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Printable resistors in LTCC systems

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Abstract

Printable resistors in LTCC technology offer some advantages in comparison with discrete components, such as the increased power handling and reliability. As the size of chip resistors decreases, also the size of printed resistors has to be reduced. For optimizing high-frequency performance the size, i.e. width in particular, has to match the width of the transmission lines. In this study the effects of different resistor dimensions and processing parameters have been analyzed. The experimental work has been made with Du Pont 951 and Ferro A6-S LTCC systems. By optimizing the processing, the resistance tolerances smaller than ±12% were achieved.

Keywords: Firing; Microwave processing; Electrical properties; Glass ceramics; Resistors

1. Introduction

The number of passive components, such as resistors, capacitors and inductors, in rf and microwave modules can be very high. Their efficient utilization requires the tight control of tolerance of the electrical values. Typical tolerance of resistance values are 20–30%. This value could be lowered by using well-controlled printing processes.[1] Currently there are several low-loss LTCC systems available.[2–4] The advantages of printable resistors over their discrete counterparts are, e.g. increased power handling, reliability and miniaturization.

This paper studies some aspects related to the processing of co-fireable resistors in Du Pont 951 and Ferro A6-S systems. Different resistor dimensions were studied and the optimal structures were selected for the realization of an rf module.

2. Design of circuits

The goal of the design was to study the effects of different resistor dimensions. A layout of the resistor pattern is shown in Fig. 1. The resistor widths (W_r) were from 250 to 1000 μm and the length of the resistors (L_r) was from 175 to 1435 μm. The width of the pads was made small in order to reduce the mismatch between the transmission lines and resistors at micro and millimetre applications. The width of the resistors was made small to be compatible with 0402 and 0201 size chip resistors. The overlap of the resistors was 150 μm in each case. The aspect ratio of the resistors (length versus width) was between 0.43 and 8.2.

3. Processing

The resistor test panels consisted of resistors and termination conductors on the surface, and four blank layers below it to make the substrate rigid enough. No embedded resistors were studied in this work. The resistor series was CF for Du Pont and FX87 for Ferro systems. The pastes used are shown in Table 1. Du Pont recommends the use of 325 mesh screens with 10–12 μm emulsion thickness which should result in printed thickness of 20 ± 2 μm. Ferro's recommendation for their own pastes is 325 mesh screen with 15 μm emulsion thickness. This should result in printed thickness of 25–28 μm. However, when the line width is becoming smaller, a more accurate screen is also needed. Therefore, Murakami screens with 400 mesh count and 15 μm emulsion thickness were used in these experiments for printing of resistors. Conductors were printed with Murakami 500 mesh screens.

The printing parameters have to be kept under a tight control. The resistor thickness variation has a direct effect on the tolerance of resistance values. Therefore, the squeegee direction in the printing process was always the same.

The lamination profile was the same for both tape systems. The lamination pressure was 3000 psi, the duration 10 min and the temperature 70 °C. The co-firing was made in Sierra Therm

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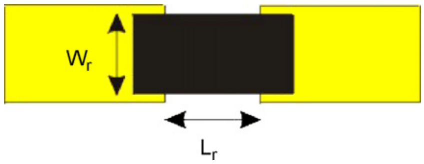

Fig. 1. A layout of the resistor and termination patterns.

Table 1
Tape and paste systems used in the experiments

Tape system	Conductors	Resistors
DP951P2, DP951PT	6942	CF011, CF021, CF031, CF041
A6-S	33-391	87-011, 87-101, 87-102

batch furnace. Du Pont firing profile consisted of burn-out temperature of 400 °C and the peak firing temperature was 872 °C. The duration of burn-out and peak temperature was 60 and 30 min, respectively. The heating rate from room temperature to burn-out was 6.7 °C/min and from burn-out to peak temperature it was 9.0 °C/min. The cooling rate was 10 °C/min. Ferro firing profile, on the other hand, consisted of burn-out temperature of 450 °C and the peak firing temperature was 850 °C. The duration of burn-out and peak temperature was 140 and 10 min, respectively. The heating rate from room temperature to burn-out was 0.7 °C/min and from burn-out to peak temperature it was 6.0 °C/min. The cooling rate was 5 °C/min.

The differences in temperature at different locations can significantly affect the resistance values. Therefore, the quality of the furnace was tested. The peak temperature values at different firing levels were very close to each other. The difference was <±1 °C. However, the difference was much higher in the horizontal level. The variation was as high as ±4 °C within the panel size of 19 cm × 19 cm. Some typical resistor patterns are shown in Fig. 2. The misalignment in the printing process was within ±15 μm.

4. Results

The thickness of resistor is one of the most important factors to affect resistance values and their tolerances. The thickness of fired resistors was measured using two separate equipment: Wentworth capacitive profilemeter at VTT and DEKTAK at University of Oulu. Same resistors were measured in three different locations of the longest resistor. The distance between the measurement locations was about 300 μm. This comparison was made for resistors printed by Du Pont CF041 paste. Wentworth profilemeter resulted in the average thicknesses of 11.4, 11.2 and 11.9 μm. DEKTAK gave thicknesses of 9.0, 9.5 and 9.9 μm. As the results show there can be significant differences depending on the location of the measurements and the equipment used.

Thicknesses were also measured after printing and drying. The measurements were made for CF031 Du Pont paste using Wentworth capacitive profilemeter. Four different resistor patterns from five sheets were totally measured and the results are shown in Table 2. Wider resistors generally resulted in about 3 μm lower thickness than the narrower ones. There were no significant differences between different modules, just in the order of 1–2 μm.

The dc resistance values were measured with a general-purpose resistance meter using a 2-wire method. The measurement wires had a negligible effect on the resistance values. Tables 3 and 4 show the resistance values for Du Pont and Ferro systems, respectively, as a function of resistor width and length. The value in parenthesis shows the ratio between the measured and designed values. The measurement values were quite high for 10 Ω/sq paste meanwhile 100 Ω/sq paste resulted

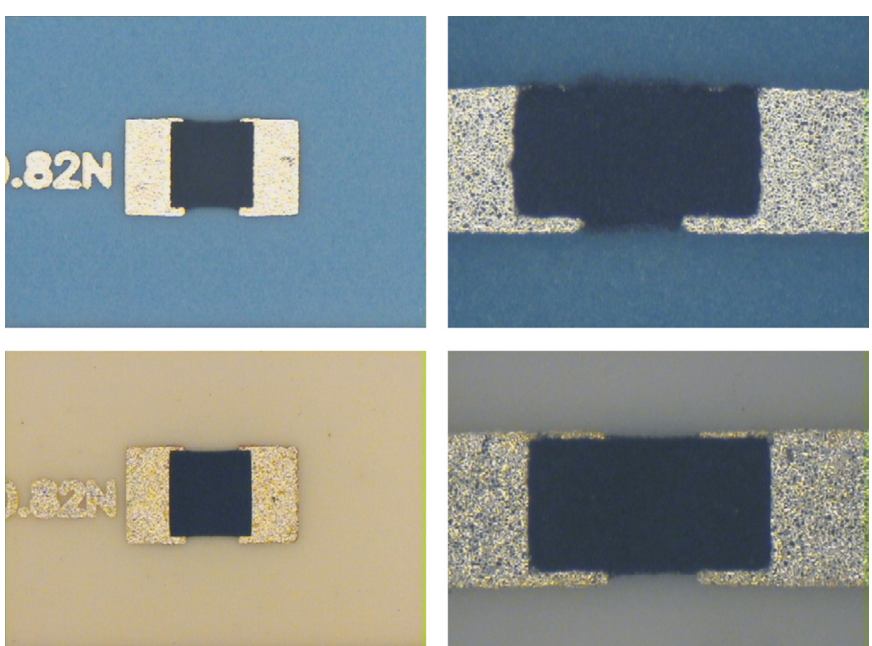

Fig. 2. CF021 Du Pont resistors on top and FX87-021 Ferro resistors on bottom.

Table 2
Thickness values (μm) from printed and dried CF031 resistors

Width (μm)	Length (μm)	Average thickness (μm)	Minimum thickness (μm)	Maximum thickness (μm)
1000	475	10.3	8.7	12.1
900	575	10.4	8.8	11.8
250	350	13.9	12.8	15.1
250	1435	12.9	12.3	13.6

Table 3
Resistance values of some Du Pont resistors as a function of dimensions

Width (μm)	Length (μm)	R (Ω) with 10 Ω/sq paste	R (Ω) with 100 Ω/sq paste	R (Ω) with 1 kΩ/sq paste
250	350	22.7 (1.6)	56.3 (0.4)	909 (0.6)
250	1435	168 (2.9)	343 (0.6)	6645 (1.2)
1000	300	3.50 (1.2)	10.5 (0.4)	138 (0.5)
1000	575	12.1 (2.1)	31.0 (0.5)	509 (0.9)

The ratio between the measured over designed values is shown in parentheses.

Table 4
Resistance values of some Ferro resistors as a function of dimensions

Width (μm)	Length (μm)	R (Ω) with 10 Ω/sq paste	R (Ω) with 100 Ω/sq paste	R (Ω) with 1 kΩ/sq paste
250	350	30.0 (2.1)	253 (1.8)	3,380 (2.4)
250	1435	108 (1.9)	23.3 (1.7)	11,500 (2.0)
1000	300	7.1 (2.4)	55.7 (1.9)	795 (2.6)
1000	575	12.6 (2.2)	111 (1.9)	1,508 (2.6)

The ratio between the measured over designed values is shown in parentheses.

in quite uniform results. The tolerance values for these pastes were <±8%.

In the case of Ferro substrate, the measured resistance values were much higher than the designed ones (Table 4). The tolerance of resistance values was <±3.5% for 10 and 100 Ω/sq resistor pastes but little bit higher (±12%) for 1 kΩ/sq resistor paste.

5. rf demonstrator module

The results from the test circuits were utilized in the realization of an amplifier module designed for the operating frequency of 2 GHz. The module was designed for Du Pont 951 system. There were three different nominal resistance values in the module: 10, 28 and 75 Ω. The layout was designed by assuming that the resistance values would be 70% of their final values. After firing the trimming would have been made by the laser to the accuracy of ±1%. The smallest resistor was printed with 10 Ω/sq paste (CF011) and the others were printed with 100 Ω/sq paste (CF021). The screen was changed to a more economic 325 mesh screen.

In the first trials the resistance values were very low. 10 Ω resistors were 4.8–5.7 and 75 Ω resistors were 21–23 Ω. The resistor structures were also modified by adding a protective glass layer (Du Pont 9615) over the resistors. This had significant effects on the resistance values. In the first trials the glass paste faced the setter plate and after firing the paste had adhered too well to the setter plate. In the next processes the substrate was flipped so that the resistor and glass pastes were facing upwards.

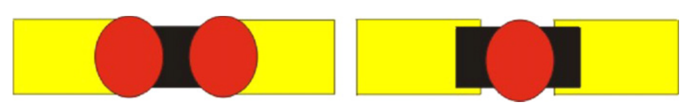

Fig. 3. Methods to spread glass paste over terminations (left) or resistor (right).

The resistance values were 5, 13 and 130 Ω for 10, 28 and 75 Ω nominal resistance values. The values for 10 Ω/sq paste resistors were acceptable although the values were about 50% of the final values. However, the values with 100 Ω/sq were too high.

The next panel was realized to test the effect of glass paste on the resistance value of 100 Ω/sq paste. Fig. 3 shows the geometries tested. When the middle part of the resistor was covered, the resistance was 67–86 Ω. When the terminations were covered and the middle part of the resistor was uncovered, the resistance was 43–54 Ω. Therefore, it was decided to manufacture a new screen to cover the terminations with glass paste. The resistance values for the final substrates were 35–46 Ω for 75 Ω nominal resistors. After laser trimming the values were within ±1%.

6. Conclusions

Several experiments have been made for commercial LTCC co-fired resistors on Du Pont and Ferro systems. The tolerance of the resistance values was small, typically <±8%. However, the absolute resistance values were generally quite far away from the designed ones. Any changes in processing, e.g. the change of the screen, can have significant effects on the resistance values. Also the printing of glass paste has to be under control.

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