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Journal of the European Ceramic Society 26 (2006) 1937–1941

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Influence of processing and conduction materials on properties of co-fired resistors in LTCC structures

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Available online 25 October 2005

Abstract

The motivation of this study is the need for fundamental understanding of the effects of processing conditions on the electrical properties of low-temperature co-fired ceramic (LTCC) tapes, those screen printed with commercial thick-film pastes of electronic components for increased reliability. The method of the study is realized by analyzing the physical and chemical effects of mono/multilayer firing and firing temperatures on the temperature coefficient of resistance (TCR) and sheet resistance (SR) values of the positive temperature coefficient (PTC) resistors screen-printed on LTCC tapes. The results are discussed with respect to the information obtained by the scanning electron microscopy (SEM), electro dispersive X-ray analysis (EDXS), X-ray and dilatometry analysis. It is shown that the content of pastes combined with varying processing conditions result in deviation from expected TCR and SR values due to the chemical and/or mechanical reactions.

Keywords: LTCC; Electrical properties; Sintering; Microstructure-final; Electron microscopy

1. Introduction

Integration of low-temperature co-fired ceramic (LTCC) tapes with commercial thick-film pastes of electronic components such as conductors, resistors, etc. has opened new gates to advanced packaging possibilities for versatile applications.[1–5] In spite of a distinction in their functions, these materials have common features in their contents such as functional elements, glass and organics, each with a specific task to accomplish during processing.[6–11] Functional elements are those, which determine physical and electrical properties, whereas glass aids low temperature sintering, densification, dimensional stability, adherence to substrate and determine final resistor properties. Organics, on the other hand, provides a medium for efficient blending of these elements for appropriate rheology and handling. Although these material systems are commercially developed and traded in large amounts with producer specifications, their handling requires extreme attention as the processing conditions directly influence the final properties. This occurs as a result of the variety and extent of physical and chemical interactions occurring between the materials during firing.

Thus, the driving force of this study is to understand the effects of the paste composition and the influence of mono/multi layer lamination of selected tape–conductor–TFR systems fired at different temperatures on temperature coefficient of resistance (TCR) and sheet resistance (SR) values. We aim to analyze and demonstrate the results using characterization techniques such as scanning electron microscopy (SEM), electro dispersive X-ray analysis (EDXS), X-ray and dilatometry.

2. Experimental procedure

In order to study the effect of processing conditions on properties of TFR's using LTCC technology, we selected an LTCC tape[12,13] (Dupont 951-AX)–conductor (Ag:Pd-based Dupont 9473–referred to as Ag from here on- and Au-based Dupont 5744)–positive temperature coefficient (PTC) resistor (ESL 2612 with TCR of 2400 ppm/K and sheet resistance of 100 Ω/□ at 25 °C) system. The selected conductor-resistor combinations were then screen-printed in two different ways: (1) on a single LTCC layer (referred to co-fired), or (2) on a single LTCC layer that is laminated with a second blank tape of same dimension (referred to as buried), according to product specification sheets. This was followed by firing of each screen-printed series at three different peak temperatures: 850, 875 or 900 °C. Firing was

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0955-2219/$ – see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jeurceramsoc.2005.09.030

The layout	Number of resistors	width / length (width =1.5 for all)
	5	1
	1	5
	1	2.5
	1	1.5
	1	0.3

Fig. 1. The layout for test patterns.

carried out in air atmosphere using a heating rate of 5 °C/min, with a 120 min organics removal dwell stage at 440 °C and a 25 min dwell at the peak temperature.

For electrical characterization, resistances were measured at 30, 65, 100 °C between consecutive pads (Fig. 1) by Keithley 2000 mm and Keithley 7000 scanner using four-wire method while a Pt-1000 PTC resistor recorded the temperatures. TCR and standard deviation values measured at 30 and 100 °C were calculated according to the following relation:

$$\mathrm{TCR} = \frac{10^6(R_{100} - R_{30})}{R_{30}(T_{100} - T_{30})} \quad (1)$$

$$\mathrm{S.D.} = \sqrt{\frac{n\sum y^2 - (\sum y)}{n(n-1)}} \quad (2)$$

where R is the resistance at a temperature T, S.D. is the standard deviation, n is the number of values y (sheet resistance or TCR).

TCR and SR values versus processing parameters shown in this paper were selected among resistor dimensions of 1.5:1.5, width to length ratio for a better statistical presentation, as each screen-printed test pattern contains five such nominally identical resistors (Fig. 1).

SEM analysis was carried out on cut and diamond-polished cross-sections of the samples. Images were taken at BSE (backscattered electron) mode for observation of phases and EDXS analysis was made on various selected areas for elemental characterization. The oxygen amount is calculated by stoichiometry after the atomic percentages of the elements are normalized to 100. For X-ray and dilatometric analysis, the organic content of the tape and thick-film pastes was first dissolved in acetone using an ultrasonic bath. The solvent was then evaporated at 250 °C.

3. Results

3.1. TCR and SR

TCR and SR versus processing parameters are presented in Fig. 2a and b. The dashes on the graphs indicate the values specified by the producer and the error bars at the end of the columns stand for the S.D. The results demonstrated that the TCR values fell in a close range to the specified ones for co-fired samples, Ag being slightly closer than Au. However, for Ag, the standard deviation was more than that of Au. The situation for the buried resistors, on the other hand, was much more different. TCR values out of the acceptable range in addition to the increased S.D. and irreproducibility were the characteristics of these samples. In some cases, open circuits were even observed. Similar results

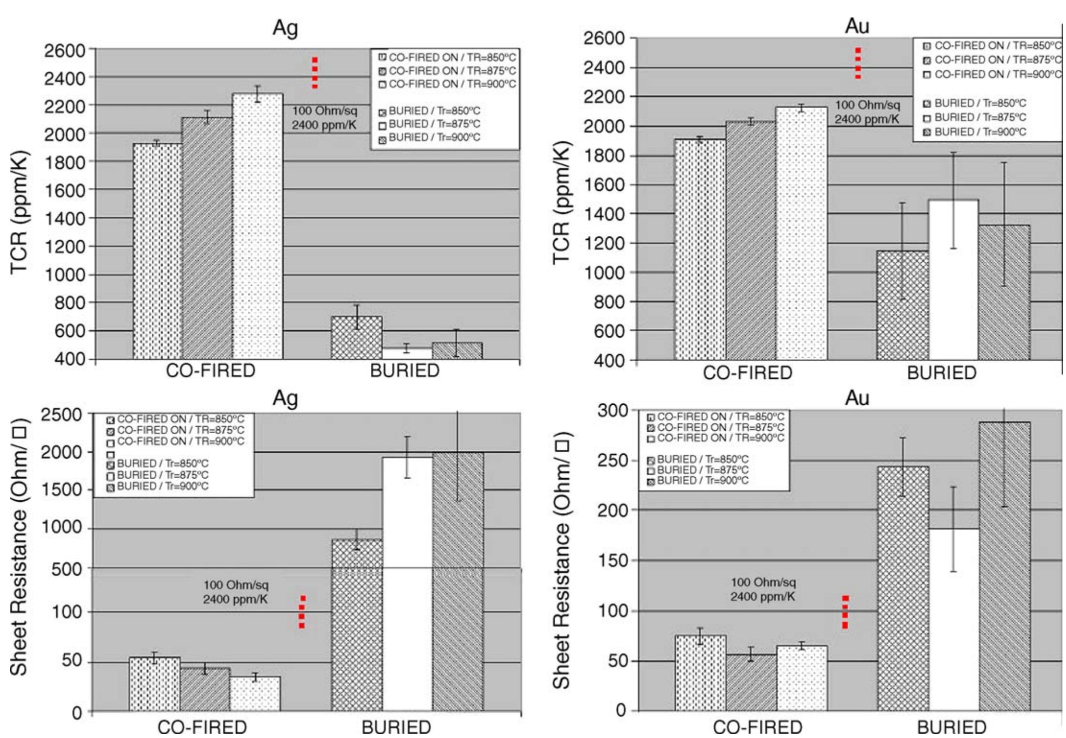

Fig. 2. (a) TCR and SR at different processing conditions for Ag (left column) and Au conductors. For SR, only values of co-fired resistors are presented. (b) TCR and SR at different processing conditions for Ag and Au conductors. Note the dissimilar graphics for SR of Ag and Au.