Thick Film Power Resistor with Thick Printed Copper Terminals

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Abstract

This paper is focused on the thick film power resistors with copper terminals. These terminals are manufactured by the new Thick Printed Copper (TPC) technology. This technology is based on sequential screen printing and firing of copper paste in nitrogen atmosphere on alumina substrate. TPC technology is predominantly used for power electronic substrates manufacturing. The major trends of power electronics are continual miniaturization and power increasing. It brings increased requirements on electronic components particularly in terms of heat dissipation. Thick film power resistor with copper terminals represents potential replacement of standard wirewound power resistors and allows direct integration of resistors on TPC substrates. Printed resistors on TPC substrates can be supplemented with discrete electronic components which creates the possibility to realize truly complex power electronic circuits. The direct integration of printed components is not possible in case of standard Direct Bonded Copper (DBC) technology. The main benefits of printed resistors based on TPC technology are its low thickness and good thermal conductivity. The low thickness of resistors is important for miniaturization of final electronic devices. The resistor main electrical parameters (temperature coefficient of resistance, temperature coefficient and nominal resistance value after aging by dry heat test, insulation resistance, dielectric strength etc.) are described in this paper.

Introduction

Resistors are one of the most commonly used components in electronics. Thick film resistors are used in integrated form in hybrid circuits or in discrete form in the other electronic applications. These resistors are based on screen printing of the resistive paste on the ceramic substrates. Resistive pastes as the conductive pastes contain metal or metal oxides particles, glass particles and organic binder [1]. Resistive layers are fired in belt furnace after printing and drying. The organic binder is removed during the firing and the glass phase creates good connectivity between the resistive particles and the ceramic substrate [2].

Concentration of the metal particles has influence on the final resistance value. The first commercial thick film resistor pastes were based on composition of palladium, palladium oxide and silver. The disadvantage of these pastes was considerable sensitivity to the changes of the firing profile. Modern commercially available thick film resistors pastes are based on ruthenium, iridium and rhenium oxides. These pastes are less sensitive to the firing profile changes, have low value of TCR (Temperature Coefficient of Resistance) and good stability [1,2]. The main parameter of resistive pastes is the sheet resistance. It is defined as resistance value on one square at a defined thickness. Resistive pastes are manufactured in wide ranges of sheet resistance (usually in decadic series). These pastes can be mixed together to achieve accurate sheet resistance value, but it brings the risk of loss of some properties (TCR, stability etc.).

The first step of the thick film resistors manufacturing process is creation of terminals. Thick film resistor terminals are usually created by silver thick films (predominantly silver-palladium pastes). Palladium restricts the electromigration and decreases silver solubility in solder. The next step for realization of printed resistors is screen printing of resistive layer on the substrate with created terminals. Printed resistive layer can be covered with overglaze material. The overglaze material protects resistor against environmental effects, chemical substances and mechanical abrasion. Typical material for overglazing is borosilicate glass [2]. Finally, resistors can be laser trimmed to the required value.

The selection of terminal materials is critical to achieve proper properties and stability of final resistor. The type of the material used for terminals manufacturing can affect the sheet resistance value [2]. The resistance value can be also affected by the terminals area and by the quality of interface between the terminal and the resistive layer.

Resistor manufactured by TPC technology

The major trends of power electronics are continuous miniaturization and power increasing. These trends bring increased requirements on power electronics components. The main problem is with heat dissipation from loaded electronic components. Thick film power resistors with copper terminal represents promising solution for miniaturization and heat dissipation of power electronic modules and they can replace standard wirewound power resistors in many applications.

Resistor terminals are manufactured by the new TPC (Thick Printed Copper) technology used for power substrates manufacturing. It is based on sequential screen printing of copper paste on ceramic substrate and firing in nitrogen atmosphere with a low concentration of oxygen [3,4]. As mentioned above, terminals of thick film resistors are usually created by silver thick films. In comparison with it, copper thick films have better solderability, comparable adhesion and enables creation of copper layer with greater thickness (up to 300 μm) [5]. The lower price of copper compared to silver is also a considerable advantage of this technology.

The main benefits of power resistor with copper terminals are good thermal conductivity and lower thickness compare to standard wirewound power resistors. The lower thickness is important for miniaturization of final electronic device. These resistors can be directly integrated on the substrates with other discrete components. Copper layer can be also printed on the bottom side of resistor for effortless assembly on the heatsink. 96% Al_2O_3 with thickness of 0.636 mm is used as substrate. Terminals are printed by copper paste Heraeus C7403 and resistive layer is created with paste Heraeus R8921 (sheet resistance 100 Ω/square). Resistive layer was covered with glass overglaze. Elimination of oxidation is crucial for realizing of resistor. This is achieved by firing in an inert (nitrogen) atmosphere.

<u>Intermittence resistor pattern</u>

Intermittence resistor pattern was designed for the verification of functionality, stability and behavior of resistors with copper terminals. It contains two resistor patterns. The first pattern consists of 10 square resistive structure and 2 contacts between the copper terminals and the resistive layer. The second pattern consists of 10 one square resistive structures and 20 contacts between the copper terminals and the resistive layers. Therefore, both patterns should have the same resistance when the contact among resistive layer and terminals is optimal. If not, the contact resistance can be calculated from the difference of resistance of both patterns. Both patterns are shown in Fig. 1. These patterns were also manufactured with silver terminals and these samples were used as reference.

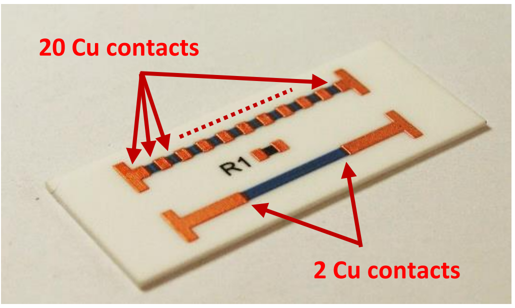

Fig. 1 Intermittence resistor pattern.

Temperature characteristics of resistance of above mentioned samples in temperature range from 0 °C to 100 °C with step 10 °C before and after aging by dry heat test (155 °C for 1000 hours, EN 60068-2-2) in thermostatic bath Lauda PJL 12 with silicon oil was measured. Temperature characteristics were also measured during aging (after 100, 200, 500 and 1000 hours). Four-terminal measuring method was used for resistance measuring and TCR value was calculated according to the following formula, where *R* is resistance value, *dR* is resistance difference and *dT* is temperature difference.

$$TCR = \frac{1}{R} \cdot \frac{dR}{dT} \cdot 10^6 \quad \text{(ppm/°C)} \tag{1}$$

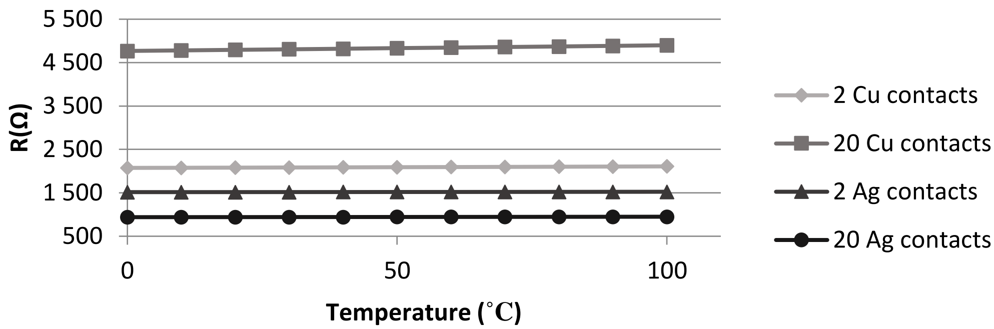

Fig. 2 Temperature characteristics.

Measuring was performed for six samples with copper terminals and three reference samples with silver terminals. Typical temperature characteristic of each sample are shown in Fig. 2. Average TCR and resistance values of each type of samples before aging are mentioned in Table 1. Average resistance values changes and TCR values changes after aging (after 100, 200, 500 and 1000 hours) were recalculate to per cent, see Fig. 3 and Fig. 4.

Table 1. TCR and resistance values.

Sample	TCR (ppm/ºC)	R at 20 °C (Ω)
2 Cu contacts	166	2080
20 Cu contacts	305	4794
2 Ag contacts	57	1517
20 Ag contacts	110	941

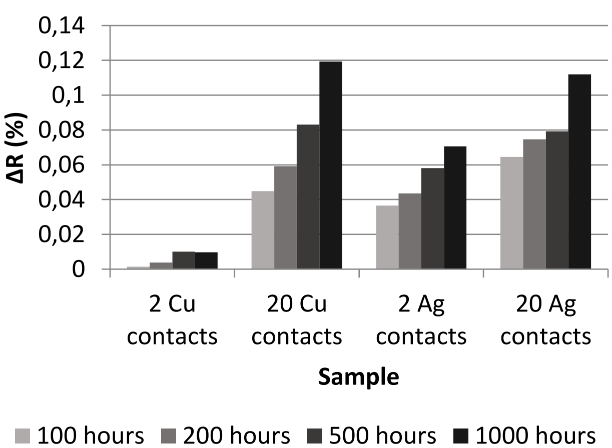

Fig. 3 Resistance value changes at 20 ˚C after aging.

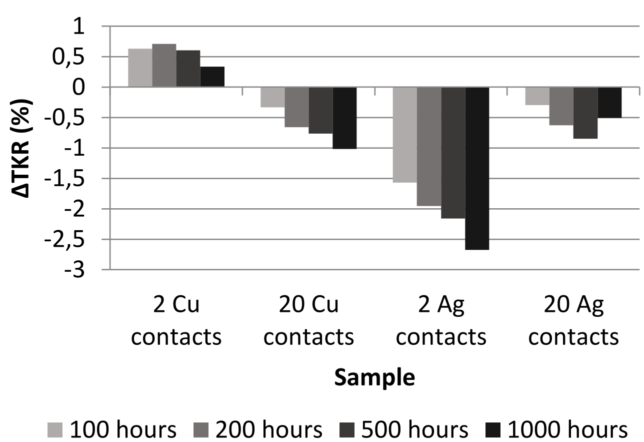

Fig. 4 TCR changes after aging.

Resistor prototype

Based on verification of functionality and stability of intermittence resistor pattern the prototypes of power resistors with copper terminals was designed and manufactured (Fig 5). It consists of two square resistive structure. The dimensions and shape of resistor are described in Fig. 6. The main electrical parameters of resistor (TCR, TCR and nominal resistance value after aging by dry heat test, dielectric strength, insulation resistance, rated power) were measured. Measuring was performed according to the standards EN 60115-1 and EN 140200. The main attention was focused on resistance stability after aging and influence of copper terminals to resistance value and stability.

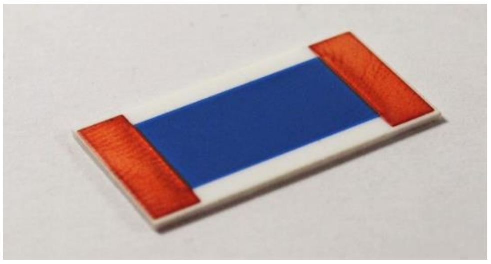

Fig. 5 Thick film power resistor with copper terminals.

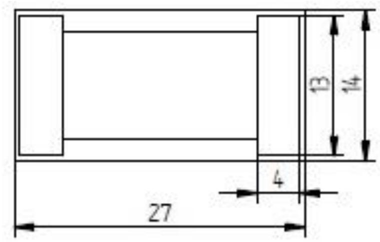

Fig. 6 Thick film power resistor dimensions.

TCR and tempereature characteristic

Temperature characteristic of resistance of ten resistor samples was measured with the same method as in the previous case and TCR was calculated using the formula 1. Results are mentioned in Table 2. Resistance value and TCR value changes after aging were also recalculated to per cent, see Fig. 7 and Fig. 8.

Table 2. TCR before and after aging.

Sample	**TCR (ppm/ºC)**	**TCR after aging (ppm/ºC)**	**ΔTCR (%)**
1	127.04	126.06	-0.77
2	115.76	114.76	-0.86
3	115.32	114.23	-0.95
4	135.35	134.29	-0.78
5	115.45	114.45	-0.87
6	87.67	86.68	-1.13
7	103.32	102.69	-0.61
8	75.04	74.47	-0.76
9	115.92	114.84	-0.93
10	145.01	143.74	-0.88
Average value	113.59	112.62	-0.85

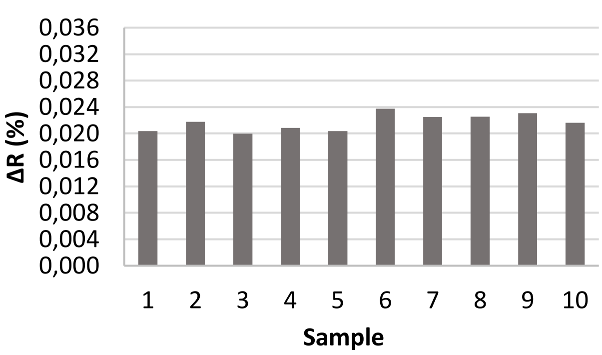

Fig. 7 Resistance value changes at 20 ˚C after aging.

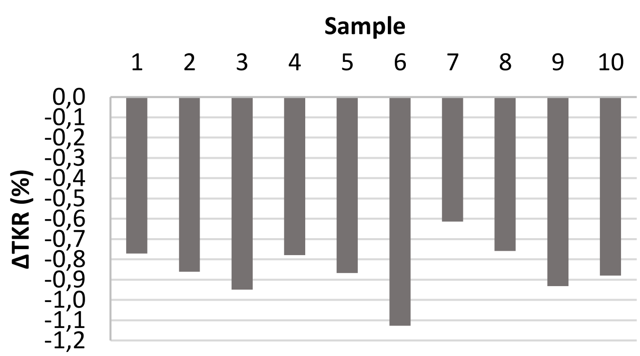

Fig. 8 TCR changes after aging.

Other parameters

The main electrical parameters of resistor are described in Table 3. Parameters measuring was performed according to the standards EN 60115-1 and EN 140200. Material which were used for manufacturing are also mentioned in Table 3.

Table 3. Resistor specification.

Substrate	96% Al_2O_3
Coating	Glass
Terminals	Copper
Resistance value	390 Ω
Resistance tolerance	±10 % without trimming
TCR	±120 ppm/°C
Rated power	1.5 W based on 70 °C free air without heatsink
Breakdown voltage	10 kV through substrate
Insulation resistance	Over 1 GΩ
Operating temperature	-55 °C to 155 °C
TCR change after dry heat test (155 °C, 1000 hours)	±1 %
Resistance change after dry heat test (155 °C, 1000 hours)	±0.05 %

Results

It has been proven that the terminals of thick film power resistors can be manufactured by TPC technology. Realized power resistors have stable nominal resistance value after long-term aging, see Fig. 7. These resistors have TCR ±120 ppm/°C and TCR value is also stable after aging, see Fig. 8. TCR changes and nominal resistance values changes of the resistors with copper terminals after aging are lower compared to changes of resistors with silver terminals. Nominal resistance values scattering of the resistors after firing is ±10 % and more accurate nominal resistance values can be achieved by trimming.

Acknowledgement

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