

Precision High Value Chip Resistors

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Abstract

There is an increasing number of applications for resistors of ever-higher ohmic value, especially in miniature sizes. Past practice has relied upon the use of composite materials in which the amount of particulate conductive phase is reduced to achieve higher specific resistivity. As this process progresses the resultant higher values are attained but are accompanied by significant penalties with respect to overall stability, especially voltage sensitivity. This report presents an alternative approach; namely, the use of more stable, lower resistivity film materials deposited in fine line patterns. Chip resistors in the popular 1206 sizes were prepared using sheet resistivity ranging from 10K to 10M ohm per square and line space dimensions as small as 4 and 2 mils respectively to obtain final resistance values in the range from 1M ohm to 10G ohm. Their voltage sensitivity and overall stability were tested and found to be greatly improved over previously reported data. Moreover the improved stability enabled the fabrication of tighter as-produced tolerances than has been previously attained.

Introduction

The value of a resistor is the product of two terms, a material factor and a geometric factor. In two dimensional film systems, it is common practice to regard the film thickness as relatively invariant and to express the material resistivity in terms of ohms per unit area, and the geometric factor as the number of unit areas (squares) in series.

Higher resistance can be achieved in film systems by either using a material of higher sheet resistivity or increasing the number of squares, or both. In thin film technology, resistance is changed by means of the geometry (adjusting the number of squares). In thick film technology, the sheet resistivity is adjusted over a range of several decades by changing the materials composition. There are difficulties with each of these approaches to fabricating high value resistors. In thin film technology the number of squares can be increased by decreasing the line width only up to a point, beyond which proportionately more substrate area is required. In thick film technology, increasing the resistivity of the material through dilution eventually reaches a level where other characteristics are severely degraded: e.g. stability, temperature coefficient, and voltage coefficient, etc. Further more, the high sheet resistivity thick film materials are very difficult to control or reproduce. In either technology, there are trade offs among element size, maximum attainable resistance value, and stability. This report describes a new approach to the fabrication of high value resistors. It explores the resistance levels attainable by employing thick film composite materials deposited in much finer line and space geometries than have previously been used, utilizing a high speed dispensing system in which ink is ejected under pressure through an orifice onto a moving substrate. The vehicle chosen to demonstrate these capabilities was a 1206 size surface mount chip resistor.

The advantage obtained by way of fine line patterning is illustrated in Figure 1, where the maximum number of squares achievable in a serpentine pattern in area 50 x 100 mils in size as a function of the line space width is represented. By conventional techniques, an aspect ratio of only

2 to 1 is achieved; whereas the use of a pattern with line space width of 3.5 mils permits an aspect ratio approaching 300 to 1 can be reached.

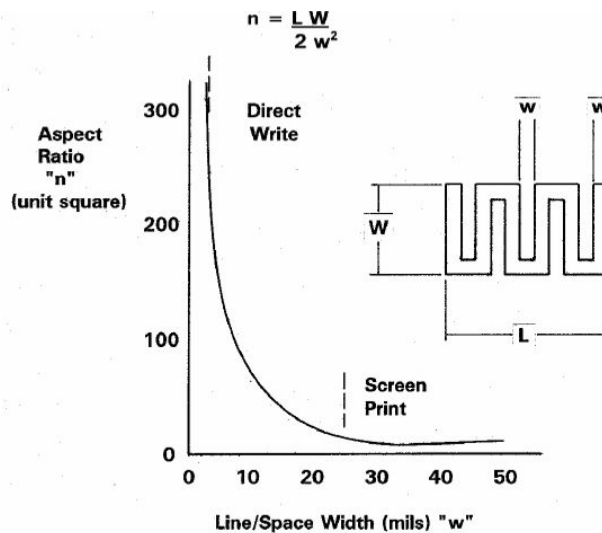


Figure 1
Maximum Aspect Ratio versus Line and Space Width

The availability of high aspect ratios presents a number of options with respect to the fabrication of chip resistors including:

- Increasing the attainable value, for a given sheet resistivity and substrate area.
- Improving the electrical performance through the use of long line length, for a given substrate area and value.
- Reducing the chip size, for a given value and sheet resistivity.
- Combinations of above.

This presentation explores all of the above factors.

High aspect ratios have additional advantages, resulting from the fact that the resistive trace has a much greater length. Because of this, the non-linear effects associated with the resistor- conductor interface are greatly reduced and the internal electric field experienced during circuit operation is also significantly lowered.

Experimental Procedures

Thick film resistor elements were made on 96% alumina ceramic substrates using the following sequence of operations:

1. Print and fire conductive terminations.
2. Print and fire resistors.
3. Print and fire over glaze.
4. Test.
5. Singulation.
6. Apply wraparound termination.

The area between terminations available for the 1206 resistor pattern was 50 mils wide x 116 mils long. The terminations were a conventional Pt/Pd/Au composition. The resistive inks were conventional ruthenium-based inks of different compositions. The over glaze was a low temperature glass formulation. Resistance firing was done in a conventional belt furnace at 850°C peak temperature. To achieve a high square count the resistor inks were deposited in a serpentine patterns using a direct write positive displacement system. Orifices of different sizes were selected to achieve a range in line width for any given ink ranging from 4 to 10 mils. The spaces between lines were typically one half the line widths. The resistance value obtained with a given line/space width and sheet resistivity is given in Figure 2.

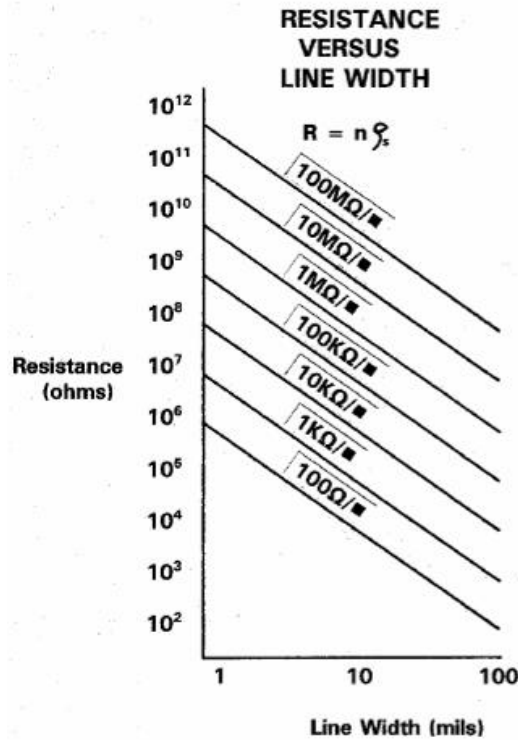
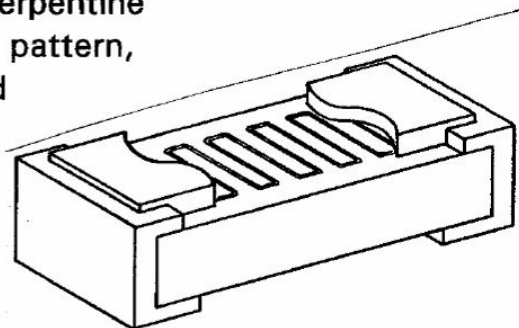


Figure 2
Resistance versus Line Width

The thickness of the deposited lines were not measured in all cases, but was generally of the same order of magnitude, or slightly thinner, than would be the case for screen-printed patterns, about 0.5 mil. The resistors were not trimmed.

The master substrates were made into wrap-around chip resistors by sawing into strips and metalizing the edges with sputtered layers of chrome, nickel and tin. The strips were solder dipped and singulated into chips. A schematic of these chips is shown in Figure 3. Resistive measurements were made using a Quadtech 1864 Megohm Meter. The temperature coefficient of resistance (TCR) was calculated from resistor measurements made at 25°C and 75°C.

Fine line serpentine
resistance pattern,
overglazed



Sputtered Warp around termination:
NiCr layer, Sn layer, solders: (lead free or 62-38)

Figure 3
Finished Chip Resistor – Construction Detail

Results

The resistance and TCR data obtained is shown in Table 1 and 2 for each ink composition and pattern.

(1206 size)					
Line Width (mils)		4	6	8	10
Aspect Ratio (squares)		270	130	73	47
Nominal Ink Resistivity (Ω/\square)	10K	2.8M	1.3M	1.0M	0.6M
	100K	30M	18M	9.4M	6.3M
	250K	68M	36M	19M	15M
	1M	-	160M	122M	75M
	10M	6,000M	2,200M	975M	650M
	100M	40,000M	12,000M	8,000M	6,000M

Table 1
Resistance Value versus
Line Width and Sheet Resistivity

Temperature Coefficient of Resistance (TCR)

The TCR of these samples is given in Table 2, for the temperature range of 25°C to 75°C. As with all inks of this type, the TCR values beyond this range are significantly different. There is no regularity of change of TCR with sheet resistivity since the various inks consist of different constituents. However, all are less than 100ppm/°C, and most are less than 50ppm/°C.

(ppm/°C, 25°C to 75°C)

Line Width (mils)		4	6	8	10
Nominal Ink Resistivity (Ω/□)	10K	+2	+2	-6	-8
	100K	+53	+39	+46	+46
	250K	+15	+11	+11	+13
	1M	-	+70	+67	+65
	10M	+50	+43	+42	+40
	100M	+55	+50	-11	-10

Table 2
Temperature Coefficient of Resistance (TCR) versus
Line Width and Sheet Resistivity

As Fired Resistance Distribution

The distribution of as fired resistance values was found to be approximately normal and surprisingly narrow. A typical histogram is shown in Figure 4. The standard deviation is in the order of 5% for all groups. The result suggests that as-fired tolerances of ±5%, ±10% and ±20% can be obtained in good yield without recourse to any sort of adjustment.

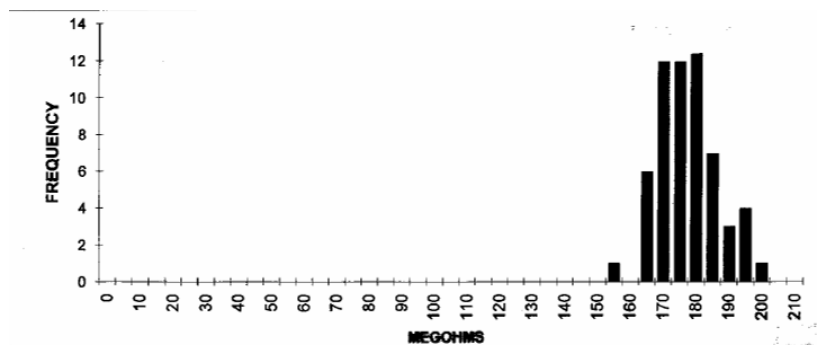
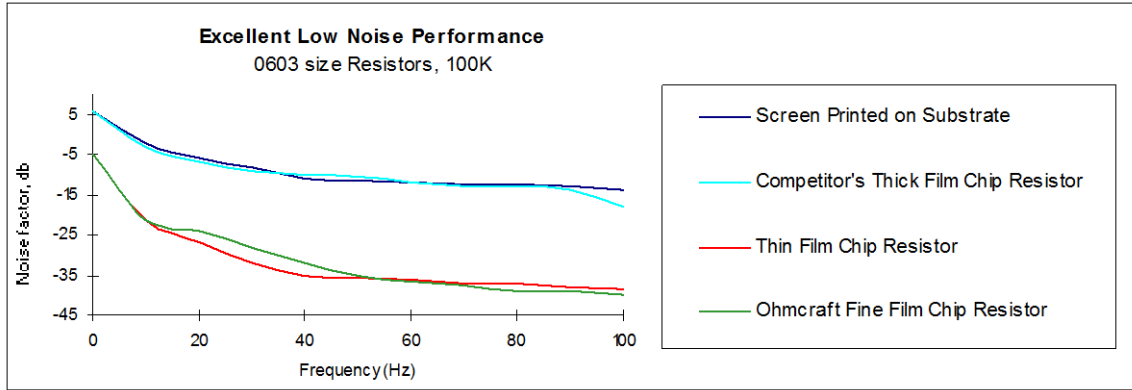


Figure 4
As Fired Resistance Distribution. 1206, 600MΩ

Current Noise

Noise figures for such high values are somewhat ambiguous. Resistance readings were, however, surprisingly stable and free of fluctuation. Typically the readings were steady to better than 4 digits. The measurements are based on average of 100 readings over a brief period, and typically had a standard deviation of the order of 50ppm or less. The data below is from a 0603 100K resistor comparison.



Voltage Coefficient of Resistance (VCR)

The variation of resistance with applied voltage was obtained on most samples. The results obtained were typified by those shown in Figure 5, for a 600M ohm element. The voltage coefficient of resistance (VCR) was computed as the slope of the resistance versus voltage curve at both the 5 volt and 50 volt level. The VCR was surprisingly low (less than -10ppm/volt), considering the resistor's high value and small size. VCR data for other values tested was of similar magnitude to those shown in Figure 5.

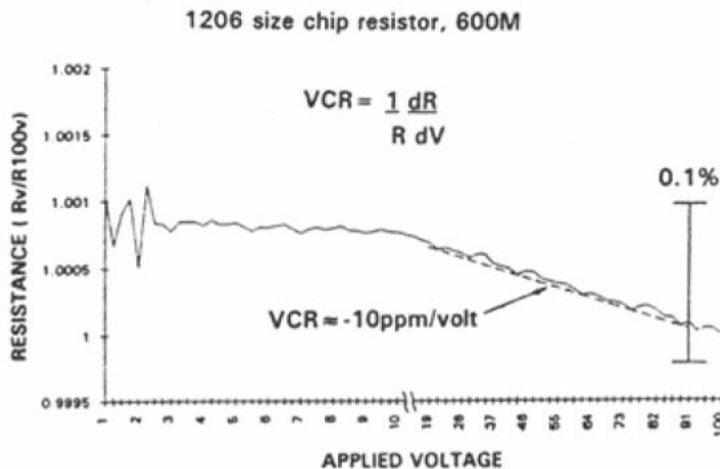


Figure 5
Variation of Resistance with Applied Voltage

Pulse Stability

Since the resistance element in these parts is several hundred mils in length, it should be capable of withstanding fairly high peak voltage. In the worse case, involving the 10 mil wide lines, a conservative assignment of 1 volt/mil to the trace would translate into peak voltage rating for 1206 size chip of at least 500 volts. This has been verified in practice; all chips withstood 1000 volts for 15 minutes without significant change in value.

Operating Life

The chips were subjected to an aging test involving 10 volts at 75°C for 1000 hours. The greatest change observed with any of these chips was less than 0.2%.

Resistance to Solder

The chips were tested before and after soldering to a ceramic circuit board. The maximum resistance change noted was less 0.5%

Conclusion

The problem of fabricating reasonably stable, linear resistors in very high values and small size has been addressed. A novel approach was taken based on combinations of intermediate resistivity thick film compositions deposited in fine line patterns. It was found that resistors in 1206 format with values extending to 40G ohms in value could be routinely produced with good reproducibility, voltage linearity, TCR, and overall stability. In the 2512 format, 200G ohms value of comparable quality was readily fabricated. The wraparound chip construction employed is of proven reliability with respect adhesion, solder least resistance, etc. This approach to the fabrication of high value resistors having enhanced performance characteristics should prove applicable in a variety of other resistor formats.