TFGS chip

In the result of modeling it was established that value of λ plays the key role in the forming of temperature distribution in TFGS chip and power P dissipating (Fig.2-3). Decreasing of λ by two orders leads to the some times growth of temperature T_{RH} in the field of heating at the constant dissipating power. Most significant growth is observed at the λ change in the range from 10 to 1 Wt/m^{2}K.

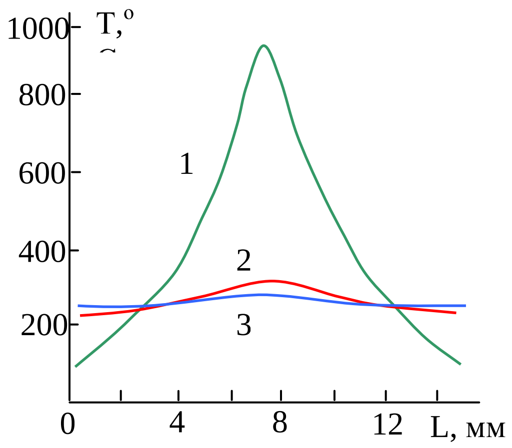

Fig.2. Temperature profile in TFGS chip on dependence on substrate λ [Wt/(м^2·K]: 1-1; 2-10; 3-100. (RH in a center of substrate. P_{RH}=0.87 Wt)

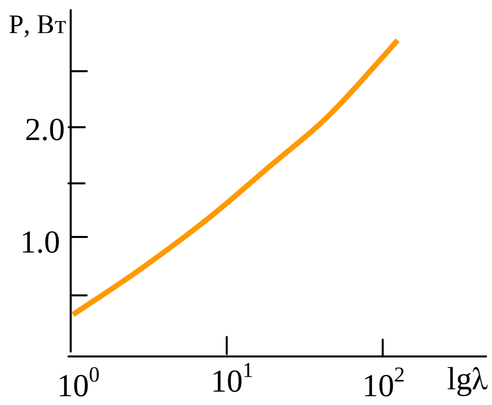

Fig.3. Dependence of average dissipated power P on λ

The second factor by the level of influence on temperature distribution in the chip of TGFGS is the position of resistive heater on substrate. One can see that shift of RH from the position in the center of substrate (Fig.2) to its edge (Fig.4) leads to the twice increase of temperature in the zone of heating up. If the same temperature is kept in a zone of heating up for different values of λ of substrate the temperature in the field of the contacts of gas sensitive elements can be decreased by 200-400^{o}C (Fig5.)

So, the carried out modeling of temperature regimes in TFGS chip allows: 1) to estimate the influence of the heat conductivity of substrate material on the temperature profile in chip;

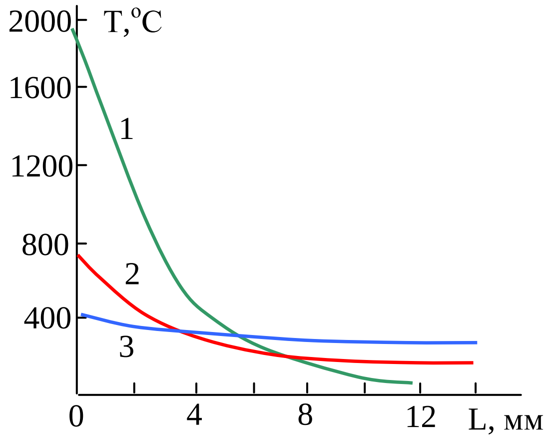

Fig.4. Temperature profile in TFGS chip on dependence on substrate λ [Wt/(м^{2}K]: 1-1; 2-10; 3-100. (RH at the edge of substrate. P_{RH}=0.87 Wt)

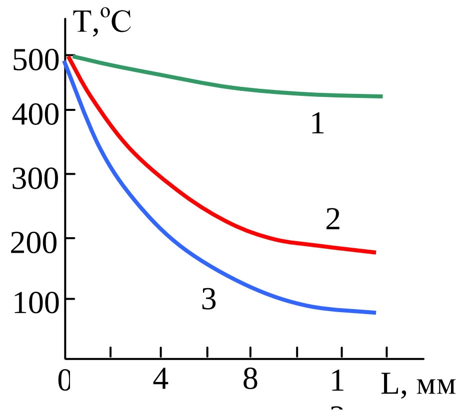

Fig.5. Temperature profile in TFGS chip on dependence on substrate λ [Wt/(м^{2}K]: 1-100; 2-10; 3-1. (RH at the edge of substrate.)

2) to account the influence of the position of resistive heater on the surface of chip on the temperature distribution and value of consuming power P; 3) to optimize topology of the TFGS chip.

4. Experimental study of temperature distribution in TFGS chip

Results of numerical modeling were tested by means of measurement of temperature profile in real, fabricated by us, TFGS chip. Topology of chip and temperature profile are shown in Fig.6. As a substrate policor (λ=10 Wt/м^{2}K) with size 6,5x5,5 мм was used. RH was placed in point with coordinates (L_x/4,L_y/2). Resistive heater supply voltage amounted 10 V and current through heater was 150 mA. Temperature was measured by means of Cu-constantan thermocpuple in the cross-section $y=L_y/2$.

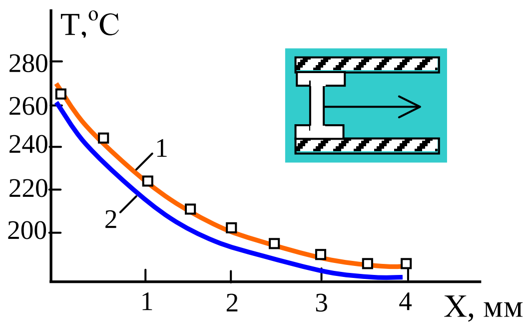

Fig.6. Temeperature profiles in TFGS chip

1-experiment; 2-calculation.

Comparison of the calculated and experimental curves T(x) in Fig.6 demonstrates sufficiently good correspondence of the modeling results to real temperature regimes in TFGS chip that allows us to conclude that the considered model is applicable for TFGS topology design.

References

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[2] G.N. Dul’nev, B.V. Pal’shchikov Temperaturnoe pole plastiny s diskretnym istochnikom energii// Injenerno-fizicheskii zhurnal - 1975. - T.29. - .4.- C.722-727.