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Z. Hotra*,#, M. Jakubowska¤, Z. Szczepański~
*National University "Lviv Polytechnic"
#Rzeszow University of Technology, Rzeszow, Poland
¤Institute of Electronic Material Technology, Warsaw, Poland
~Technical University of Warsaw, Warsaw, Poland

NEW THICK FILM MATERIALS FOR PIEZORESISTIVE CERAMIC PRESSURE SENSOR

В даній статті представлено конструкцію керамічного сенсора тиску, який базується на п'єзорезистивному ефекті в товстоплівкових резисторах, виготовлених з паст з високим значенням розмірного коефіцієнта. Для резисторів, використаних в даному сенсорі, розроблено товстоплівкові пасти, які базуються на діоксиді рутенію і свинцево-боро-силікатному склі. Представлено характеристики і параметри сенсорів тиску.

The construction of ceramic pressure sensor based on piezoresistive effect of thick film resistors made of paste with high Gauge Factor is presented. Thick film paste based on ruthenium dioxide and lead-boro-silicate glass has been elaborated for resistors applied in the sensor. The characteristics of the resistors as well as the parameters of the pressure sensor are also presented.

1. Introduction

Piezoresistive pressure sensors are most often based on silicon structures [1]. These sensors are suitable for measuring the pressure in the range from 10 Pas to 100 MPas. But they are sensitive to temperature changes and other ambient stresses. During the last few years thick film technology has gained increasing importance in the field of sensors, especially pressure sensors [2,3]. The latter ones can work in broad range of temperatures what predestinate them for application in automotive.

This paper describes the pressure sensor containing thick film resistor made of newly developed by the authors pastes on ceramic membrane. Thick film resistors applied in the sensor must exhibit reversible resistivity changes under the external stresses. These changes are described as:

$$\frac{\Delta R}{R_0} = GF\,\varepsilon$$

where $\Delta R/R_0$ – relative changes of resistance of resistor; ε - strain in the resistor which causes the resistivity changes $\Delta R/R_0$; *GF* - gauge factor (*GF*) characterising the piezoresistive properties of thick film resistor.

Taking into account the resistor orientation with respect to applied strain, two types of *GF* are defined:

GF_L – longitudinal gauge factor where the current flows parallelly to the stress direction (longitudal effect),

GF_T – traverse gauge factor where the current flows vertically to the stress direction (transversal effect).

A new method for determination of *GF* of the resistors was designed, the new resistive compositions were elaborated, as well as the construction of the pressure sensor containing these resistors was proposed.

2. Testing procedure of thick film resistor GF

The scheme of method for *GF* determination of thick film resistors and the scheme of test pattern for determination of *GF* of investigated resistors are presented in fig. 1 and fig. 2.

GF measurement method utilizes the ceramic substrate with two longitudinal (R3, R4) and two traverse (R1, R2) resistors as it is presented in fig. 1. The resistors were situated at different points on the substrate, so the strain in resistors R_1 and R_4 is greater than in resistor R_2 and R_3. One end of the substrate is subjected to external load then it is deflected at the free end as shown in fig. 2. External load deflects the substrate's free end by distance δ, induces strain in the resistors and changes in resistance ΔR. The strain ε is proportional to the substrate deflection δ. We can easily calculate the strain ε applying principles of engineering mechanics:

$$\varepsilon = \frac{3\,t\,x}{2L^3}\,\delta$$

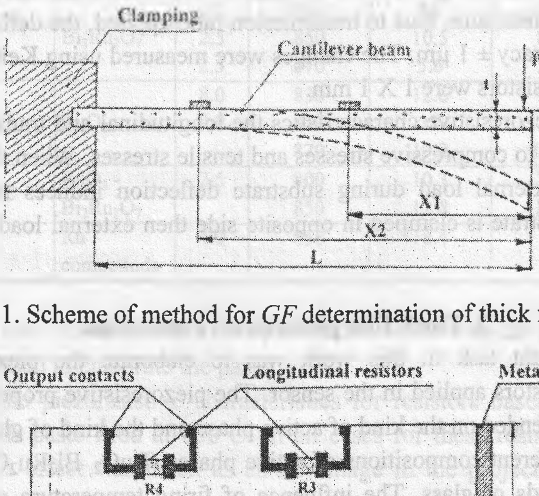

Fig. 1. Scheme of method for *GF* determination of thick film resistors.

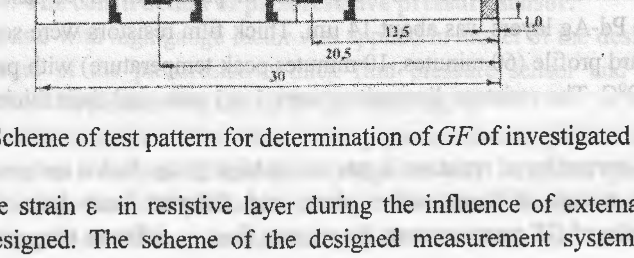

Fig. 2. Scheme of test pattern for determination of *GF* of investigated resistors.

To estimate the strain ε in resistive layer during the influence of external load a simple method has been designed. The scheme of the designed measurement system for *GF* test is presented in fig. 3.

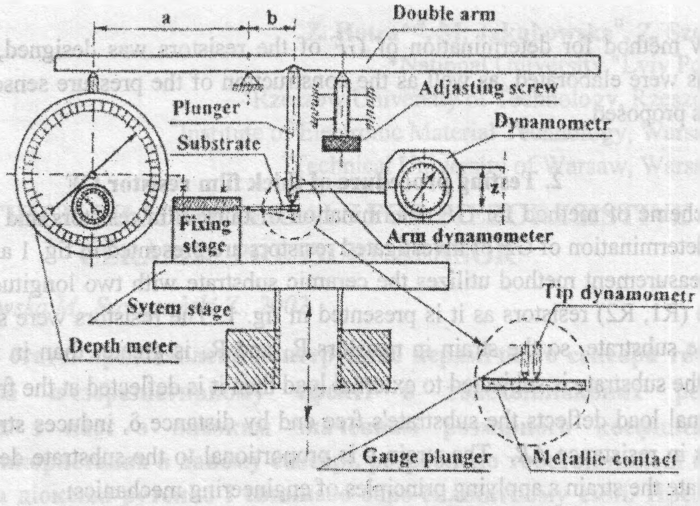

Fig. 3. The scheme of the designed measurement system for *GF* test.

In applied measurement system gauge plunger was used to deflection cantilever beam measure. It is connected with depth meter by means of a double arm lever. External load was obtained using dynamometer arm. Due to transmission ratio applied, the deflection of the substrate was measured with accuracy ± 1 μm. The changes were measured using Keithley 2001 6-1/2 digit multimeter. All tested resistors were 1 X 1 mm.

To achieve full piezoresistive characteristics the longitudinal and transverse resistors on the substrate were subjected to compressive stresses and tensile stresses. When the resistors are on the top of the substrate, external load during substrate deflection induces tensile stresses in the resistors. When the substrate is clamped in opposite side then external load induces compressive stresses in resistors.

3. Thick film piezoresistive materials.

The most important task in this work was to elaborate the piezoresistive thick film composition for the resistors applied in the sensor. The piezoresistive properties of the thick film resistor are strongly depended on the kind of active phase and the kind of glass [4, 5]. The authors investigated several different compositions of active phases (RuO_2, $Bi_2Ru_2O_7$ and their mixtures) as well as different kinds of glass. The influence of firing temperature and the profile of the resistors was also investigated.

The terminations of the resistors were made of palladium-silver paste P-202 (ITME). The thickness of the Pd-Ag layers was about 14 μm. Thick film resistors were screen printed and fired using the standard profile (60 minutes, 10 minutes peak temperature) with peak temperature in the range 770 – 870°C. The resistors dimensions were 1 x 1 mm, and their thickness was in the range of 12 – 18 μm.

The main properties of resistive layers which high gauge factor are presented in table 1. The resistive pastes contain different active phase and different lead- boro-silicate glass. Table 2 presents the results of *GF* measurements for resistor fired in different temperatures of the layers.

Table 1

The main properties of resistive layers with high gauge factor.

Symbol of paste	Conductive phase	R/□ kΩ/□	Firing temp. °C	Thickness μm.	Resistor termination
R-344 – ITME	$Bi_2Ru_2O_7$	4.0 2.5 2.5	830 850 870	- 16 -	Pd-Ag
R-RuO_2 – ITME	RuO_2	8.0 9.0 -	830 850 870	- 15 -	Pd-Ag
R-RuO_2 – ITME	RuO_2 - $Bi_2Ru_2O_7$	2.5	800 850	17 -	Pd-Ag
3414-B – ESL	Ru compounds	4.0	850	11	Pd-Ag

Table 2

The results of GF measurements for resistor fired in different temperatures.

Symbol of paste	Conductive phase	R/□ kΩ/□	Firing temperature °C	GF_L	GF_T	TCR ppm/°C
R-344 – ITME	$Bi_2Ru_2O_7$	4.0 2.5 2.5	830 850 870	8.3 10.5 5.6	6.5 8.1 3.6	30 123 190
R-RuO_2-1– ITME	RuO_2	8.0 9.0 -	830 850 870	12.6 18 19.2	9.3 12 12.8	82 53 -
R-RuO_2-2-– ITME	RuO_2 - $Bi_2Ru_2O_7$	2.5	800 850	10.3 12.8	7.9 8.5	204
3414-B – ESL	Ru compounds	4.0	850	18.4	11	56

The best results were obtained when the ruthenium dioxide with the grains of 1 μm and the glass of 2 μm was applied to elaborate the paste.

Fig. 4 presents the piezoresistive characteristics for resistors based on ruthenium dioxide made of R-RuO_2 ITME paste fired at 850°C. In all cases for these resistors were that GF_L was greater than GF_T. This effect was taken as an advantage in the project of the topology of the sensor.

4. The construction of piezoresistive pressure sensor.

The elaborated paste with high gauge factor was applied in model of the designed thick film pressure sensor. Scheme of the piezoresistive thick film pressure sensor and scheme of the resistive thick film part of the pressure are shown in fig. 5 and fig. 6.

Piezoresistive pressure sensor utilizes four sensing piezoresistors, printed on thin ceramic membrane and connected in a form of Wheatstone's bridge network. Alumina type Rubalit 708 S (Ceramtec) with the thickness of 0.25 μm was used as a membrane material. Since the slope of sensor characteristic depends on diameter to thickness ratio of the membrane, the membrane of 40 mm inside diameter was used. This allows the sensor to be sensitive to low pressure.

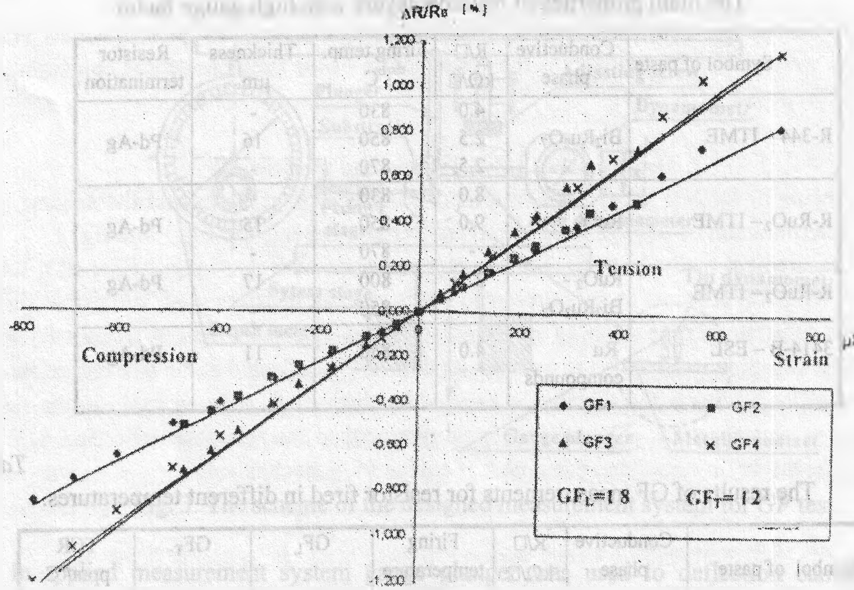

Fig. 4. Piezoresistive characteristic of thick film resistors made of R-RuO_2 ITME paste fired at 850°C.

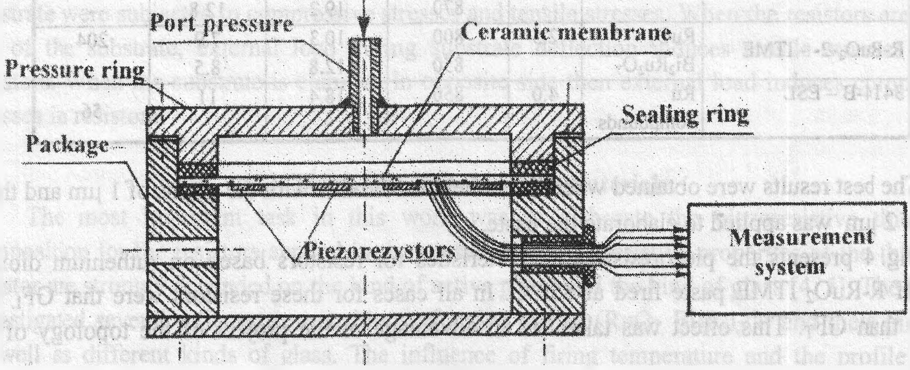

Fig.5. The scheme of the piezoresistive thick film pressure sensor.

Two resistors are located near the center of membrane, two others near the periphery. Such designed membrane was clamped in a special package and to test the pressure subjected. The imbalance of Wheatstone's bridge signal due to pressure effect represents the electrical output signal of the sensor.

The chacteristic of the elaborated of thick film sensor was measured for pressure in the range 0 – 20 kPa.

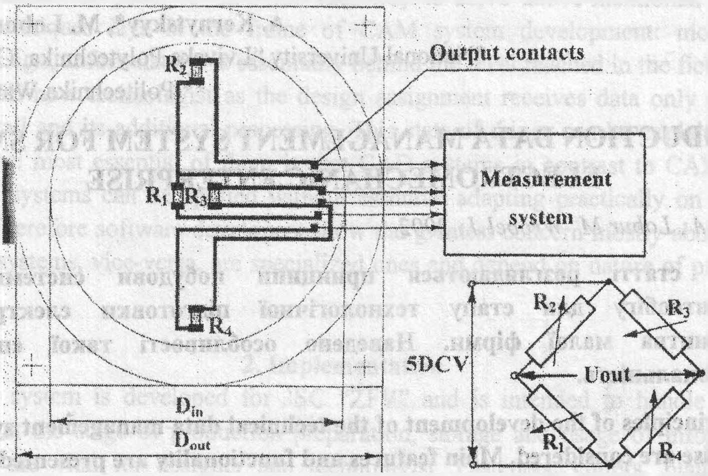

Fig. 6. Scheme of the resistive thick film part of the pressure.

The parameters of elaborated pressure sensors are :
- sensor sensitivity 0.5 mV/kPa,
- no linearity of its characteristic ≈ 3 %,
- supply voltage 5 DCV,
- The range of measured pressure 0-100 kPa.

5. Conclusions

The construction of ceramic pressure sensor based on piezoresistive effects of cermets resistors elaborated from new developed thick film paste with high Gauge factor. The sensor can be applied to measure pressure in the range of 0-100 kPa. It's sensitivity is 0.5 mV/kPa, and non linearity of the characteristics is under 5 %.

The new developed resistive paste is based on ruthenium dioxide and lead-boro-silicate glass. with suitable grain size and weight ratio. The resistors were produced from this paste and their piezoresistive characteristics were measured. It occurred that GF_L is higher than GF_T. This fact was important in the project of the sensor.

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