The Effect of Miniaturization on Embedded Resistors in High Density Interconnecting Substrates.

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Abstract

This paper reports experiments to determine the maximum power rating of buried resistors and the findings that smaller resistors may operate at higher power densities than larger resistors in the same board.

The trend towards extreme miniaturization in wireless products has an effect on the design and performance of embedded resistors in high-density substrates. Smaller resistors dissipate less heat and have wider tolerances than larger ones. Accordingly, the PCB designer must know what the minimum size is for a given embedded resistor.

Experiments were conducted to determine the effective minimum size of the resistor elements in a high-density substrate. These tests were performed on thin film nickel-phosphorous planar resistors embedded in high Tg epoxy substrates.

The maximum power density was compared to standard design parameters - predicted power densities based on temperature rise and unit area. The findings are that as the resistors become smaller, the maximum power density exceeds the predicted maximum by a greater degree. These findings indicate that, for a given power rating, smaller resistors may be designed than would have been allowed under previous design parameters.

Key Words:

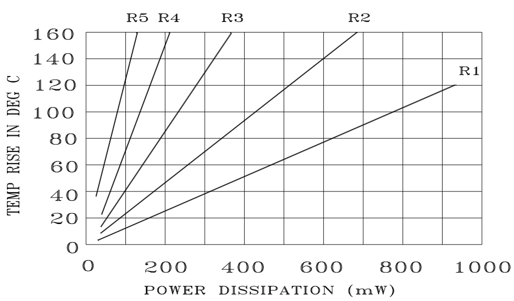
Embedded Planar Resistors, Thin-film Resistive Materials, Power Density, Power Rating,

1. Introduction

Embedded planar resistors are thin-film resistive elements created on existing layers within a high density interconnecting substrate. The ohmic value of a planar resistor is determined by the sheet resistivity of the material and the geometry (length vs width) of the resistive element. The physical size of the resistor is limited by the power rating of the resistor. Power density is limited by the maximum temperature (ambient temperature plus the resistive element temperature rise) that can be tolerated by the insulating dielectric. Although thermal modeling is a complex subject requiring knowledge of material properties and heat transfer coefficients, the design of planar resistors can be simplified by design rules that use a power density constant. Power density is measured in watts per square centimeter and determines the minimum area for a resistive element created on a given substrate. As resistor sizes decrease, the power density increases. The use of BGA packaging and the need to terminate signals within the footprint of the BGA array is driving embedded planar resistor sizes below what is normally allowed by the existing design rules. Determining the true limits of power density and, hence, the smallest possible size of the resistor elements in these substrates, is the object of this research.

2. Methodology

Power rating is the maximum power the resistor can dissipate without becoming unstable, overheated and damaged. Prior experiments have shown that the temperature rise of an embedded resistor increases almost linearly with applied power, with the smaller the resistor, the greater the heat rise.



R1 = 25ohms, 12.5mm x 12.5mm
R2 = 25ohms, 6.2mm x 6.2mm
R3 = 25ohms, 3.1mm x 3.1mm
R4 = 25ohms, 1.5mm x 1.5mm
R5 = 25 ohms, 0.8mm x 0.8mm

The effects of geometry are relatively small but the temperature of the resistor drops significantly in the presence of adjacent power/ground planes[1].

The heat sinking effects are what allow the resistors to operate at higher power levels and the smaller the resistor the greater the effect. However, many HDI designs have logic over logic layers without adjacent power/ground planes. Accordingly, experiments were conducted to determine the effective minimum size of the resistor elements in a HDI substrate. The test methodology used a standard “short term load” step-to-failure test in which the power applied to the resistors was increased until the resistor became unstable or opened.

3. Experimental Work

Tests were performed on Ohmega-Ply® thin-film nickel-phosphorous planar resistors embedded in a high Tg epoxy substrate within the footprint of a BGA package. The sheet resistivity was 25 ohms per square. The Ohmega-Ply® material specification allows a maximum power density rating of 24watts/sq cm (this is based on typical resistor sizes of 0.5mm x 1.0mm buried in a standard multilayer PCB)[2].

Forty sample resistors were selected from the two PCBs, using ten 33ohm (0.4mm x 0.5mm) and ten 47ohm (0.4mm x 0.7mm) resistors from each board to perform the power-rating test. The power rating of a resistor was determined by increasing the (d.c) voltage applied to the resistor every two minutes at an ambient temperature of 25 °C until it became unstable and opened. The resistance values were measured at the end of every two minutes after the resistors had cooled to room temperature. The maximum power rating was de-rated two steps to assure a stable condition. The maximum power density parameter was calculated by dividing the de-rated maximum power rating of the resistor by the area of the resistive element.

The following is one of four charts summarizing the results of these tests:

Power Rating Test Result Chart
Two minute "step-test -to -failure"
Average ten 33ohm resistors - PCB #1

Voltage Applied	Change in Ohms %	Power Rating mw	Power Density watt/cm2
0.2	-0.02	1.3	0.7
0.4	-0.16	5.1	3.0
0.6	0.10	11.4	6.7
0.8	0.55	20.1	11.9
1.0	0.05	31.6	18.7
1.2	0.23	45.4	26.9
1.4	-0.15	62.1	36.6
1.6	-0.14	81.0	48.0
1.8	-0.08	102.5	60.6
2.0	-0.02	126.5	74.9
2.2	-0.03	153.0	90.6
2.4	0.48	181.2	107.4
2.6	0.12	213.4	126.4
2.8	-0.17	248.3	147.0
3.0	-0.73	286.6	169.8
3.2	Open		

The average maximum power rating and power density of the 33 ohm resistors were 211 milliwatts and 125 watts/cm^2 . The 47 ohm resistors had an average maximum power rating and power density of 302 milliwatts and 123 watts/cm^2. At the maximum power ratings, the applied voltages were 2.6 volts and 3.8 volts for the 33 ohm and 47 ohm resistors, respectively.

At the maximum voltages, the resistors were held for 12 hours under continuous load to assure that the power rating was stable. At the conclusion of the test, the change in resistance was less than 1.4 percent indicating a stable condition.

Since the maximum power density is a function of the ambient temperature and the element temperature rise, the effect of raising the ambient temperature was studied. Ten sample resistors, 0.75mm square, on an innerlayer of a standard PCB were tested at 25 °C and 40 °C using the same two minute voltage step test as described above.

The results indicated that the maximum power rating of the resistors was 434 milliwatts at 25 °C and 240 milliwatts at 40 °C. The resistors were held in an oven under continuous load at temperature for 24 hours and the average percent change in resistance was 0.7% indicating a acceptable condition.

4. Conclusion

The maximum power density for the BGA terminating resistors of approximately 125watts/cm far exceeds the Ohmega-Ply® specifications of 24 watts/sqcm. maximum. The interpretation of these findings is that the surrounding co-planar copper traces, pads and buried vias provide a heat sinking effect for the small 0.4mm wide resistors. The reason the 47 ohm resistors have higher power ratings than the 33 ohm resistors is due to their larger area. The power densities are almost identical. Since terminating resistors operate well below the 200 to 300 milliwatts power ratings reported herein, the possibility of much smaller resistor sizes than the 0.4mm wide resistors used in this test is indicated.

References

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2. Bruce Mahler, "Embedded Resistors in HDI Applications." IPC APEX Conference 2000 Long Beach, California.

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About the Author

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