Висновки

Методом золь-гель технології одержано дві системи титанобарієво-боратного скла. Скло, до складу якого внесена додаткова домішка міді, формує структуру, яку можна охарактеризувати "середньою" упорядкованістю. Для цього скла при збільшенні кількості $Ti0_2$ характерною є нарівні зі значним збільшенням коефіцієнта заломлення невелика зміна КЛТР та λ.

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THICK FILM STRUCTURE RESISTOR ON DIELECTRIC

Розглянуто нові товстоплівкові матеріали для структурного резистора на діелектрику і описано властивості такої структури. Досліджено стабільність та п'єзоелектричні властивості резистора на діелектрику.

The new set of thick film materials for a structure resistor on dielectric and the properties of the of this structure are presented in this paper. The properties of resistor placed on dielectric such as stability, piezoresistive properties as well as microstructure was investigated.

1. INTRODUCTION

Miniaturisation in thick film microcircuit is realized by higher density packaging of elements. It could be achieved by producing thinner and closer paths and/or producing more levels in the multilayer structure. Introducing resistors to the multilayer structures always causes problems.

Resistors could be introduced to thick film multilayer structure in different ways [1,2,3]:

a) use both side of a substrate; on one side multilayer structure is placed, the resistors on the other,

b) use of chip resistors surface mounted,

c) division of the substrate into areas for resistors and the areas for multilayer connections,

d) deposition of resistors onto the substrate and built up of multilayer over them (buried resistors),

e) deposition of resistors onto the top of dielectric layer.

The simplest alternative is to a pre-completed multilayer structure as a substrate for resistor deposition, which becomes the last layer to be printed and fired. This reduces the number of resistor firings to one and eliminates level changes. It is necessary to find sufficiently large flat areas for resistor deposition. This configuration allows the laser trimming of resistors. But this method has also some disadvantageous. The pastes used must be very carefully selected. Most of standard resistive do not react with dielectric layer in the same way as with alumina [4]. In some cases the interaction of dielectric with resistor is significant [5-10]. This process is more intensive for buried resistors [11-15] where the resistors are placed on dielectric layer and covered with another one.

The materials for producing the structure resistor on dielectric must be carefully elaborated and selected. When resistor is placed on dielectric layer, diffusion from resistor to dielectric and from dielectric to resistor takes place and can affect the resistor parameters and the resistor structure [16]. The proper selection of thick film materials can minimized this effect. The aim of this work is to such set of thick film materials, to produce the structure "resistor on dielectric" and examine its properties.

2. DESCRIPTION OF STRUCTURE RESISTOR ON DIELECTRIC

The simplest structure defined as resistor on dielectric (R-D) which was investigated in this paper. The structure placed on 96 % alumina substrate was obtained by screen-printing and firing in air atmosphere the following layers:

– dielectric layer,

– onductive for resistor terminations,

– esistive layer.

The scheme of this structure is presented in Fig. 1.

a – alumina substrate, b – dielectric layer,
c – resistor terminations, d – resistive layer

Fig. 1. The scheme of the simple structure resistor on dielectric

When the choice of materials suitable for a structure resistor on dielectric is discussed it is necessary to have in mind a set of materials consisting of:

– dielectric paste (or pastes) on which resistor is placed or which covers the resistor (in case of buried resistors),

– conductive paste for resistor terminations,

– resistive paste (or a set of resistive pastes) of producing a resistor,

– overglaze for resistor protection (optionally).

3. BASIC PROPERTIES OF THE STRUCTURE RESISTOR ON DIELECTRIC

3.1. The properties of thick-film materials used for the structure resistor on dielectric

Dielectric paste D-421 [17], palladium silver P-202 (ITME) and a resistive one based on ruthenium dioxide and lead-silica-aluminium glass was chosen to elaborate the structure resistor on dielectric. Paste composition and basic properties of elaborated dielectric layer is shown in Table 1. Table 2 shows the basic properties of chosen palladium/silver 3:1 conductor placed on dielectric and bare alumina substrate.

Table 1

The basic parameters of dielectric layer used in structure resistor on dielectric

Properties of the dielectric layer	D-421
Glass composition	PbO, Al_2O_3, SiO_2, $BaTiO_3$ ZnO, TiO_2
Thermal expansion coefficient of the glass 10^{-6} $1/^{O}C$	$\alpha_{200 C} = 4{,}57$ $\alpha_{300 C} = 5{,}02$ $\alpha_{25-400 C} = 5{,}52$
Density of the glass, g/cm^3	3,65
DTM	720 ^{o}C
T_g	590 ^{o}C
The paste composition	Glass 90,7 % Al_2O_3 4,8 % Pigment 4,5 %
Firing temperature	850 ^{o}C
The layer thickness of triple layer	66 µm
Dielectric constant	4,0
The dielectric losses	66 x 10^{-4}
Short circuit voltage	> 800 V

Table 2

The basic parameters of conductive palladium-silver layer placed on dielectric layer and bare alumina

	The kind of substrate	Sheet resistivity R/ , mΩ/	Solderability , %	Adhesion, $N/4mm^2$
Pd/Ag (P-02,ITME)	D-421	23.1	90	18
	Al_2O_3	20.4	100	19

The resistive paste elaborated for the investigated structure consists of 37 % ruthenium dioxide and of 63 % lead-silica-aluminium glass. The melting point of the glass was 660 ^{o}C. A vehicle composed of ethyl cellulose dissolved in terpineol was used. The paste was fired at 850 ^{o}C with the use of standard 60 minutes profile. Sheet resistivity and temperature coefficient of resistance (TCR) of resistors with palladium/silver terminations placed on dielectric and bare alumina substrate are presented in table 3.

Table 3

The basic parameters of resistors placed on dielectric layer and bare alumina

Paste	The kind of substrate	Sheet resistivity R/ , kΩ/	TCR, ppm/K
RuO_2 with Pd/Ag terminations	D-421	20.1	61
	Al_2O_3	18.2	83

All pastes used to elaborate the structure "resistor on dielectric" should be compatible, that means that all layers obtained from these pastes placed on one another do not affect their properties that unable them for application in a particular structure [18].

Test pattern to investigate the structure is presented in Fig. 2. The dielectric layer was double to avoid the short circuit in case, if there would be a need of placing it on the thick film structure. It was screen-printed and fired at 850 °C twice. Then, the palladium/silver terminations were prefired at 850 °C. At last, the resistors fired as at last at 850 °C. They were of 1 mm width and from 1 to 9 mm long.

Fig. 2. Test pattern for investigation the resistor on dielectric structure

3.3. The basic properties of the investigated structure

At the beginning, the compatibility of resistor and its termination was examined. The influence of terminations on resistor resistivity is presented in Fig. 2,b. Normally, the short resistors are affected by diffusion of silver and other ions into resistor body and sheet resistivity is lower than for longer ones. In our case, the resistivity of resistor 1 mm long placed on dielectric is higher than placed on alumina. For longer resistors the effect is not so big. That means that the diffusion of silver to resistor body is not significant. The resistivity growth is caused by the diffusion from dielectric to resistor (see the cross-section of resis-tor, Fig. 6).

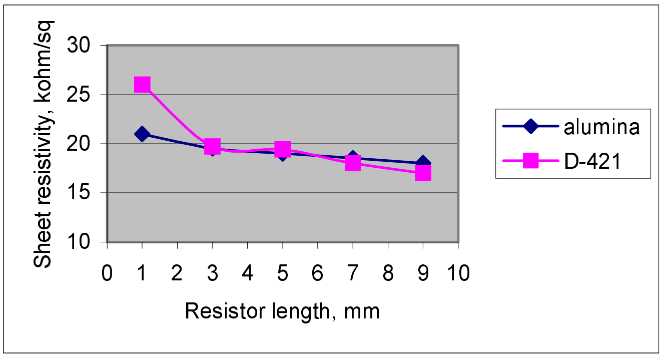


Fig. 3. The sheet resistivity of resistors versus resistor length for resistors placed on bare alumina and dielectric layer

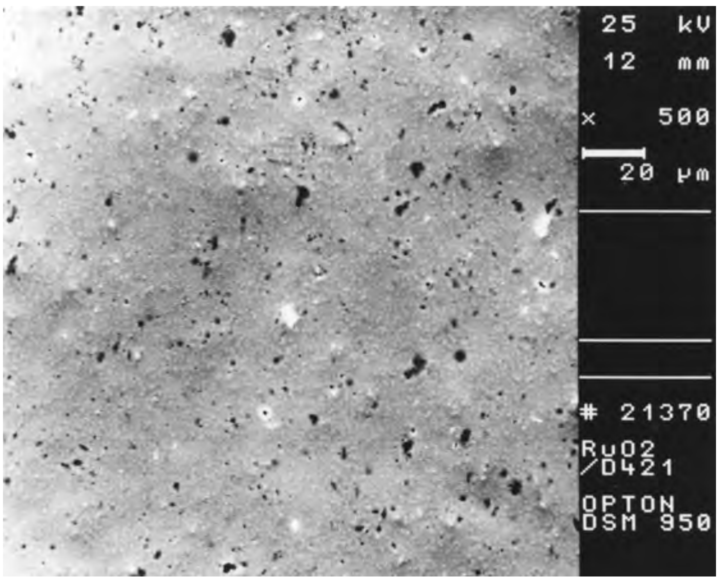
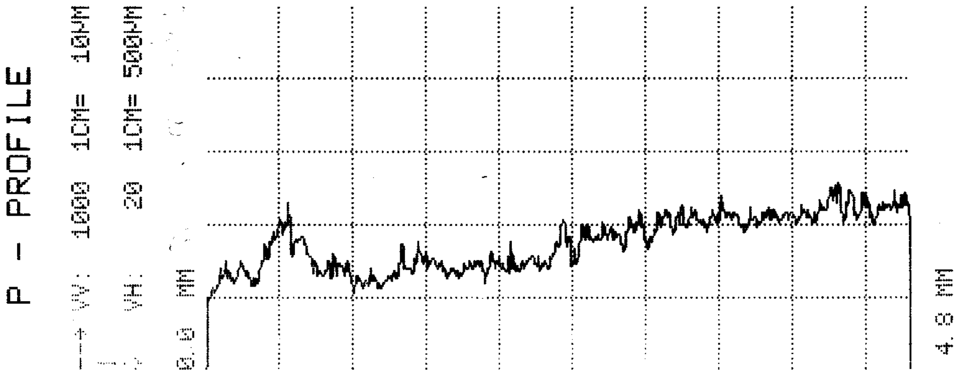
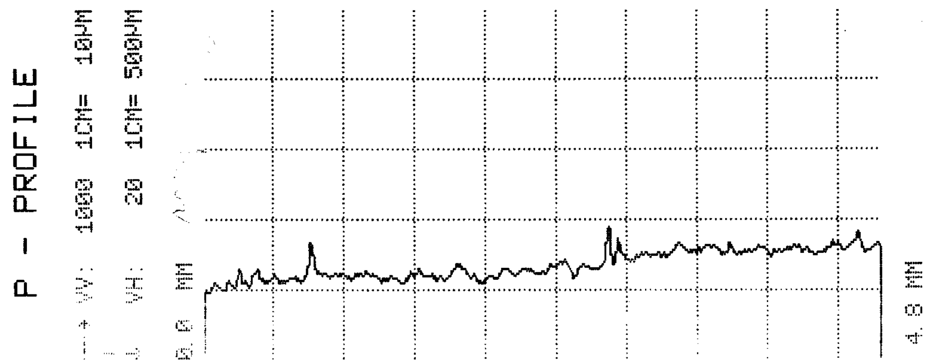


Fig. 4. The microstructure of resistive layer placed on dielectric. Top view. Magnification 500 x

Fig. 4 presents the image of microstructure of resistive layer ("top view") described in § 3.2. The resistive layer was deposited on dielectric layer D-421. The structure is homogenous, dense and without micro cracks. It is confirmed on profilographs of dielectric layer (Fig. 4,a) and resistive layer on dielectric (Fig. 4,b). The roughness R_a of dielectric layer is 1,2 μm, while the roughness R_a of resistive layer on the dielectric 0,6 μm. The last value is comparative with the roughness of resistors obtained from the same paste deposited on bare alumina equal to 0,4 μm.



A



B

Fig. 5. Profilograms of dielectric layer (A) and resistive layer on dielectric (B)

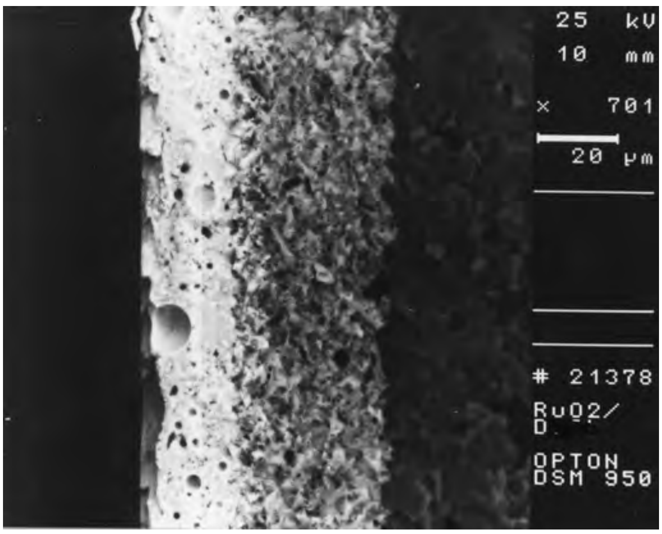


Fig. 6. Cross-section of the structure resistor on dielectric

Fig. 6 presents the SEM image of cross-section of the structure resistor on dielectric D-421. An interlayer between the resistive and dielectric layer could be observed. This is caused by diffusion both from resistive to dielectric layer and from dielectric to resistive one. The width of this interlayer is about 7 μm. This is the reason of higher resistivity of resistor when deposited on dielectric.

3.4. Stability of elaborated resistors placed on dielectric

Stability of elaborated resistors placed on dielectric was determined by measuring sheet resistivity R/ and temperature coefficient of resistors (TCR) in the temperature range from – 170 °C to + 130 °C. The results are presented in Fig. 7 and 8. The resistivity of the resistor on dielectric is quite stable. The changes were below 6 %, while for the same resistor placed on bare alumina were 5 %. The value of TCR changed from negative values for negative temperatures to positive values (below 100 ppm/K) for higher temperature.

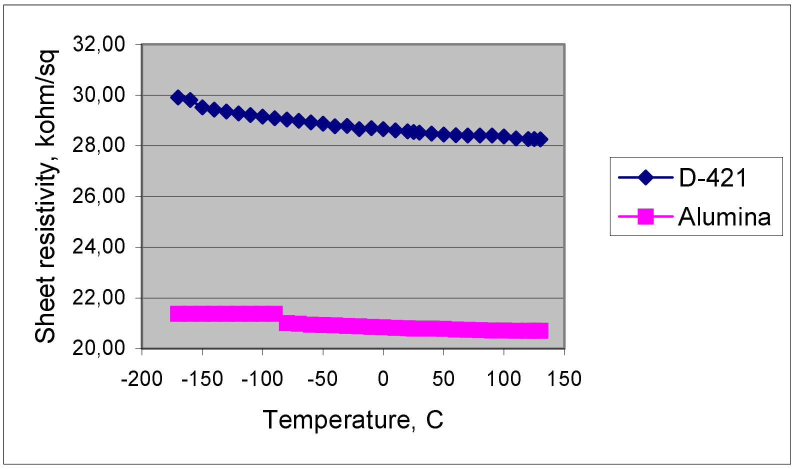


Fig. 7. Sheet resistance versus temperature for RuO_2 resistors placed on dielectric layer. and alumina

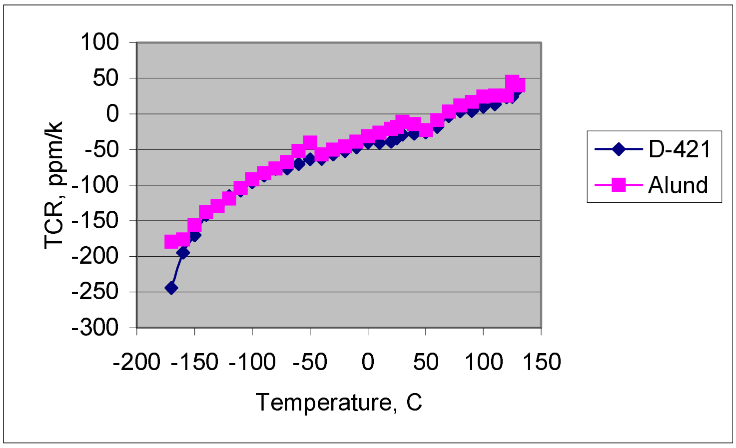


Fig. 8. Temperature coefficient of resistance versus temperature for RuO_2 resistors placed on dielectric layer and alumina

3.5. Piezoresistive properties of resistor on dielectric

Piezoresistivity in thick film resistors is characterised by so called gauge factor (GF), which can be defined as:

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

where:

ε – strain in resistor; $\Delta R/R_0$– relative change in resistance.

To estimate piezoresistivity in thick film resistors, a simple measurement method has been designed and applied. The measurement method is described in details in [19]. The GF measurement method utilized the ceramic substrate with longitudinal and traverse resistors. One end of the substrate is subjected to external load then it is deflected at the three end. The scheme of the measurement method is presented in Fig. 9.

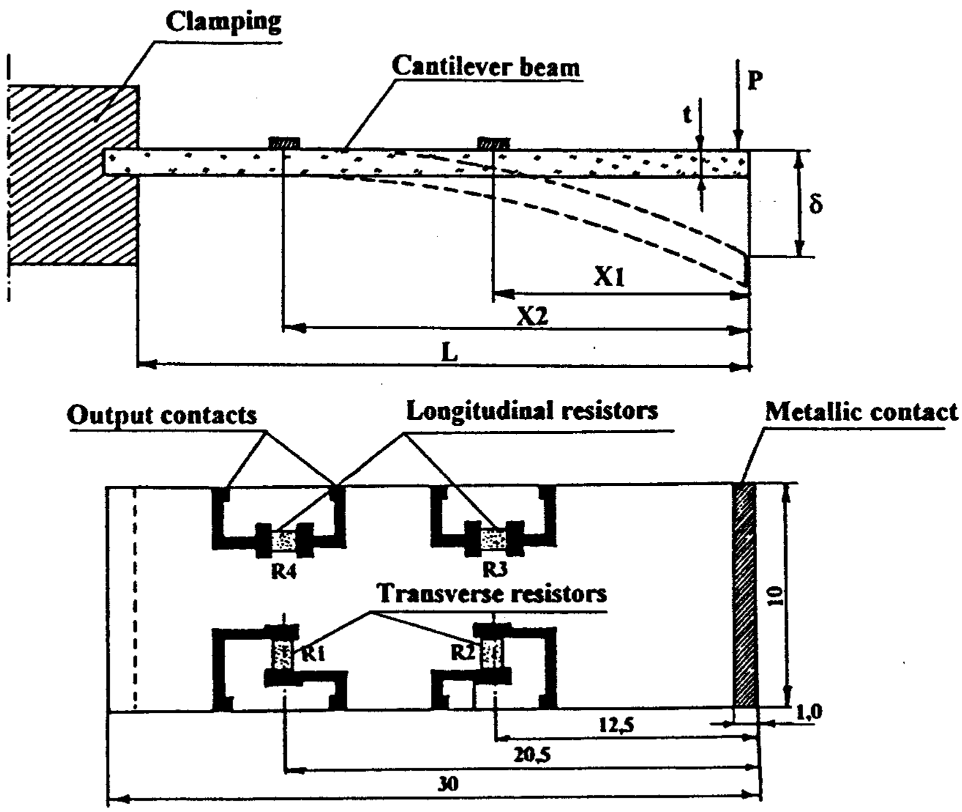


Fig. 9. The scheme of testing GF of resistors

Test resistors on alumina substrate has two longitudinal resistors (R_3, R_4) and two traverse (R_1, R_2). The resistors were placed at different points of the substrate, so strain in resistors R_1 and R_4 is greater than in resistors R_2, R_3. Taking into account the resistor orientation with respect of applied strain, two types of GF are defined: GF_L – longitudinal gauge factor and GF_T – transverse gauge factor. All tested resistors were of 1 mm square.

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

Table 4 presents the piezoresistive properties of elaborated compositions. The best results were obtained for resistors made of described above resistive paste (based on RuO_2) when the resistor was placed on alumina substrate covered with dielectric layer. For comparison the results of other pastes placed on alumina are presented too. Piezoresistive characteristics of the structure resistor on dielectric is presented in Fig. 10.

Table 4

Piezoresistive properties of selected resistive paste

Paste	Conductive phase	R/ kΩ/	GF_L	GF_T	TCR ppm/°C
R-RuO_2-II- on dielectric	RuO_2	2,5	22	15	25
R 342 on alumina	$Bi_2Ru_2O_7$	2,5	10.5	8.1	23
R-RuO_2 on alumina	RuO_2	9,0-	18	12	53

The presented results shows that the elaborated structure exhibit high gauge factors. It is due to stresses caused by the difference of thermal expansion coefficients between alumina substrate and dielectric and resistive layers which are:

– alumina substrate – 6,8 x 10^{-6} / °C,
– dielectric layer – 5 x 10^{-6} / °C,
– resistive layer – 5.8 10^{-6} / °C.

Some authors presented their results of GF for resistors placed on dielectricequal to 30 [20-21], but it was due to micro cracks existing in the resistive and dielectric layers. In our case the micro cracks do not exist what could be seen in the cross-section of the structure (Fig. 5).

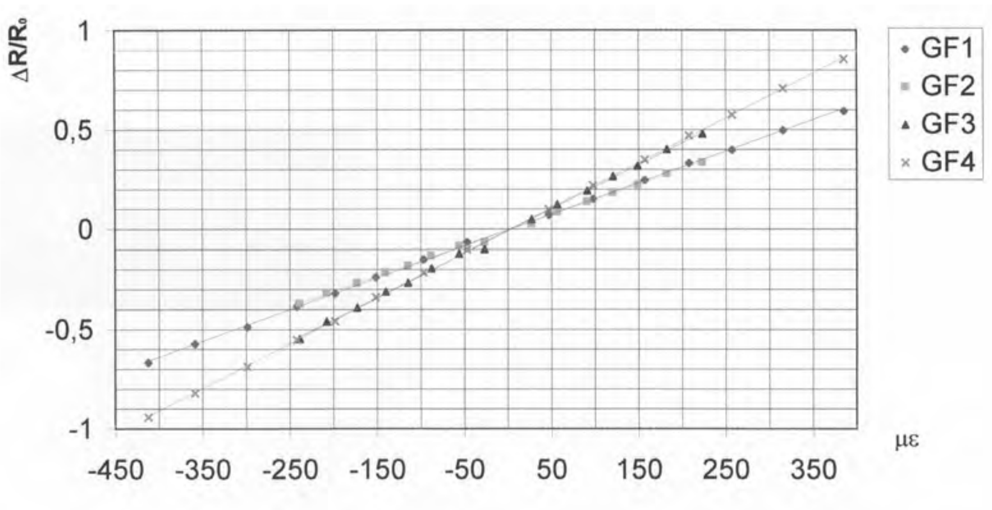
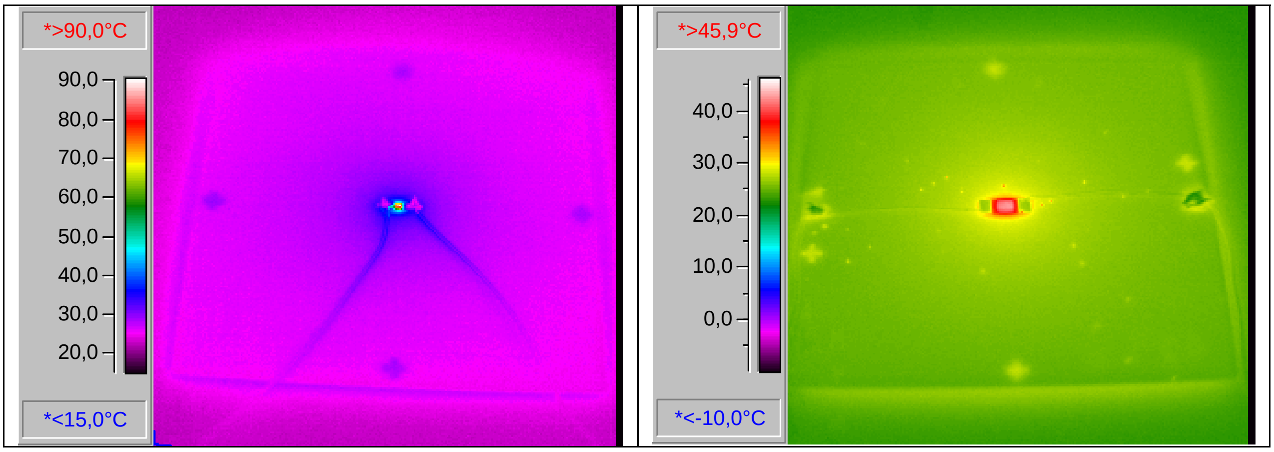


Fig. 10. Piezoresistive characteristics of newly developed paste

3.5. Thermal properties of the investigated structure resistor on dielectric

Thermal properties of structure resistor on dielectric was also investigated with the use of thermo vision camera. The resistor of 1x1 mm placed on dielectric layer was loaded with power of 500 mW. The image from the camera is presented in Fig. 11,a. For comparison the image for resistor placed on bare alumina is presented in Fig. 11,b. Dielectric layer is playing the role of a thermal barrier., in contradiction to dielectric layers of high thermal conductivity [22].



A B

Fig. 11. Thermograph of the structure resistor on dielectric layer D-421 (A) and on bare alumina substrate (B). The resistors were loaded with power 500 mW/mm^2.

4. EXAMPLE OF APPLICATION OF ELABORATED STRUCTURE RESISTOR ON DIELECTRIC

The structure resistor on dielectric was applied to a thermal overhead in laser printers. The microcircuit presented in fig. 12 contains several resistors place on dielectric layer. The resistors are heating the moving paper in certain points. The dielectric layer is a thermal barrier for not loosing the heat.

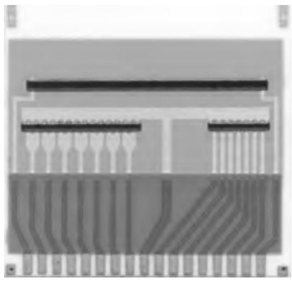


Fig. 12. The example of a structure resistor on dielectric to the microcircuit for laser printers

5. CONCLUSIONS

The new set of thick film materials for a structure resistor on dielectric and the properties of this structure are presented in this paper. The properties of resistor placed on dielectric such as stability, piezoresistive properties as well as microstructure was investigated. An example of application of the structure to a thermal overheadin laser printer was described.

The structure resistor on dielectric could be also applied in sensors, especially for medical applications, in microcircuits for automotive industry as well as for different heaters. Different applications needs different sets of materials which will not affect the properties of compatible layers. Elaboration of such materials is a task for pastes producers.

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ЕЛЕМЕНТИ ТЕОРІЇ РЕЗИСТИВНИХ НАПІВПРОВІДНИКОВИХ СЕНСОРІВ ТЕМПЕРАТУРИ

За допомогою сучасної кінетичної теорії з'ясовано природу важливих параметрів напівпровідникових терморезисторів.

In this paper the nature of important parameters of semiconductor thermoresistors is cleared up by modern kinetics theory.

Терморезистори – нелінійні опори, виготовлені з напівпровідникового матеріалу з великим від'ємним температурним коефіцієнтом опору. Дія терморезисторів базується на залежності опору напівпровідника від температури. Їх температурна залежність описується: