Electrocomponent Science and Technology
1975, Vol. 2, pp. 61–66

STATE OF THE ART OF THIN FILM COMPONENTS†

H. HEYWANG and A. SCHAUER

Siemens AG, Unternehmensbereich Bauelemente, München, Germany

(Received July 11, 1974; in final form August 18, 1974)

The main reasons for the development of thin film technology are miniaturisation, reliability and high frequency applications. A comparison with conventional components, and with the demands of system engineers shows that the thin film resistor problem is solved and that there are thin film capacitors for many applications, whereas coils of only small values and low Q can be made. As the distances between thin film circuit elements can be extremely small, low conductor resistance between components is possible. The inherent advantages of thin film technology are good reliability because of fewer connections, the possibility of functional trimming, small TCR and TCC variation in a circuit, and TCR-TCC balancing. Furthermore parasitic effects can be well controlled, distributed elements realized and large scale integration carried out.

1 INTRODUCTION

In modern electronics the use of thin film circuits is increasing. It is worthwhile therefore to consider briefly the state of the art of thin film components. We will try to answer these questions: Has the research and development of thin film technology been successful? Are we able to fulfill the wishes of system engineers? Let us begin by noting the reasons which led to the development of thin film circuits.

1) After the war we were successful for some twenty years in the miniaturisation of discrete components. In many cases the volume was reduced by a factor of 2 every 5 years. In the sixties it became obvious that it was impossible to continue in this way. It was not so much a problem of physics as a problem of our fingers and our machinery. We produced thousands or even millions of Ω or pF in an astonishingly small volume, but we needed nearly the same size for components with a few Ω or pF, because a very great deal of the volume was needed for contacts, leads and encapsulation.

2) The reliability of discrete components was originally adequate, but the requirements of our customers became more stringent, and the increasing number of components per device demanded a corresponding improvement in their reliability. In many cases even higher reliability was necessary because electronic devices had to control processes where failure would cause considerable economic damage.

3) Soldered joints were found to be an important source of failure. The number of connections rose with the number of components per device, and reliability decreased correspondingly.

4) Discrete components change their function with increasing frequencies: capacitors act as coils, coils as capacitors and resistors as coils or capacitors. Leads often have inductances higher than those of capacitors or resistors themselves.

5) In the range of microwaves, discrete components fail entirely because the dimensions of components and wires are greater than the wave length.

6) Conventional circuits suffer from parasitic effects especially in the field of high frequencies. The troublesome task of reducing such effects by the bending and shaping of lead wires is well-known to system engineers.

2 COMPARISON OF THIN FILM COMPONENTS WITH CONVENTIONAL COMPONENTS

Now let us see to what extent thin film circuits have solved these problems. It is possible to compare the properties of all thin film elements with those of all conventional components, therefore we must restrict ourselves to the most frequently used thin film techniques employing Ta and NiCr–SiO, and compare them with the most important discrete

†This paper was presented at the Thin Film Technology Symposium held at the University of Stuttgart, Germany, March 18-19, 1974, organized by the Institut für Netzwerk–und Systemtheorie.

		Discrete Resistors Carbon Film	Discrete Resistors Metal Film	Thin Film Resistors
range of resistance	Ω	1 . . . 10^9	10 . . . 10^6	1 . . . 10^6
tolerance	%	1 . . . 20	0.1 . . . 10	0.1 . . . 10
functional trimming		no	no	yes, to 0.1%
stability (2000 h, 125 °C	%	0.5 . . . 5	0.2 . . . 0.5	0.1
TCR	10^{-6}/K	– 200 (< 10^5Ω) – 800 (10^7 Ω) – 2000 (10^9 Ω)	about 0	about 0 – 60 (Ta_2N) – 200 (Ta_2O_2N)
TCR-variation in a circuit	10^{-6}/K	± 50	± 30	± 10
smallest area	mm^2	6	20	1
inductivity	nH	5 . . . 20	5 . . . 20	1 . . . 10
noise	µV/V	1 to 10	< 0.1	< 0.1

FIGURE 1 Resistors.

components. We will consider only typical values, as special units are often considerably better than those commonly used.

1) Let us begin with resistors (Figure 1). Thin film techniques make possible resistors of 1Ω or smaller up to about 10^6 Ω; higher values require too great an area. Low values up to about 1000 Ω can be realized on an extremely small area of about 1 mm^2, whereas conventional resistors need 6 mm^2 minimum. Tolerances can be as close as with discrete metal film resistors. The possibility of functional adjustment is a special advantage of thin film circuits, and stability is very good. The TCR-problem is well solved with values near zero, or with values needed for the compensation of the temperature coefficient of capacitors. The TCR-values of resistors on the same substrate coincide very well, within a range of 5 to

		Polystyrene Capacitors	Ceramic Capacitors High Q	Ceramic Capacitors High K	Thin Film Capacitors Ta_2O_5	Thin Film Capacitors SiO/SiO_2
range of capacitance		2 pF...0.5µF	2 pF...30 nF	100 pF...4µF	60 pF...60 nF	10 pF....3 nF
tolerance	%	± 2	± 5	± 20	± 3	± 5
functional trimming		no	no	no	not yet	yes,to0.5%
stability	%	± 0.5	± 0.1	± 10	0 to – 0.4	± 0.3
TCC	10^{-6}/K	– 150	0	indefinite	+ 200	+200 | +30
TCC-variation in a circuit	10^{-6}/K	± 50	± 30	"	± 10	± 10
insul. resistance	MΩ	> 10^5	> 10^6	> 10^4	> 10^4	> 10^2

FIGURE 2 Capacitors.

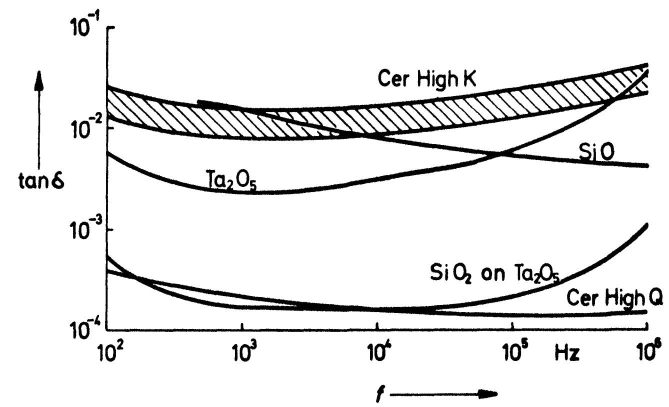

FIGURE 3 Dissipation factor as a function of frequency.

10.10^{-6}/K. The inductance of thin film resistors depends on their geometry; values as low as 1 nH are possible, a great advantage especially in the field of high frequencies. Noise is extremely low. In summary, it can be said that the resistor problem is solved.

2) Now let us compare thin film capacitors on the base of Ta_2O_5, silicon monoxide or silicon dioxide with discrete polystyrene and ceramic capacitors. (Figure 2). The range of thin film capacitors from 10 pF to 60 nF fulfills many demands. Higher values need too large an area. Tolerances, stability and insulation resistance are sufficient. The TCC is determined by the properties of the film material and is therefore very consistent, especially for capacitors on the same substrate, an advantage which is not possible with discrete components.

Figure 3 shows the dissipation factor as a function of frequency. Thin film capacitors are not as good as high Q ceramic capacitors or polystyrene capacitors with a dissipation factor of about 10^{-4}, but are generally better than high K ceramic capacitors.

Now let us compare the area required by different capacitors (Figure 4). Thin film capacitors, for values

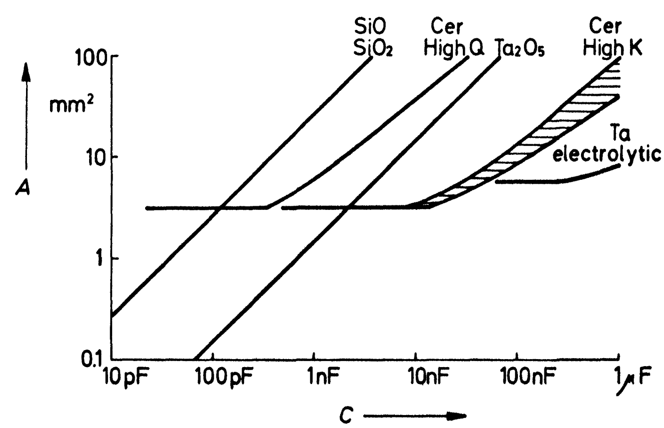

FIGURE 4 Area needed for capacitors.

	Conventional Discrete coils	Chip-Coils	Thin Film Coils
range of inductivity	10 nH . . . 10 H	50 nH . . . 100 mH	1 nH . . . 1 μH
tolerance %	± 3	± 10	± 1
TCL 10^{-6}/K	all needed values available	+ 200	< 5
tunable	yes	typically not	no
quality	50 . . . 1000	20 . . . 80	10 . . . 50
strayfield	small	small	large

FIGURE 5 Coils.

up to 1 nF, require areas no larger than 1 mm^2, and capacitors with an area as small as 0.1 mm^2 can be made. For values higher than 10 nF, multilayer high K capacitors and Ta electrolytic capacitors are smaller, but these can be used only if low tolerances and little stability are acceptable. With conventional electronic techniques, high value plastic film and electrolytic capacitors with values up to 150,000 μF, are used. This range cannot be covered by thin film capacitors at present, or in the near future.

To summarize: There are good thin film capacitors for many purposes, but an enlargement of the range of capacitance particularly to higher values would be useful, and lower dissipation factors would be welcome.

3) Thin film coils (Figure 5) reach only to about 1 μH, which is a very small value compared with discrete coils up to Henries. The stray field of thin film coils is large, and Q is low. Here thin film components are clearly at a disadvantage.

	Wire Circuits Cu 0.6 mm ∅		Printed Circuits Cu 0.035.1 mm^2		Thin Film Circuits Au 1μm · 0.5 mm		Thin Film Circuits solder 30μm · 0.5 mm	
resistance per mm length mΩ	0.05		0.5		120		10	
length between two elements mm	typ 50	min. 10	typ 30	min. 10	typ 6	min. 0.2	typ 6	min. 0.2
resistance between two elements mΩ	2.5	0.5	15	5	720	20	60	2
influence of conductors on TCR of 1Ω resistors 10^{-6}/K	+ 10	+ 2	+ 60	+ 20	+1600	+100	+ 240	+ 8.6
conductor inductivity between two elements nH	50	10	27	7	5	0.02	5	0.02

FIGURE 6 Conductors.

4) It is obvious (Figure 6) that the resistance of a wire or a copper sheet in a printed circuit is far smaller than the resistance of a thin film conductor. However, it is not the resistance per mm length but the resistance between two components, which is significant. In thin film circuits, the distance can be made extremely short–for example 0.2 mm. In this case a gold conductor of 1 μm thickness and 0.5 mm width has a resistance of only 20 mΩ, reducing to 2 mΩ with a solder layer of 30 μm thickness. However, with a resistor of 1 Ω and a distance to the next component of 6 mm, the gold conductor will give an additional resistance of 720 mΩ and an increase in the TCR of $1600 \cdot 10^{-6}$/K due to the TCR of gold. Such effects decrease with increasing resistance in the circuit. The inductance of a capacitor between two components becomes extremely small in thin film circuitry because of the close proximity of components.

5) Further aspects of integration are shown in Figure 7. We have already mentioned that soldered joints are an important reason for failures. Discrete components generally need 4 connections, two outer ones to connect them with other elements, and two interior ones between the component itself and the wires. The reduction in the number of joints depends upon the number of elements and outer connections. Typically, only 1 connection per film component is needed, which makes thin film circuits generally more reliable.

The capacitance of a crossover in printed circuits – one conductor on each side – will amount to 0.04 pF (conductors of 1 mm width and 1 mm distance, permittivity of the insulator $\epsilon = 4$).

Astonishingly the capacity of an air gap crossover proposed by Bell Laboratories for thin film circuits is even smaller: 0.006 pF (conductors of 125 μm width and 25 μm distance, permittivity of the air gap $\epsilon = 1$).

Finally let us note some advantages of thin film circuits as a whole. For functional trimming, conventional circuits need potentiometers or trimmers – relatively expensive components. These costs can be saved in thin film circuits by functional adjustment of resistors or capacitors. As thin film components and conductors have a very definite geometry, parasitic effects are exactly reproduceable. Large scale integration is not possible with conventional circuits, but possible with thin film circuits, as very fine and complex patterns can be produced by using thin film techniques.

Finally, an important feature of thin film technology is the possibility of realizing components with distributed functions, for example with distributed R and C.

3 CONCLUSIONS

Looking back on the reasons for the development of thin film techniques, discussed in the intro-

	Wire Circuits	Printed Circuits	Thin Film Circuits
number of connections for n components	~ 4·n	~ 4·n	~ 1·n
crossover capacitance pF	extremely low	0.04	0.006
functional trimming	potentiometer needed		possible
parasitic effects	not exactly reproducible		exactly reproducible
hybrid large scale integration	impossible		possible
distributed elements	impossible		possible

FIGURE 7 Aspects of integration.

duction of this paper, we can say: with regard to (1). The miniaturisation of discrete components which slowed down in the sixties, could be continued by using thin film techniques.

With regard to (2) and (3). The reliability of thin film components themselves is at least as good as the reliability of discrete components, and the danger of failures in connections and conductors can be reduced substantially

With regard to (4). The critical frequencies, where discrete components change their functions, could be shifted to far higher frequencies by miniaturization of the components and shortening of the conductors.

With regard to (5). The field of microwaves is open for thin films, especially with the strip line technique.

With regard to (6). Because the parasitic effects are exactly reproduceable they can be compensated in most cases.

In this paper we have compared thin film components with conventional components but we did not consider thick film techniques. We are aware of the importance of thick film circuits and that in many practical cases they can be as effective as thin film circuits. A comparison between the two techniques should be the object of a separate paper. On the whole, we think that thin film capabilities are superior, for instance on the grounds of precision, fine pattern generation, low noise and TCR-TCC balancing.

After this very short summary of the state of the art, system engineers are asked to avoid the weak points and use the advantages of thin film techniques.

ACKNOWLEDGEMENTS

We would like to thank Prof. Dr. Lueder, who provided the stimulus for the writing of this paper. We are grateful to Dr. Hanke, Mr. Kausche and Dr. Wohak for compiling the data and preparing the figures.