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Performance of Low-Ohmic Co-Fired Buried Resistors in A6S Tape

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ABSTRACT

Low Temperature Cofired Ceramic (LTCC) offers numerous opportunities for circuit designers. Embedding of passive elements inside a multilayer structure is one of them. However, there are some specific problems not usually encountered with standard thick film resistors, but inherent to development of resistors for LTCC applications. Co-fired buried resistors are completely surrounded by the sintering tape and tend to interact with the tape during firing and refirings resulting in unpredictable shifts in resistivity and TCR. This paper focuses on the behavior of new low-Ohmic co-fired buried resistors developed for Ferro’s A6S tape system and CN33-398 (100%Ag) conductor. Resistive ink formulations were adjusted so low changes of both resistivity and TCR after three re-firings were achieved.

Key Words: LTCC, Buried Resistors, TCR

INTRODUCTION

Low Temperature Cofired Ceramic (LTCC) is among the most advanced approaches to miniaturization of electronics packaging. The integration of passives such as resistors and capacitors with increased functionality is key to the future of LTCC and can be considered a matter of vital importance.

There are a few downsides to embedding passives into LTCC. The tolerances are inferior to those of the same elements placed on regular alumina substrates. Also, buried resistor values commonly cannot be adjusted by laser trimming. Therefore, electrical properties of co-fired buried resistors must be extremely predictable after initial firing and subsequent refirings.

Incorporation of co-fired resistors into LTCC structure is a difficult task due to shrinkage mismatch and complications from chemical reactions occurring during firing and postfiring. Glasses in the resistors tend to interact with the tape glass, resulting in different sheet resistance and temperature coefficient of resistance (TCR).

Co-fired resistors undergo additional firings at 850°C with each post-fire step. Some resistor systems show performance loss after further re-firing, which is unacceptable for LTCC applications. Therefore it is necessary to develop an LTCC resistor system with predictable, controllable, and minimal performance change after additional postfirings.

EXPERIMENTAL PROCEDURE

Resistive compositions were formulated using proprietary glass frits and commercially available RuO₂ powders. Appropriate amounts of selected powders were mixed with organic vehicle and three roll milled.

LTCC structure was fabricated using a stack of 4 layers 10 mil thickness each of Ferro A6S tape, which was laminated in an isostatic laminator at 70°C and 3000 psi.

Termination conductor ink CN33-398 was screen printed and dried at 80°C for 10 minutes. Then resistive inks were screen printed to a dried thickness 24 ± 2 μm. Resistor patterns of 1, 2 and 3 square geometries with 40 mil widths were used for resistor fabrication.

Blank tape of 10 mil thickness was placed on top of the pattern and laminated using isostatic laminator to create a buried resistor structure. The patterns were fired at peak temperature 850°C using standard Ferro profile
for LTCC materials [1] and re-fired in belt furnace using regular 10 min at 850°C profile.

After the first firing and each refiring, the parts were tested in a Wilkins Engineering TCR Test System from -55°C to +125°C with reference point +25°C. Resistance readings were taken each 10°C and saved for further calculations. Cross sections of buried resistors were studied using SEM.

RESULTS AND DISCUSSION

Development of Resistor Compositions

LTCC tape and co-fired resistors sinter within almost the same temperature range. The tape usually contains glassy materials, which soften before the firing temperature is reached. Thus specific features of buried LTCC resistors processing exceedingly aggravate problems inherent to regular resistor technology.

The following difficulties of any resistor development commonly have to be overcome: sensitivity to temperature and time of firing, aspect ratio effect, improper ratio of hot and cold TCRs, insufficient reproducibility, diffusion of termination material to resistor causing resistor performance shift.

Since the tape material interacts during firing with LTCC buried resistor, supplementary problems have to be solved: unpredictable shift in resistor performance, shrinkage mismatch of resistors and LTCC tape, which effects on TCR. Also, unusual effects of common modifiers on TCR may occur [2]. Additional requirement to resistor performance stability after multiple refirings at 850°C creates further problems. LTCC buried resistors must be a stable material and able to undergo several refirings [3].

Termination ink composition also effects resistivity and TCR shift after refiring. Adding an amount of palladium to the conductor composition restricts diffusion of silver into resistor. The requirement to develop resistor for 100% silver conductor (Ferro CN33-398) makes the task more challenging.

A set of proprietary glasses with compatible glass chemistry and appropriate sintering characteristics along with selected modifiers were used for resistor compositions development. Effective methods for keeping resistor performance stable after three refirings were established. The buried resistors are compatible with the tape and no shrinkage mismatch was found after first firing and third refiring (Figs.1, 2).

Common Buried Resistors Performance

The typical behavior of low-Ohmic co-fired buried resistors after being subjected to three refirings is presented on Figs. 3 - 5. Depending on actual resistor composition, resistance shift after a third refiring can dramatically impact resistivity values from -50% to +180%. The difference between TCR values can range (180–300) ppm/°C. The current benchmark of TCR targets the values within the range of ±200 ppm/°C after three refirings.

A correlation between all three types of LTCC resistors (co-fired buried, co-fired surface and post-fired) was obtained for the same resistive ink. Co-fired buried resistors had the most change in resistivity after three refirings (Fig.6).

Little has been published upon resistor refire stability performance to date. The influence of postfirings on resistivity and TCR of co-fired resistors were described in the papers [2,3]. It was also noted in the paper [2] that although the change in TCR with refiring provided acceptable values, the resistor pastes would need to be formulated to arrive with TCR values better than ±100 ppm/°C.

A Need for TCR Controllable Slope

Compliance with ±100 ppm/°C TCR requirement for up to three refirings was set as a goal for the present work. To make it feasible, special attention had to be paid to the ratio between hot and cold TCRs. All resistors were tested in -55°C to +125°C temperature range so continuous TCR curves could be obtained. Usually, cold TCR values are more negative than hot TCR values. For example, values such as +50 ppm/°C for hot TCR and -50 ppm/°C for cold TCR characterize precise resistors for hybrid circuits on alumina.

Our experimental low-Ohmic resistors were tested after initial firing and following three refirings to generate continuous TCR curves over the range of -55°C to +125°C. All four curves had virtually the same low slope. Quite accurate TCR values of less than ±50 ppm/°C were obtained, as well (Fig. 7 and Fig.8).

Dependence of resistivity and TCR on resistor geometry (aspect ratio) was another concern. As can be seen from the charts on Figs.7-10, 1-square and 3-square experimental resistors had very close values for resistivity, relative resistivity change and TCR.
Effect of Refirings on Resistivity and TCR

Resistor performance change after refirings is highest for resistors printed on 100% silver conductors. Experimental resistive inks with resistivity ~30 Ω/□ and ~80 Ω/□ were adjusted so that low resistivity and TCR values changes after three refirings were achieved (Fig. 9 and Fig. 10).

SUMMARY

New experimental low-Ohmic co-fired buried resistor inks were developed for Ferro A6S tape and 100% silver conductor CN33-398. The shrinkage characteristics were matched to that of A6S tape. Resistivity changes after three refirings did not exceed ± 5%. TCR values complied with ± 100 ppm/°C requirement after three refirings. Additional advantage of the developed inks is that dependence of resistivity and TCR on geometry, and TCR curve slopes are controllable.

REFERENCES

Fig. 3  Typical resistivity changes of non-adjusted buried resistors after three refirings

Fig. 4  Typical TCR changes of non-adjusted buried resistors after three refirings

Fig. 5  Typical TCR change of non-adjusted buried resistors after three refirings

Fig. 6  Resistivity change of non-adjusted buried resistors after three refirings
Fig. 7  TCR VS temperature for adjusted buried resistors 40 mil x 40 mil

Fig. 8  TCR VS temperature for adjusted buried resistors 120 mil x 40 mil

Fig. 9  Resistivity changes of adjusted buried resistors after three refirings

Fig. 10  TCR changes of adjusted buried resistors after three refirings