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Stability of miniaturized non-trimmed thick- and thin-film resistors

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ABSTRACT

This paper is focused on reliability tests of non-trimmed miniaturized thin-film and thick-film resistors. Thick-film resistors are screen printed by polymer paste on LTCC (Low Temperature Co-fired Ceramic) substrate by two different approaches. Nonstandard precise screen printing process provide tolerance of resistivity less than 5% and thus further trimming is not necessary. OhmegaPly material with Nickel Phosphorous (NiP) metal alloy is used for thin-film resistors fabricated by subtractive process. Miniaturized resistors have dimensions 0.5 × 0.5 mm, and thus 1 square, with thickness 1 μm for thin-film and 20 μm for thick-film resistors. Stability of miniaturized resistors were tested by humidity test, thermal shocks, long-term thermal ageing, direct current stress, current pulses and simulation of soldering process using VPS (Vapour Phase Soldering). Resistivity of resistors is measured by four wire method before and after each set of test and relative change of resistivity is plotted in graphs. Influence of every test on each type of resistor is analysed.

1. Introduction

Passive components like resistors, capacitors, coils, thermistors, switches etc. are essential parts of every electronic device. It can be proved by simply look on the surface of PCB (Printed Circuit Board). All these components as well as electronic devices came through big changes in the past decades. The most significant change except rising reliability of the mentioned components is their size. Reducing the size nowadays is more than trend in electronics it is necessity. Reducing the size causes migration from the through-hole packaging to SMT (Surface Mount Technology), wirewound components were substituted by SMT passives very rapidly and more than 80% of passives nowadays are SMT components [1–3]. In general size reduction of the components was focused to reduce the size mainly in axis X and Y at the beginning but in the past years new trend to reduce the size also in axis Z appears hand in hand with screen printed and embedded passive components. We can consider screen printed passive components as embedded if they are printed between layers of multilayer PCB substrate prior laminating process [4–6].

The embedded passives increase circuit density, improve functionality and performance of electronic devices but the most important advantage is minimalizing number of solder joints which can cause a lot of problems related to voids etc. [7,8]. On the other hand the embedded passives can cause problems associated with delamination and cracks. Furthermore the biggest disadvantage of the embedded components is that they cannot be easily replaced like discrete components. It means that only one wrong embedded e.g. resistor can cause malfunction of the entire electronic device [9–11]. The idea of embedded capacitors started at the end of sixties [12] and embedded resistors appears for the first time at the beginning of seventies by applying NiP or NiCr layers [4,10]. Nowadays many companies like Ohmega, Ticer, Sheldahl, and DuPont Electronic Technologies have introduced embedded thin-film resistors and materials. Thin-film resistors is limited in the range of resistivity, sheet resistance of thin-film resistors is usually from 10 Ω/□ to 250 Ω/□ which causes that resistor with resistivity several kΩ and more needs either lot of space on substrate or very precious fabrication process [13].

The PTF (Polymer Thick-Film) resistors in general consist from polymer resistive inks. These inks are compatible with various PCB or LTCC (Low Temperature Co-fire Ceramics) substrates and composed of carbon and/or silver filler blended with polymer resin with the addition diluters and solvents and insulating powder fillers to achieve appropriate rheological properties [14]. The sheet resistance of thick-film resistors has a much wider range in comparison with thin-film resistors but with higher tolerance. The accuracy of the absolute value of resistivity could be improved by laser or any other way of trimming depending on specific application. Our experiments are focused on very precious screen printing process to achieve tolerances less than 5%. Precious screen printing process provides that further trimming is not necessary.

This paper presents influence of various tests on the stability of non-trimmed miniaturized (0.5 × 0.5 mm) thick-film and thin-film resistors during humidity test (85 °C/85%), temperature shocks (125 °C/−55 °C), long-term thermal ageing (125 °C), direct current stress

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(0.1 mA), current pulses (0.15 mA/0.05 mA) and simulation heating during soldering using VPS (Vapour Phase Soldering). Stability of resistors in this paper is evaluated by relative resistance change but except resistivity there are other important properties of resistors e.g. TCE (Thermal Coefficient Expansion), noise coefficient, breakdown voltage etc. which were described in various scientific works [6,11,13,15].

2. Thin- and thick-film materials and fabrication of resistors

The PTF resistors were made by standard screen printing technology. Two types of pastes from Electra Polymers & Chemicals Ltd were used: resistive paste ED7500 with carbon and silver fillers and the sheet resistance 20 Ω/□/25 μm, conductive silver-filled paste ED2000 with the sheet resistance 30 mΩ/□/15 μm [16]. In our previous experiments thick copper foil on PCB substrate caused problems with stability [17] and deformation of printed resistors [18]. For that reason we decided to print resistors on fired LTCC substrate with AgPt conductive tracks. Resistors were printed through stainless steel mesh (mesh 325 with capillary film of thickness 28 μm) on fired LTCC substrate DuPont GreenTape 951 with the conductive tracks based on AgPt post-fireable paste DuPont LF171 (fired resistivity 2.5 mΩ/□). Despite the fact that manufacturer recommend mesh 200 for printing polymer conductive paste stainless steel mesh with the mesh 325 was used to provide precise dimensions and miniaturization of the resistors which do not need trimming. Curing of the printed polymer conductive tracks and resistors was done in convection oven at temperature 150 °C for 30 min, the most suitable curing temperatures of polymer resistors were analysed in our previous work [17]. In Fig. 1 two different approaches of printing process are shown, Fig. 1a shows printing resistor over fired AgPt conductive tracks, Fig. 1b shows printing resistors into the gap between fired AgPt conductive tracks and conductive connection is made afterward by printing the polymer conductive paste over fired AgPt conductive tracks and printed polymer resistor.

The thin-film resistors were created by using Ohmega-Ply® technology based on a thin-film of Nickel-Phosphorous alloy electrodeposited on copper foil and laminated to a dielectric material [19]. For the purposes of these experiments Ohmega-Ply resistive material with sheet resistance 10 Ω/□ was chosen. Thickness of the NiP thin-film alloy is 1 μm which allows to bury planar resistor without increasing the final thickness of the board. Planar resistors are fabricated by multiple print-and-etch process procedures in 8 steps [20]:

- Apply Photoresist to Ohmega-Ply laminate
- Print and Develop Composite Image
- Etch unwanted copper using any conventional etchant (1st etch process)
- Etch unwanted resistive material with Copper Sulfate solution (2nd etch process)
- Strip Photoresist
- Apply Photoresist, print and develop conductor protect image (2nd print)
- Etch away copper over the designed resistor area using a selective Alkaline etchant (3rd etch process)
- Strip Photoresist

Samples with 25 planar resistors and conductive tracks on LTCC/ Ohmega Ply are shown in Fig. 2a. Dimension of the resistors were 0.5 × 0.5 mm, thickness were 0.02 mm for the thick-film and 0.001 mm for the thin-film resistors. As it was mentioned previously the thin- and the thick-film resistors can be used as embedded or non-embedded with combination of PCB. It is very important to take into account that in our experiments all resistors are on the top of substrate without any further covering or shielding.

3. Experiments and results

To minimalize errors caused by wire resistance the 4-wire method was chosen to measure the resistivity of each resistor. Averaging of Milliohmmeter Agilent 4338B was set to 10 to achieve high accuracy of the all measurements. All samples were not measured immediately after loading tests but after acclimatization for 8 h at ambient temperature. Average values of resistors are shown in Fig.3.

3.1. Humidity test

Temperature humidity chamber was used to simulate environment with 85% humidity and temperature 85 °C for a certain amount of time. This humidity test determines the sensitivity and stability of the thin- and the thick-film resistors in the point of long-term loading. Each of 25 resistors was measured before and after each of 6 testing periods (0, 20, 50, 100, 200, 500 and 1000 h) to get precious dependence of long term relative resistance change of the thin- and the thick-film resistors.

Fig. 4 presents dependence of relative resistance change under long term loading by the humidity tests. The relative resistance change of the thick-film polymer resistors raised rapidly in the first 100 h up to 5.7% and at 6.5% in 200 h started to slightly decrease to 5.1% in 1000 h. The approach of screen printing process has no influence on stability of the PTF resistors. The relative resistance change of the thin-film resistors increased very rapidly in the first 20 h up to 19.4% and keeps rising slightly in 1000 h up to 28.5%. It was caused by direct exposure of NiP

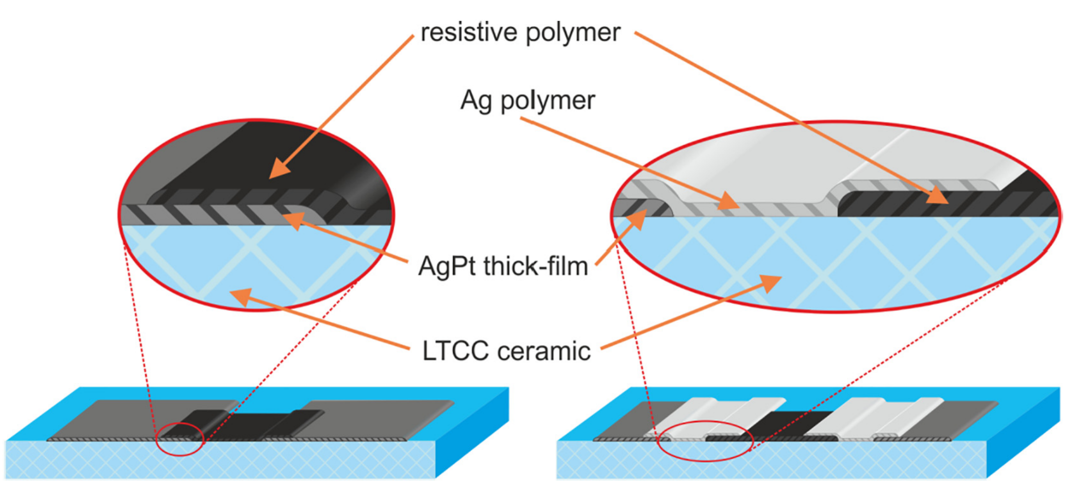

Fig. 1. a, polymer resistor printed directly over fired AgPt conductive tracks b, polymer resistor printed between two conductive tracks connected afterwards by conductive polymer paste.