INVESTIGATION OF LTCC THERMISTOR PROPERTIES*

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The work is conducted on NTC (*Negative Temperature Coefficient*) thermistors. An influence of different type of the substrate (DP 951 and lead free ESL 41020) on basic electrical properties: sheet resistance at a room temperature, R = f(T) dependence, B constant and a long-term stability is analyzed. The resistance values are measured twenty times in the range from 25°C to 125°C at 5°C intervals, while temperature is recorded using Pt-100 resistor. Long-term stability is investigated by annealing at 150°C for 200 h.

Key words: LTCC, thermistor

1. INTRODUCTION

Fast development of the LTCC (*Low Temperature Co-fired Ceramics*) technology enables to manufacture various type of sensors. Especially popular are temperature and gas/liquid flow sensors [1-2]. Metals with high TCR (*Temperature Coefficient of Resistance*) and thermistors [3-4] are used in these devices. Thick-film thermistors are very popular because of low price and high TCR coefficient. However, they have lower long term stability. High TCR gives an ability to manufacture smaller and more sensitive components. The electrical properties of the screen printed components are very important. They must be analyzed before using at various microsystem applications. Good parameters of these components provide high quality

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of the thermistor based sensors. The most important NTC (*Negative Temperature Coefficient*) thermistor parameters are: constant B, tolerance of the constant B and long-term stability. High value of constant B ensure good sensor sensitivity. Repeatability of the sensor parameters depends on the constant B variability coefficient. The sensor long-term stability depends on the thermistor long-term stability. The passive electrical properties must be stable. Unfortunately, most of the commercially available thermistor compositions are dedicated to alumina substrate. The shrinkage mismatch and a difference in TCE (*Thermal Coefficient of Expansion*) between LTCC and alumina substrates cause tapes deformation during firing process. Moreover, physicochemical interaction between the tape and the paste materials affects thermistor properties [5]. The basic electrical properties of the ESL NTC-2114 alumina dedicated thermistor composition screen printed on the LTCC substrates are described in the paper. An influence of the substrate (DuPont 951 and ESL 41020 tapes) and the thermistor placement (placed on the LTCC surface or buried inside) on temperature dependence of resistance, sheet resistance, thermistor constant B and long-term stability are investigated.

2. EXPERIMENTAL

The NTC thermistors, conductive lines and terminations are screen printed through 325 mesh stainless steal screen. The NTC resistor paste (ESL NTC-2114 dedicated to alumina substrate) and silver-based composition as terminations (ESL 963-B and DP 6160) are used. The NTC thermistors are fabricated as a surface [Fig. 1 (a)] and buried [Fig. 1 (b)] components. The thermistors are manufactured on/in DuPont 951 and ESL 41020 Green Tape^{TM} system. The lamination process is made with parameters recommended for DP 951 tape. The layout for test structures is presented in Fig. 1. The thermistors surface area is 1.2x1.2 mm^2 (1 square). After screen-printing the pastes are dried in a lab oven at 120^{o}C for 5 min. Next, they are fired according to a two-step firing profile with a maximum temperature equal to 875^{o}C.

The resistance values are measured twenty times in the range from 25^{o}C to 125^{o}C at 5^{o}C intervals, while temperatures are recorded using Pt-100 resistor. The measurements are made by the Agilent 34970A data acquisition unit using two-wire method. The B constant value can be calculated from equation:

$$R(T) = R_{298} \exp\left[B\left(\frac{1}{T} - \frac{1}{298}\right)\right] \tag{1}$$

where: R is the resistance at a certain temperature T and R_{298} is the resistance at temperature 298 K. The standard deviations of the resistance (σ_R) and constant B (σ_B) are described by equation :

$$\sigma_{R,B} = \sqrt{\frac{\sum\left(y-\bar{y}\right)^2}{(n-1)}} \tag{2}$$

where n is the number of y values (sheet resistance or B constant).

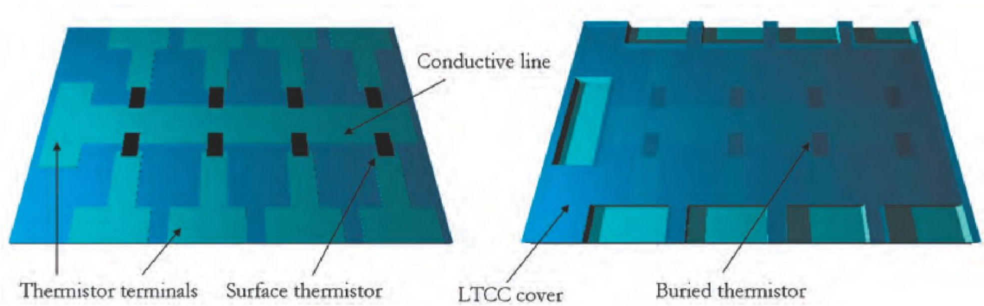

Fig. 1. Surface (a) and buried (b) configuration of the LTCC thermistors.
Rys. 1. Powierzchniowe (a) i zagrzebane (b) termistory na podłożu LTCC.

The temperature dependence of resistance and basic electrical properties of the investigated NTC resistors are presented in Fig. 2 and Tab. 1, respectively. As it can be seen from Fig. 2, temperature coefficient of resistance is negative. Buried

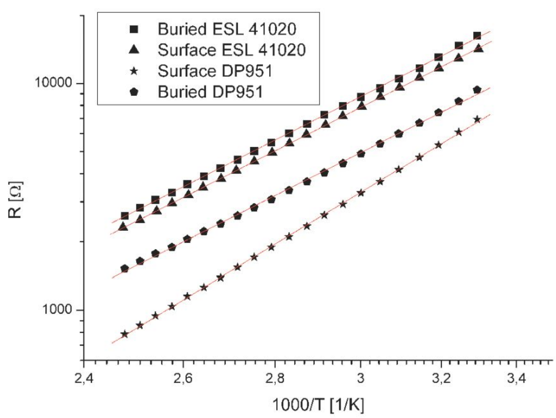

Fig. 2. The temperature dependence of resistance for NTC thermistors made on DP951 and ESL 41020 substrates.
Rys. 2. Zależność rezystancji od temperatury dla termistorów NTC nadrukowanych na podłożu DP951 i ESL41020.

components show higher sheet resistance values with higher standard deviation in comparison to surface ones. The variability coefficient of the sheet resistance is better for the thermistors fabricated in/on the ESL substrate. The B constant value dependents much weaker on the kind of substrate than sheet resistance and is very similar to the catalogue data (on alumina substrate). The variability coefficients of the B constant for both surface and buried components made in/on DP951 and ESL 41020 substrate are very low and do not exceed 3%. However, they are significantly better for DP 951 substrate.

Table 1. Basic electrical properties of the investigated thermistors.
Tabela 1. Podstawowe parametry elektryczne badanych termistorów.

Position	Sheet resistance, $R_{\square}$ kΩ/□]	Standard deviation of sheet resistance σ_R [kΩ/□]	Variability coefficient of resistance V_R %]	Thermistor constant, B [K]	Standard deviation of constant B σ_B [K]	Variability coefficient of the constant B, V_B [%]
Surface DP	7.63	2.08	27	2463	31	1.3
Buried DP	9.26	2.95	32	2210	32	1.5
Surface ESL	16.1	3.20	20	2085	61	2.9
Buried ESL	17.8	4.27	24	2230	69	3.0
Catalogue Parameters*	10.0	-	-	2125	-	-

* on alumina substrate

Long-term stability was investigated, as well. It is analyzed by annealing all test structures at 150°C for 200 hours. As is shown in Fig. 3 (a) and (b) the percentage resistance changes $\Delta R/R_0$ are function of the ageing time. However, this parameter depends also on the applied substrate. All tested surface thermistors exhibit worse long-term stability than buried ones. This agrees with situation observed in LTCC resistors [6], where it is also noted that embedded components are somewhat more stable than surface ones. All test surface components exhibit high resistance changes, more than 15 % and 70 % for DP 951 and ESL 41020 substrates, respectively. The ESL recommends to anneal the thermistor composition for 16 hours at 150°C. For surface structures the resistance is changing very fast for the first 10 hours of the ageing process. After 10 hours the resistance changes of the surface components made on both substrates have been stabilized and do not exceed 5%. In the case of buried structures the changes of resistance during the whole ageing cycle of 200 hours for thermistors manufactured in DP 951 and ESL 41020 do not exceed 2% and 12%, respectively.

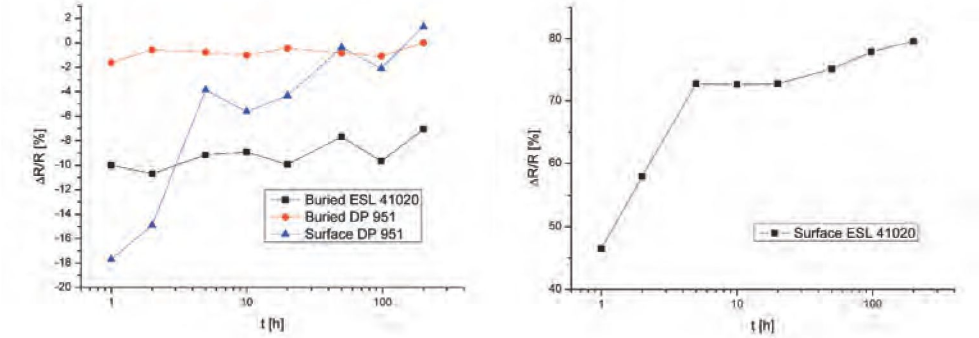

Fig. 3. Long-term stability of NTC thermistors made in/on various LTCC substrates: (a) long-term stability for buried ESL, buried DP and surface DP, (b) for surface ESL.
Rys. 3. Stabilność długoterminowa dla termistorów NTC: (a) zagrzebanych folia ELS, zagrzebanych folia DP, powierchniowych folia DP; (b) powierzchniowych folia ESL.

3. CONCLUSIONS

The influence of the LTCC material (DP 951, ESL 41020) on basic properties (sheet resistance, B constant and temperature dependence of resistance) of the NTC thermistors (NTC-2114, ESL) is presented.

Basic electrical parameters of the NTC thermistors depend on the kind of substrate and placement in/on the LTCC substrate. The buried components show higher sheet resistance value with higher standard deviation in comparison to the surface ones.

The buried thermistors exhibit much better long-term stability than the surface ones. This is because of the good encapsulation of the buried components. Therefore, their durability to high temperature and harmful environment is increased.

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SUMMARY

BADANIE WŁAŚCIWOŚCI TERMISTORÓW WYKONANYCH NA PODŁOŻACH LTCC

W pracy przedstawiono wyniki badań związanych z elementami termistorowymi NTC (*Negative Temperature Coefficient)*. Zbadano wpływ rodzaju podłoża (DP 951 i bezołowiowego ESL 41020) oraz konfiguracji elementów (zagrzebane, powierzchniowe) na podstawowe parametry elektryczne: rezystancję na kwadrat, zależność rezystancji od temperatury, stałą termistorową B, stabilność długo terminową. Wartości rezystancji były mierzone 20 razy w zakresie od 25°C do 125°C ze skokiem 5°C. temperatura była mierzona za pomocą rezystora PT-100.. Stabilność długoterminowa była badana przez wygrzewanie w 150°C przez 200 h.

Słowa kluczowe: LTCC, termistor