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STABILITY AND PERFORMANCE CHARACTERIZATION OF THICK FILM MICRORESISTORS

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In recent years, interest in the performance of small dimension resistors has increased primarily due to the need to reduce parasitic resistance in high frequency applications. This paper presents results on the characterization of thick film microresistors, i.e. resistors of 80 × 80 mil to 10 × 10 mil dimension.

The thickness, sheet resistance and temperature coefficient of resistance were dependent on the resistor length, whereas, thermal ageing drift and the thermal cycling drift values did not exhibit any such dependence.

With reasonable precautions and optimization of the manufacturing conditions highly stable and good quality microresistors can be fabricated.

1. INTRODUCTION

The general trend towards hybrid miniaturization, the increasing customer's demand for high density circuits and the need to reduce parasitic resistance in high frequency circuits motivated this investigation on characterization of thick film microresistors. These have reduced dimensions compared with those generally used in hybrids and that are recommended by the ink vendor. It is known that the resistor performance is effected by its dimension.

The purpose of this study was not to introduce any major changes to our thick film manufacturing line, nor to investigate any particular ink source or any new material. The properties of as-fired resistors, terminated on gold, have been measured as a function of resistor length and resistance value. The post-trim drift, temperature coefficient resistance and stability have been considered.

To the author's knowledge this is one of the first investigations on performance of thick film microresistors having dimensions smaller than 40 × 40 mils. Bellardo et.al[1] and Naguib[2] have reported on resistors of larger dimensions, i.e. 50 mils.

2. EXPERIMENTAL METHOD

The inks used in this work were DuPont 1711 (10 ohm/sq) and the DuPont 1600 series (100 ohm/sq to 1 Mohm/sq). All resistors were terminated with gold conductors (4119) and overglazed with 3563. Ceramic substrates of 96% alumina and 2 in. × 2 in. were used.

The test pattern, as illustrated in figure 1, consisted of 20 parts (specimens) having nine resistors each. The resistors were of equal aspect ratio (AR = 1.0) but of different lengths, i.e. from 80 × 80 mils to 10 × 10 mils. The specimens were prepared under the normal thick film production processing conditions; conductors and resistors were printed with a 325 mesh screen to a fired average thickness of 20–25 μm. Prior to the final specimen preparation initial work was done to establish the optimum fabrication parameters. All resistors were laser trimmed and encapsulated before subjecting them to stability tests. The resistors were trimmed to approximately 2.3 times the as-fired value with conventional plunge cuts. Laser trimming conditions were those normally used on our production line.

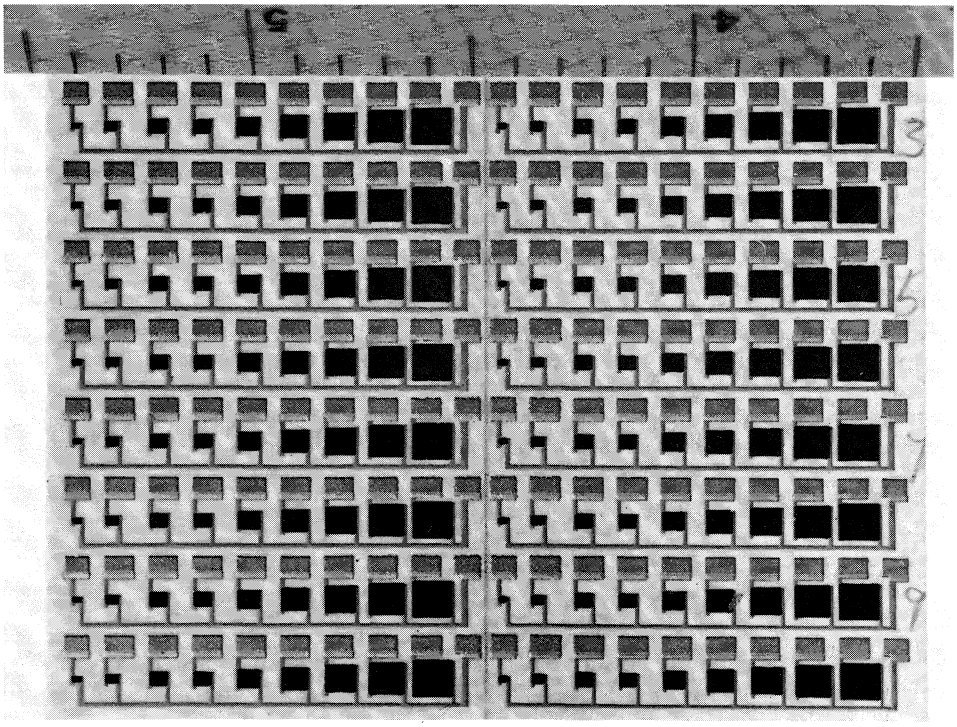

FIGURE 1. Test pattern: (Scale in inches)
R1 — 80 × 80 mils; R2 — 70 × 70 mils; R3 — 60 × 60 mils;
R4 — 50 × 50 mils; R5 — 40 × 40 mils; R6 — 30 × 30 mils;
R7 — 30 × 30 mils; R8 — 20 × 20 mils; R9 — 10 × 10 mils.

3. RESULTS AND DISCUSSION

The post-trim drift at room temperature was negligible (average $(\triangle R/R)\% < 0.1$) over a two month period. The pre-trimmed average resistance values are tabulated in Table I. It is observed that there is a strong dependence of resistance on the resistor length. The sheet resistance is constant down to 50 mils and decreases with further decrease in length (Figure 2). This is due to the larger thickness of the smaller dimension resistors. Analysis of thickness profiles of resistors is illustrated in Figure 3. The results indicate that films of length

TABLE I
Pre-trimmed Average Resistance vs. Resistor Length

length (mil)	Average Resistance (ohm) 1711	1621	1631	1641	1651	1660
80	14.04	155.63	1410	10640	83750	1912000
60	13.60	150.62	1340	10270	81920	1857000
30	12.35	136.46	1180	9110	73350	1524000
20	11.26	116.52	1080	8770	65150	1268000
10	8.61	93.3	790	7010	50420	888000

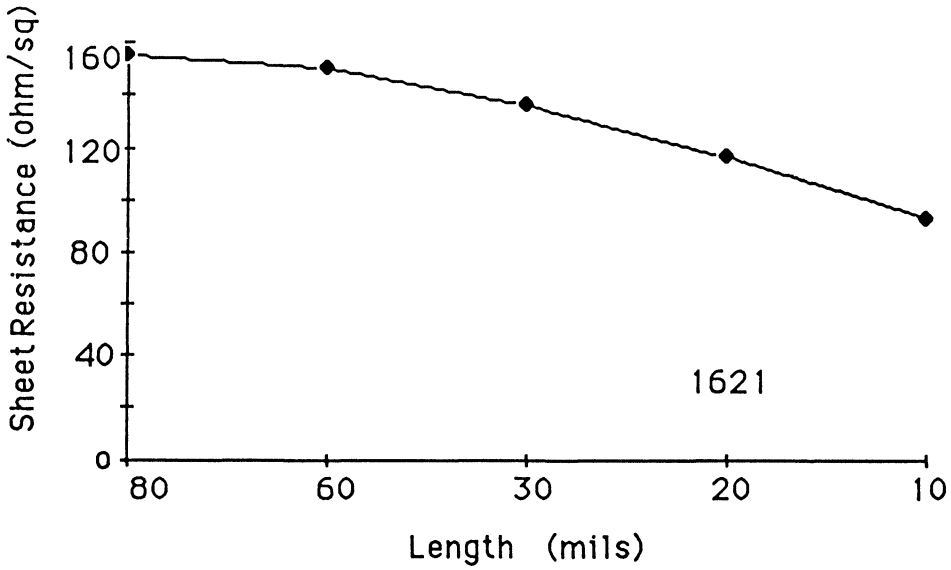

FIGURE 2. Dependence of sheet resistance on resistor length

less than 50 mils are thicker. The thickness is constant down to 50 mils and increases with further decrease in length. This behavior of sheet resistance and thickness is independent of the resistance value of the paste.

4. TEMPERATURE COEFFICIENT OF RESISTANCE

'Hot' and 'Cold' temperature co-efficient of resistance (TCR) were calculated from the measurements taken between +25°C and −55°C respectively. As expected, the TCR

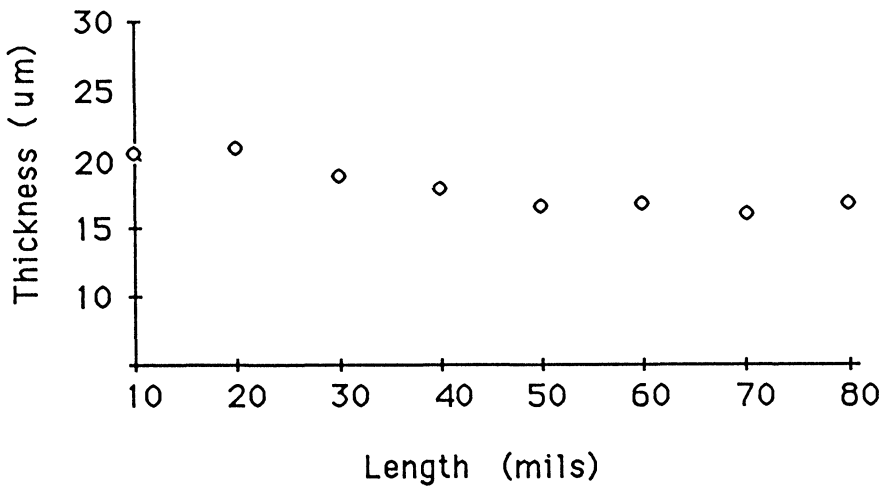

FIGURE 3. Thickness variation with resistor length

TABLE II
Average TCR (ppm/°C)

Res. Length (mils)	1711		1621		1631		1641		1651		1660	
	H	C	H	C	H	C	H	C	H	C	H	C
80	+71.35	+25.74	− 69.93	−170.10	− 50.01	−141.09	−4.59	− 82.85	−29.17	−118.58	−41.98	−125.81
70	+77.65	+30.98	− 68.16	−171.82	− 51.88	−145.61	−4.91	− 83.89	−28.93	−117.65	−43.82	−128.93
60	+80.71	+33.14	− 73.27	−179.06	− 51.58	−146.98	−7.24	− 88.04	−30.12	−120.06	−45.10	−129.86
50	+87.85	+38.28	− 75.69	−181.04	− 53.05	−147.60	−9.11	− 91.41	−31.39	−121.65	−44.68	−128.18
40	+78.81	+29.85	− 80.51	−186.98	− 55.62	−151.01	−1.41	− 96.82	−33.67	−124.81	−45.96	−130.05
30	+74.05	+29.82	− 87.61	−197.38	− 66.41	−167.27	−1.85	−102.89	−37.59	−128.02	−44.88	−128.18
30	+73.32	+30.74	− 86.93	−191.59	− 68.02	−175.34	−1.78	−104.21	−36.93	−136.43	−43.63	−132.16
20	+73.06	+32.93	−103.14	−214.74	− 79.72	−181.07	−3.43	−122.51	−51.60	−147.39	−46.22	−133.28
10	+87.41	+48.07	−144.77	−270.76	−142.42	−260.95	−7.43	−181.07	−88.24	−195.11	−69.15	−157.11

behavior trends for the two series, 1711 and 1600, were quite different. Both the 'Hot' and 'Cold' TCR values are positive for 1711 paste, whereas, it is negative for 1600 series (Table II). This could be due to their different rheological properties and also due to the higher metal content of the 10 ohm/sq paste. However, in both cases the TCR values do not change sign with decrease in length.

All the higher resistivity (100 ohm/sq to 100K ohm/sq) resistors have TCR strongly dependent on resistor length. Our results indicate that the magnitude is constant down to 50 mils and increases with further decrease in resistor length. This behavior is independent of the paste resistance value. Thus, this is a consequence of the observed decrease in sheet resistance with length.

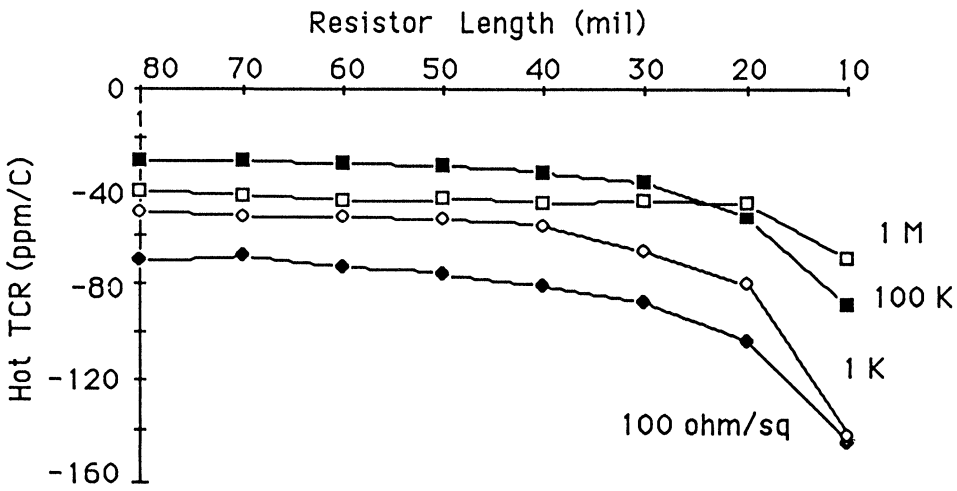

FIGURE 4. Dependence of temperature co-efficient of resistance on resistor length

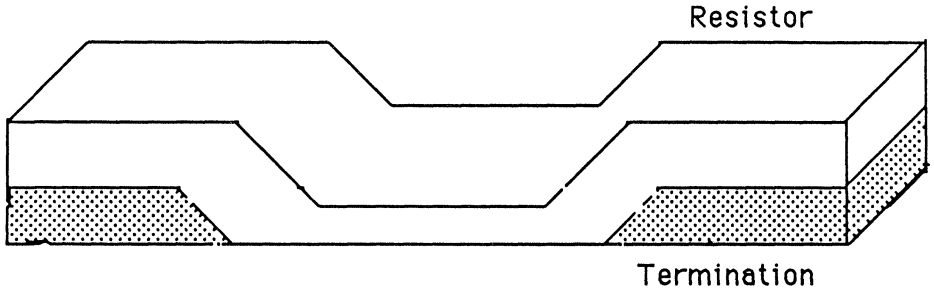

FIGURE 5. Illustration of thick film resistor

A simple formula for the total resistance is (3):

$$R = \varrho s\,(l/w) + \varrho' s\,(2d/w)\,(1 + \varrho' s/\varrho s)^{-1} + Rc \tag{1}$$

where

ϱs and $\varrho' s$ are the sheet resistivities of the thick film resistor and the conductive termination material, l and w are the length and width of the resistor and d is the overlap length of the resistor on the termination (Figure 5).

The first term represents the resistor sheet resistance, the second is that of the parallel combination of resistor and conductor overlap and the third term, RC, is the contact resistance at the resistor-conductor interface. Rc can be expressed as (3):

$$Rc = 2/w \times (\varrho s/G)^{1/2} \tag{2}$$

where

G is the conductance of the resistor-conductor interface.

From Eqns. 1 and 2 the effective sheet resistance is given by

$$R = \varrho s\,(l/w) + \varrho' s\,(2d/w) \times 1/(1 + \varrho' s/\varrho s)) + 2/w \times (\varrho s/G)^{1/2} \tag{3}$$

The second term can be neglected since $\varrho s \gg \varrho' s$. Thus,

$$R = \varrho s\,(l/w) + 2/w \times (\varrho s/G)^{1/2} \tag{4}$$

The resistance is thus a function of geometry and the interface conductance. This explains the decrease in resistance and the subsequent increase in TCR with decrease in resistor length.

It is also observed that the magnitude of TCR is dependent on the resistivity of the paste. As shown in Figure 6, the TCR decreases with increase in paste resistivity, attains a minimum value at 10 Kohm/sq and then increases with further increase in resistivity. This behavior is independent of the resistor length. The first part of the curve can be explained as due to the increase in resistor resistivity and consequently a decrease in TCR. The increase in TCR observed in the latter half of the curve may be due to the large change in resistance ($\triangle R$) with temperature. It is well known that higher resistivity materials undergo a larger change in resistance than low resistivity materials.

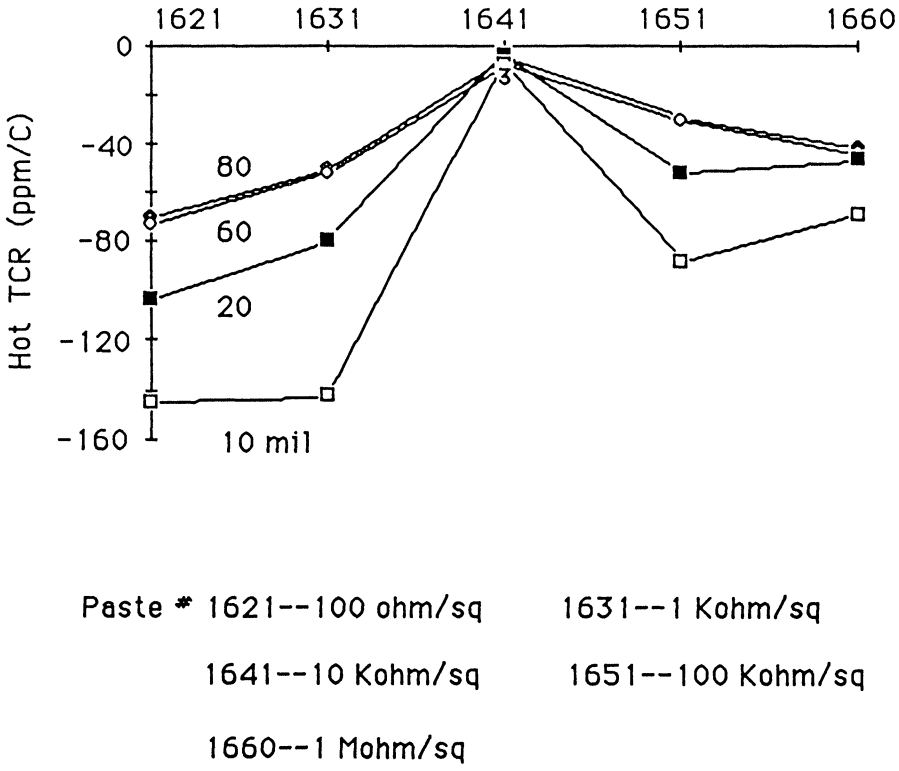

FIGURE 6. Variation of temperature co-efficient of resistance with resistivity of the paste

5. THERMAL AGEING

Thermal ageing of encapsulated, trimmed resistors was carried out at 125°C for 100 hrs with no load applied. The average percentage change in resistance ($\Delta R/R$, %) is tabulated as a function of resistor length in Table III. The results can be summarized as follows:

1. Not all the drifts were positive
2. The 10 ohm/sq paste resistors have a relatively higher drift value
3. There is no dependence on the resistor length nor on the resistivity

TABLE III
Thermal ageing @ 125 C for 100 hrs.

length (mil)	(ΔR/R)% 1711	1621	1631	1641	1651	1660
80	−0.31	+0.02	+0.04	−0.06	+0.42	−0.09
60	−0.33	+0.03	−0.11	−0.09	+0.50	−0.14
30	−0.41	−0.10	−0.04	−0.07	+0.17	−0.17
20	−0.36	−0.07	+0.13	−0.20	+0.12	−0.11
10	−0.39	−0.09	−0.07	+0.12	+0.42	−0.15

TABLE IV
Percentage resistance drift after 20 thermal cycles

length (mil)	1711	1621	1631	1641	1651	1660
			(ΔR/R%)			
80	0.14	0.06	0.04	0.04	0.01	0.05
60	0.08	0.02	0.01	0.02	0.09	0.06
30	0.09	0.02	0.00	0.07	0.05	0.08
20	0.10	0.04	0.01	0.11	0.16	0.06
10	0.16	0.04	0.06	0.14	0.22	0.06

6. THERMAL CYCLING

The thick film resistors were subjected to twenty thermal cycles between −55°C and +125°C, and the percentage resistance drift was measured. As shown in Table IV, the geometry and resistivity of the resistors do not effect the stability. All the resistors exhibit excellent stability: $\Delta R/R < 0.20\%$ after twenty cycles. The drifts were all positive.

7. CONCLUSIONS

The resistor thickness increases with decrease in resistor length below 50 mils. The post-trim drift is negligible (less than 0.1% over a two months period) and is independent of the resistor length and resistivity. The temperature coefficient of resistance is minimum for the 10 Kohm/sq paste (1641). The 'Cold' TCR value is in general larger than the 'Hot' TCR value. TCR is length independent down to 50 mils, increases gradually at 20 mils and sharply for a 10 mil resistor. The thermal ageing drift is less than 0.2% and the thermal cycling drift (20 cycles) is less than 0.20%

The performances of these microresistors having dimensions as small as 10 × 10 mils are acceptable and have qualified the MIL-STD-202 specifications. However, good control during manufacture is necessary. All the above data presented in this paper has been averaged over 500 thick film resistors for each test.

ACKNOWLEDGEMENT

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