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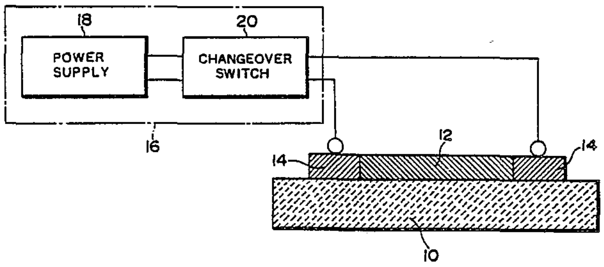
(54) **Method of producing thick film resistor element of accurate resistance.**

(57) In producing a thick film resistor element (12) having a predetermined resistance by the steps of applying a conducting paste to a substrate (10) to form a desirably patterned paste layer and then firing the substrate (10) to sinter the metal powder contained in the applied paste, the paste-applying and firing steps are performed such that the sintered thick film (12) has a provisional resistance lower than, e.g. 70–85% of, the predetermined resistance, and an alternating voltage which is higher than a maximum voltage to be applied to the thick film resistor element (12) in its practical use is applied to the sintered thick film (12) so as to increase its resistance up to the predetermined resistance. By this method the percentage of acceptable products in mass production can be greatly increased.



EP 0 051 826 A2

ACTORUM AG

METHOD OF PRODUCING THICK FILM RESISTOR ELEMENT OF ACCURATE RESISTANCE

BACKGROUND OF THE INVENTION

This invention relates to a method of producing a thick film that serves as a resistive element on an insulating substrate by applying a paste containing a powder of a resistor material onto the surface of the substrate to form a paste layer and then firing the substrate to sinter the resistor material contained in the applied paste, and more particularly to a technique to enhance accuracy of the resistance of the sintered thick film produced by this method.

Thick film resistor elements of the above mentioned type are formed largely as basic elements of hydrid integrated circuits, but also they are utilized in some other electric or electronic devices other than integrated circuits. As a specific example, an oxygen sensor element of the solid electrolyte concentration cell type recently used in automobiles includes a thick film resistor as a heat-generating means for maintaining the sensor element at a desirably elevated temperature.

In the present application the term "thick film" is used in the sense of a film thicker than about 1 μm, as is customary in the current electronic technology.

There is no strict upper limit to the thickness of the film. The thickness may reach tens of microns.

A thick film to serve as a resistive element is usually formed by a printing-and-firing method using a paste containing a powder of an electronically conducting resistor material such as a noble metal powder. The first step of this method is to print the paste adjusted to a suitable viscosity onto a major surface of an insulating substrate. Usually a screen-printing method is employed to form a desirably patterned paste layer. After drying of the printed paste layer to evaporate the liquid component of the paste, the substrate is fired so as to achieve sintering of the resistor material contained in the paste layer. The sintered powder of the resistor material constitutes a thick film which may be microscopically porous but adheres firmly to the surface of the substrate.

To obtain a thick film of this category with a resistance value accurately as intended, it is important to strictly control the thickness of the paste layer formed by the screen-printing process. That is, the resistance of the sintered thick film depends greatly on the thickness of the printed paste layer. Therefore, not only the viscosity of the paste but also the pressure exerted on the squeegee of the screen-printing apparatus and the speed of the movement of the squeegee relative to the screen are minutely adjusted so as to form a paste layer of an appropriate thickness. The thickness control at this stage can be accomplished fairly accurately, but in the case of mass production some dispersion of the thickness values is inevitable. Furthermore, the resistance of the sintered thick film is affected considerably by the firing conditions represented by the firing temperature and the duration of firing, and also by the physical state of the printed and dried layer subject to firing. For these reasons, dispersion of the resistance values of the mass-produced thick film resistor elements is considerably large and sometimes reaches about ±20% of the intended value even though the printing process is performed with due control of the thickness. On the other hand, the tolerance of the resistance is rarely larger than ±5%.

With a view to incresing the number of acceptable products in mass production of thick film resistor elements by the printing-and-firing method, it has been put into practice to determine optimum firing conditions for each lot by extracting a small number of samples out of the unfired intermediates given by the printing process, firing these samples under standard firing conditions and measuring the resistance of the sintered thick film of every sample. However, even when the firing conditions are adjusted through such a procedure, the resistance values of the sintered thick film exhibit a dispersion of about ±10% in most cases.

Therefore, a considerably large number of the mass-produced sintered thick film must be picked out as rejects, and the loss of such a large number of products naturally leads to an unwantedly high selling price. Nevertheless, it is rather impractical to enlarge the tolerance of the resistance because it will result in lowering of the precision of the devices in which the thick film resistor elements are used or will raise the need of modifying the circuit design of such devices.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved method of producing a thick film resistor element, which method fundamentally belongs to the above described printing-and-firing method but, nevertheless, gives a thick film of which resistance is very close to an intended resistance and, when applied to mass production, can greatly increase the percentage of acceptable products.

A method according to the invention for the production of a thick film resistor element having a predetermined resistance on an insulating substrate has the steps of applying a paste containing a powder of an electronically conducting resistor material dispersed in a liquid vehicle onto a major surface of the substrate to form a paste layer, drying the paste layer and then firing the substrate to achieve sintering of the resistor material contained in the paste layer, and the improvement according to the invention resides in that the above three steps are performed such that a thick film as the product of the firing step has a provisional resistance lower than the predetermined resistance, and that the method further comprises the step of applying an alternating voltage to the sintered thick film so as to increase the resistance of the thick film up to the predetermined resistance. In this step, the magnitude of the alternating voltage is required to be higher than a maximum voltage to be applied to the thick film resistor element in its practical use.

The magnitude of the alternating voltage and the duration of aplication of the alternating voltage would be selectively determined according to the difference between the predetermined resistance and the provisional resistance.

The application of an alternating voltage to the sintered thick film causes displacement of microscopical voids among the fine crystal grains of the sintered resistor material as the effect of a phenomenon called electromigration and results in partial breaking of the contacts between the crystal grains. Therefore, the effect of this treatment can be regarded as a decrease in the effective cross-sectional area of the sintered thick film, and a resultant increase in the resistance. As will be understood, the resistance of the sintered thick film under this treatment increases as the duration of the treatment is prolonged and as the magnitude of the alternating voltage is raised.

The improvement according to the invention can readily be put into industrial practice without the need of modifying the apparatus and fundamental procedures of the conventional printing-and-firing method and has the effect of enhancing the accuracy of the resistance of the produced thick film resistor elements and greatly increasing the percentage of acceptable products. Therefore, this invention will bring about a considerable reduction of the total production cost and will enable to lower the selling price. Furthermore, this invention is expected to allow automation of the production of thick film resistor elements by a printing-and-firing method.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows diagrammatically the manner of application of an alternating voltage to a thick film resistor element, which is shown in a sectional view, in an example of the method according to the invention;

Fig. 2 is a chart showing an exemplary waveform of an alternating voltage used in a method of the invention;

Fig. 3 is a graph showing the degree of increase in the resistance of a thick film resistor element to which an alternating voltage of the characteristic as shown in Fig. 2 was applied for a variable duration in an example of the method of the invention; and

Fig. 4 is a graph similar to Fig. 3 but shows an experimental result in another example of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In a method according to the invention, the application of a conducting paste onto a substrate and sintering of the printed and dried paste layer are accomplished by using known techniques. That is, the application of the paste is usually accomplished by a screen-printing method, and the sintering is effected in either air or a non-oxidizing gas atmosphere at a temperature in the range from about 800°C to about 1500°C depending on the kind of the resistor material.

To obtain a sintered thick film having a provisional resistance R_a lower than a truly desired resistance

R_s of the finished thick film, it is necessary to suitably adjust the composition of the paste, viscosity of the paste, thickness of the paste layer given by the printing process and/or the firing conditions. In practice, it will be most suitable to realize the provisional resistance R_a primarily by adjusting the thickness of the paste layer because often it is difficult to significantly alter the paste composition and/or the firing conditions without unfavorably affecting the properties of the sintered thick film other than the resistance.

The proportion of the provisional resistance R_a to the truly desired resistance R_s can be selected in a pretty wide range. However, in most cases it is undesirable to make the provisional resistance R_a below 50% of the desired resistance R_s because the application of an alternating voltage high in magnitude and long in duration enough to increase such a low resistance R_a up to the level of R_s tends to cause weakening of the mechanical strength of the sintered thick film or the adhesion strength between the thick film and the substrate. In theory, there arises little problem even if the provisional resistance R_a is very close to the desired resistance R_s, but from a practical point of view an extremely small difference between these two resistance values R_s and R_a, for example R_a being 99% of R_s, will be meaningless. Accordingly the upper limit of R_a in the practical sense will be about 90% of R_s.

In the case of industrial production of thick film resistor elements, a primary factor in determining the proportion of the provisional resistance R_a to the desired resistance R_s is the width of dispersion of the provisional resistance values R_a of the actually obtained sintered thick films in comparison with the tolerance of the resistance R_s of the final products.

For example, assume that the tolerance of the desired resistance R_s is ±2% (that is, resistance values in the range from $0.98R_s$ to $1.02R_s$ are acceptable) and that actual values of the provisional resistance R_a exhibit a dispersion of ±20%. In this case, if the provisional resistance R_a (as an aimed value or average value) is set at 90% of R_s, the actual values of R_a will disperse in the range from $0.72R_s$ to $1.08R_s$ so that a portion of the sintered thick film become above $1.02R_s$ (upper control limit) in resistance. This portion of the intermediate products cannot be remedied and must be picked out as rejects, so that the object of increasing the percentage of acceptable products cannot fully be accomplished even though the intermediates lower in resistance R_a than $0.98R_s$ can be rendered acceptable by the voltage application according to the invention. When the aim of the provisional resistance R_a is set at 85% of R_s, actual values of R_a will fall within the range from $0.68R_s$ to $1.02R_s$. Then the percentage of the finally rejected products becomes almost 0% since the sintered thick films below $0.98R_s$ in resistance can be rendered acceptable by the treatment according to the invention while the remaining portion having resistances of $0.98R_s$ to $1.02R_s$ can be accepted without any treatment. If the dispersion of actual values of the provisional resistance R_a can be assumed to be ±10%, a similarly good result can be obtained even by setting the aim of R_a at 90% of R_s because actual values of R_a will not exceed $0.99R_s$.

Care should be taken also when it is intended to provide a relatively large difference between the desired resistance R_s and the provisional resistance R_a because in that case there arises a possibility that actual values of R_a will become below about 50% of R_s. If the tolerance of R_s is ±2% and the dispersion of R_a is considered to be 20%, it is unsuitable to make the aim of R_a as low as 60% of R_s because then actual values of R_a will range from $0.72R_s$ to $0.48R_s$, whereas it is difficult to achieve about 100% increase in the resistance (e.g. from $0.48R_s$ to at least $0.98R_s$) by the treatment according to the invention without unfavorably affecting the mechanical strength of the thick film. When the aim of the provisional resistance R_a is raised to 70% of R_s, actual values of R_a will fall within the range from $0.84R_s$ to $0.57R_s$ and, therefore, it will be possible to increase the resistances of almost all the intermediates of the thick film resistor elements to acceptable values within the range from $0.98R_s$ to $1.02R_s$ without significantly suffering from unfavorable side-effects.

For the above explained reasons, in most cases it is suitable to set the aim of the provisional resistance R_a at a value in the range from 70 to 85% of the truly desired resistance R_s.

The magnitude of an alternating voltage used in the method of the invention is usually made to be more than two times as high as a maximum voltage to be applied to the thick film resistor element in its practical use and in most cases does not need to be more than about five times as high as the aforementioned maximum voltage. Usually it is suitable to use an alternating voltage of a very low frequency such as about 1/300 Hz to about 1 Hz, and the duration of application of the alternating voltage is usually from several seconds to tens of minutes.

The present invention places no particular restriction on the materials or composition of the conducting paste for forming the thick film. That is, conducting pastes conventionally used to produce thick film resistor elements are all useful in the present invention. As mentioned hereinbefore, the paste is a uniform dispersion of a powdered resistor material in a liquid vehicle, which is usually a solution of an organic polymer in an organic solvent. For example, the resistor material may be a noble metal powder such as silver powder, platinum powder or ruthenium powder or a powder of an alloy of noble metals such as Pt-Rh, Ag-Pd, Au-Pt or Au-Pd. To adjust the viscosity of the paste or the resistance of the formed thick film and/or enhancing the adhesion strength of the formed thick film, such a metal or alloy powder may optionally be admixed with a glass frit powder and/or a metal oxide powder such as RuO_2 powder, Al_2O_3 powder or ZrO_2 powder. An example of organic polymers suitable as the binder component of the organic vehicle is a cellulose derivative such as methyl cellulose or ethyl cellulose, and an example of organic solvents suitable to cellulose derivatives is terpineol. The material of the substrate can freely be selected among various ceramic materials. Some examples are alumina, mullite, spinel, silica and forsterite. If desired, it is possible to use a metal substrate having a ceramic coating.

The following examples are presented to illustrate the method according to the invention. Needless to mention, these examples are by no means limitative of the invention.

EXAMPLE 1

A platinum paste was prepared by first dissolving 15 parts by weight of an ethyl cellulose resin in 85 parts by weight of α-terpineol to obtain an organic vehicle and then uniformly dispersing 65 parts by weight of a fine powder of platinum in 35 parts by weight of the organic vehicle.

Referring to Fig. 1, this platinum paste was applied onto a major surface of an alumina substrate 10 by a screen-printing method by using a screen patterned correspondingly to the intended pattern of a thick film to be formed. The printed paste layer was dried at a temperature of 100°C for a period of about 1 hr, and thereafter the substrate 10 with the dried paste layer thereon was fired in air at about 1400°C for 2 hr to thereby achieve sintering of the platinum powder contained in the printed paste layer. The sintered platinum powder constituted a thick film resistor element

12 which adhered firmly to the surface of the substrate 10. Indicated at 14 are a pair of conducting leads, which were arranged prior to the firing process such that the two terminals of the sintered thick film resistor element 12 made intimate contact with the two leads 14, respectively.

At the screen-printing stage, the thickness of the printed paste layer was controlled such that, when a large number of samples of the thick film 12 were formed by the same procedure and under the same conditions, the average resistance R_a of the sintered thick film became 4.8 ohms. In this example, a truly desired resistance R_s of the thick film resistor element 12 was 6.0 ohms, but it was intended to make the actual resistance R_a of the sintered thick films about 80% of the truly desired resistance value R_s (6.0 ohms).

By measuring the resistance R_a of each thick film 12 formed in this example, the following six groups of samples were selected out of the many products.

Group A: R_a = 3.1 ohms (about 52% of the truly desired value R_s)

Group B: R_a = 3.4 ohms (about 57% of R_s)

Group C: R_a = 4.0 ohms (about 67% of R_s)

Group D: R_a = 5.0 ohms (about 83% of R_s)

Group E: R_a = 5.4 ohms (about 90% of R_s)

Group F: R_a = 5.8 ohms (about 97% of R_s)

To each of these samples, an alternating voltage was applied by connecting the leads 14 to an alternating voltage supplying circuit 16, which was fundamentally a combination of a DC power supply 18 and a switching device 20 for periodical changeover of the polarity of the output voltage. The circuit 16 was adjusted such that a square wave alternating voltage of the characteristic shown in Fig. 2 was applied to each sample thick film 12. That is, +10 volts and -10 volts were alternated every one minute. The duration of the application of the alternating voltage was varied from Group to Group of the samples and made longer for the samples of smaller resistance values, and more minutely varied for the individual samples of the same Group. The details of the variations are shown in the following Table 1. After the application of the alternating voltage the resistance of each sample was measured. The resistance values measured at this stage are also contained in Table 1. Assuming that the tolerance of the desired resistance R_s is 6.0 ohms ±2% (i.e. in the range from 5.88 to 6.12 ohms), the samples in Table 1 were evaluated as OK when the resistance after the application of the alternating voltage was within this range but otherwise as NG. It was confirmed that the application of the alternating voltage caused an increase in the resistance of each thick film and that the manner of increase in the resistance was as shown in Fig. 3 for the samples of Groups D, E and F.

We have recognized that the application of an alternating voltage to the sintered thick film 12 has an unfavorable effect on the strength of adhesion of the thick film 12 to the substrate 10, presumably as the result of a change in the physical structure of the sintered film 12 attributed to the aforementioned electromigration phenomenon. In this example, the degree of this side-effect of the voltage application was examined by the following test method.

The above described platinum paste was applied onto the alumina substrate 10 by screen-printing in a rectangular pattern (20 mm x 5 mm), and a cylindrical rod (not illustrated) of alumina having a diameter of 2 mm was vertically placed on the printed paste layer. The substrate was fired in this state at 1400°C for 2 hr to complete the formation of the thick film 12 which adhered to both the substrate 10 and the alumina rod. This thick film was so formed as to have the same thickness as the thick films 12 in the samples subjected to the above described resistance-increasing treatment. A number of samples were produced by this procedure, and a portion of these samples were subjected to an adhesion strength test in which the alumina rod was pulled until separation of the thick film from the substrate, or separation of the rod from the thick film, to measure the pull force at the moment of beginning of the separation as the peel strength of the thick film. On the average, the peel strength of the tested thick films was 4.4 kg/mm^2.

The remaining samples were classified into six groups according to the resistance values of the thick films similarly to the Groups A to F in the foregoing test, and the alternating voltage of the characteristic of Fig. 2 was applied to each sample for a period of time different from sample to sample depending on the initial resistance value, as shown in Table 1. After the application of the alternating voltage, every sample was subjected to the above described strength test. The peel strength values measured in this test are also presented in Table 1. From a practical viewpoint, it is required that the peel strength of the thick film after the resistance-increasing treatment be at least 60% of the initial peel strength value, 4.4 kg/mm^2. In Table 1, therefore, the samples below 2.64 kg/mm^2 in the peel strength are evaluated as NG and the others as OK.

Table 1

Resistance R_a of Sintered Thick Film (ohm)	Duration of Voltage Application (min)	Resistance after Voltage Application (ohm)	Peel Strength (kg/mm^2)	Total Evaluation
3.1 (Group A)	45	5.83 NG	2.42 NG	NG
	46	5.89 OK	2.38 NG	NG
	47	5.95 OK	2.36 NG	NG
	48	6.01 OK	2.33 NG	NG
	49	6.08 OK	2.30 NG	NG
	50	6.14 NG	2.24 NG	NG
3.4 (Group B)	37	5.85 NG	2.82 OK	NG
	38	5.92 OK	2.78 OK	OK
	39	5.98 OK	2.74 OK	OK
	40	6.05 OK	2.69 OK	OK
	41	6.12 OK	2.64 OK	OK
	42	6.19 NG	2.60 NG	NG
4.0 (Group C)	24	5.84 NG	3.38 OK	NG
	25	5.92 OK	3.34 OK	OK
	26	6.00 OK	3.30 OK	OK
	27	6.08 OK	3.26 OK	OK
	28	6.16 NG	3.22 OK	NG

Table 1 (cont'd)

5.0 (Group D)	9	5.80 NG	4.04 OK	NG
	10	5.90 OK	4.00 OK	OK
	11	6.00 OK	3.96 OK	OK
	12	6.10 OK	3.92 OK	OK
	13	6.20 NG	3.88 OK	NG
5.4 (Group E)	5	5.83 NG	4.22 OK	NG
	6	5.94 OK	4.18 OK	OK
	7	6.05 OK	4.14 OK	OK
	8	6.16 NG	4.10 OK	NG
5.8 (Group F)	1	5.80 NG	4.40 OK	NG
	2	5.92 OK	4.36 OK	OK
	3	6.03 OK	4.32 OK	OK
	4	6.15 NG	4.28 OK	NG

As can be seen in Table 1, in this experiment it was impossible to obtain fully practicable thick film resistor elements from the samples of Group A, because the application of the alternating voltage for a very long period of time to increase the resistance by nearly 100% (the initial resistance R_a was about 52% of the desired resistance R_s, 6.0 ohms) caused a great decrease in the peel strength of the thick film. For the samples of Groups B-F (i.e. when the initial resistance R_a was above 56% of the desired resistance R_s), it was possible to realize the desired resistance R_s (considering the tolerance of ±2%) with the maintenance of an acceptable peel strength by adequately determining the duration of the application of the alternating voltage. The thick film resistor elements produced in this example were intended to be used with the application of a voltage not higher than 3 volts. This means that the magnitude of the voltage used in the resistance-increasing treatment was more than three times as high as a maximum voltage during use of the thick film resistor elements. Therefore, there is little possibility that the resistance of the thick film resistor elements after the treatment will further increase during practical use thereof.

By further experiments, it was confirmed that the fraction defective after the resistance-increasing treatment can be made less than 5% even when the tolerance of the resistance is as strict as ±2%. This is a surprising improvement because in the case of aiming at the acceptable resistance range of $R_s \pm 2\%$ without using the method of the invention about 50% of the products should be rejected.

The square wave alternating voltage used in this example is merely exemplary. It is also possible to use an alternating voltage of a different waveform such as sine wave or sawtooth wave.

EXAMPLE 2

A commercially available conducting paste DuPont's No. 9051 paste) containing a silver-palladium powder was applied onto the alumina substrate 10 by the same screen-pringing method as in Example 1. The thickness of the printed paste layer was controlled so as to obtain a thick film having a resistance R_a of 4.8 ohms. This resistance value R_a was 80% of a truly desired resistance R_s, 6.0 ohms. The printed paste layer was dried at a temperature of 100°C for a period of 1 hr, and thereafter the substrate with the dried paste layer thereon was fired at about 900°C for 1 hr to thereby achieve sintering of the Ag-Pd powder contained in the printed paste layer. The sintered Ag-Pd powder constituted a thick film resistor element 12 which adhered firmly to the surface of the alumina substrate 10. The leads 14 in Fig. 1 were provided in the same manner as in Example 1.

By measuring the resistance R_a of each thick film formed by the above procedure, the following five groups of samples were selected out of the many samples produced by the same method and under the same conditions.

Group G: R_a = 3.2 ohms (about 53% of the truly desired value R_s)

Group H: R_a = 3.4 ohms (about 57% of R_s)
Group I: R_a = 4.5 ohms (about 75% of R_s)
Group J: R_a = 5.0 ohms (about 83% of R_s)
Group K: R_a = 5.8 ohms (about 97% of R_s)

To each of these samples, an alternating voltage was applied by using the apparatus 16 described in Example 1. The characteristic of the alternating voltage was as shown in Fig. 2, but in this example the amplitudes of the voltage were ±7 volts. That is, +7 volts and -7 volts were alternated every one minute. The duration of the application of the alternating voltage was varied from Group to Group of the samples, and also from sample to sample in the same Group. The details of the variations are shown in Table 2, together with the resistance of each sample measured after the application of the alternating voltage. The criterion for evaluation of the resistance values after the application of the alternating voltage was the same as in Example 1. Fig. 4 shows the relationship between the duration of the voltage application in this example and the extent of increase in the resistance of the thick films of the Groups I, J and K samples. The influence of the resistance-increasing treatment on the adhesion strength of the thick film was examined by the peel strength test described in Example 1, and Table 2 contains evaluation of the peel strength after the resistance-increasing treatment on the same criterion as in Example 1. The thick film resistor elements produced in this example were intended to be used with the application of a voltage not higher than 3 volts.

Table 2

Resistance R_a of Sintered Thick Film (ohm)	Duration of Voltage Appli-cation (min)	Resistance after Voltage Appli-cation (ohm)	Peel Strength (kg/mm^2)	Total Evaluation
3.2 (Group G)	28	5.79 NG	NG	NG
	29	5.89 OK	NG	NG
	30	5.98 OK	NG	NG
	31	6.08 OK	NG	NG
	32	6.18 NG	NG	NG
3.4 (Group H)	23	5.64 NG	NG	NG
	24	5.75 NG	NG	NG
	25	5.85 NG	OK	NG
	26	5.95 OK	OK	OK
	27	6.05 OK	OK	OK
	28	6.15 NG	NG	NG
4.5 (Group I)	10	5.72 NG	OK	NG
	11	5.85 NG	OK	NG
	12	5.99 OK	OK	OK
	13	6.12 OK	OK	OK
	14	6.26 NG	OK	NG
5.0 (Group J)	6	5.75 NG	OK	NG
	7	5.90 OK	OK	OK
	8	6.05 OK	OK	OK
	9	6.20 NG	OK	NG
5.8 (Group K)	1	5.80 NG	OK	NG
	2	5.97 OK	OK	OK
	3	6.15 NG	OK	NG

As can be seen in Table 2, in this experiment it was impossible to obtain fully satisfactory thick film resistor elements from the samples of Group G in which the initial resistance R_a was only about 53% of the desired resistance R_s, 6.0 ohms. For the samples of Groups H-K (i.e. when the initial resistance R_a was in the range from about 56% to about 97% of R_s), it was possible to realize the desired resistance R_s (considering the tolerance of ±2%) with the maintenance of an acceptable peel strength by appropriately determining the duration of application of the alternating voltage. However, in the case of industrial production it is important to determine the nominal value of the initial or provisional resistance R_a with due consideration of the width of dispersion of actual values of R_a, as explained hereinbefore.

WHAT IS CLAIMED IS:

1. In a method of producing a thick film resistor element having a predetermined resistance on an insulating substrate, the method having the steps of applying a paste containing a powder of an electronically conducting resistor material dispersed in a liquid vehicle onto a major surface of the substrate to form a paste layer, drying the paste layer and then firing the substrate to achieve sintering of the resistor material contained in the paste layer,

the improvement comprising performing said steps such that a thick film as the product of the firing step has a provisional resistance lower than said predetermined resistance, and the step of applying an alternating voltage to said thick film so as to increase the resistance of said thick film from said provisional resistance up to said predetermined resistance, the magnitude of said alternating voltage being higher than a maximum voltage to be applied to the thick film resistor element in practical use thereof.

2. A method according to Claim 1, wherein said provisional resistance is in the range from about 50% to about 90% of said predetermined resistance.

3. A method according to Claim 2, wherein said provisional resistance is in the range from about 70% to about 85% of said predetermined resistance.

4. A method according to Claim 2, wherein the magnitude of said alternating voltage and the duration of application of said alternating voltage being selectively determined according to the difference between said predetermined resistance and said provisional resistance.

5. A method according to Claim 2, wherein the magnitude of said alternating voltage is more than two times as high as said maximum voltage.

6. A method according to Claim 1 or 2, wherein the thickness of said paste layer is controlled such that said thick film has said provisional resistance.

7. A method according to Claim 1 or 2, wherein said paste is applied to said substrate by a screen-printing technique.

8. A method according to Claim 1, wherein said resistor material is a noble metal.

9. A method according to Claim 1, wherein said resistor material is an alloy of noble metals.

10. A method according to Claim 8 or 9, wherein said paste additionally contains at least one metal oxide powder.

11. A method according to Claim 8 or 9, wherein said paste additionally contains a glass frit powder.

12. A method according to Claim 1, wherein said substrate is formed of a ceramic material.

FIG.1

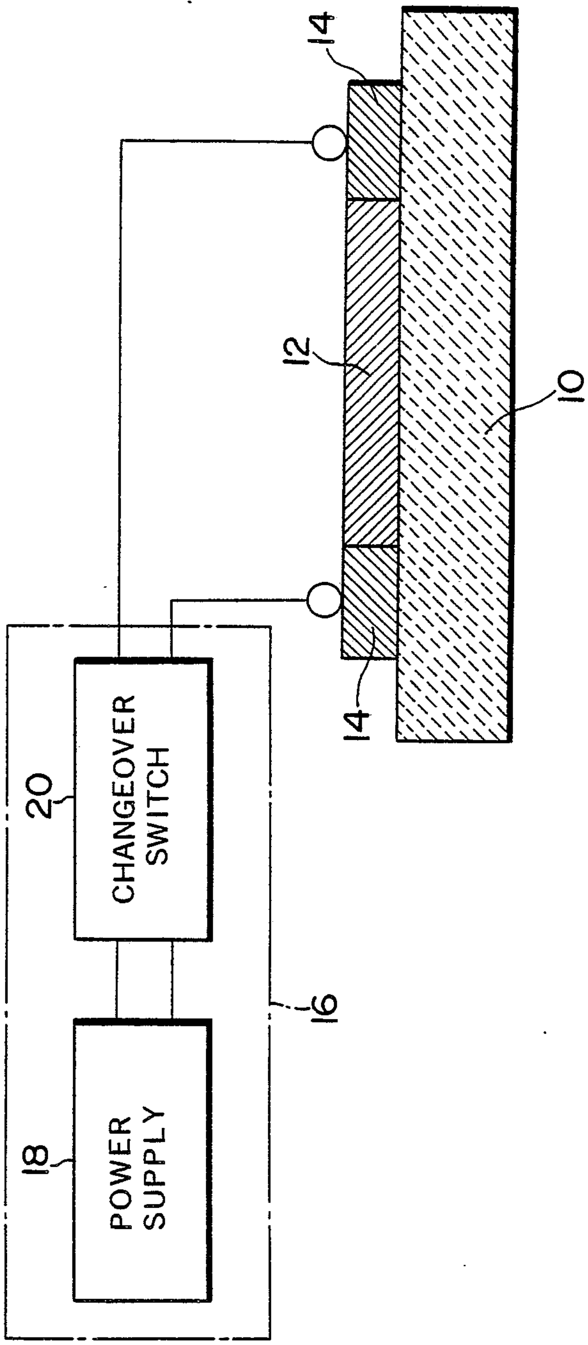


FIG.2

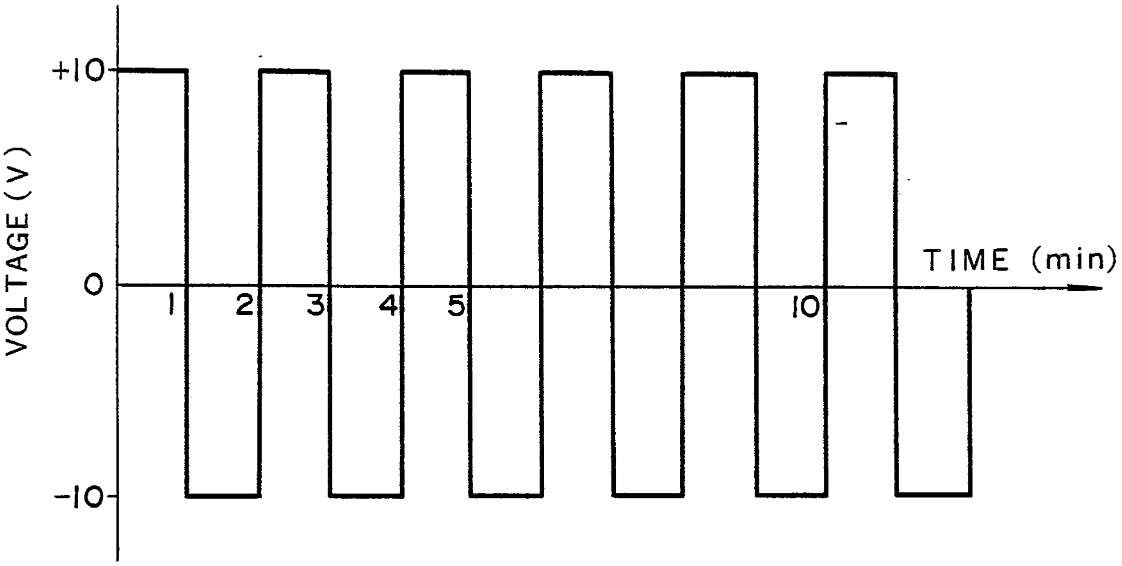

+10
0
-10
VOLTAGE (V)
TIME (min)
1
2
3
4
5
10

FIG.3

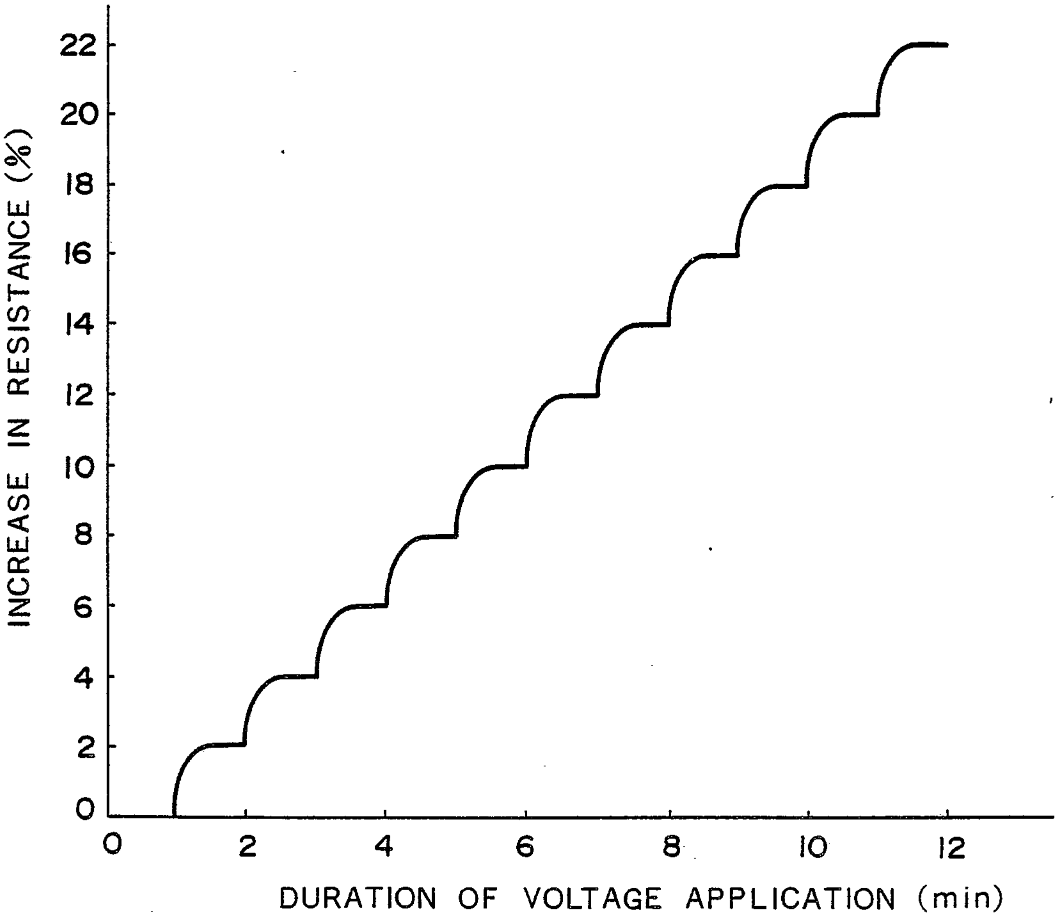
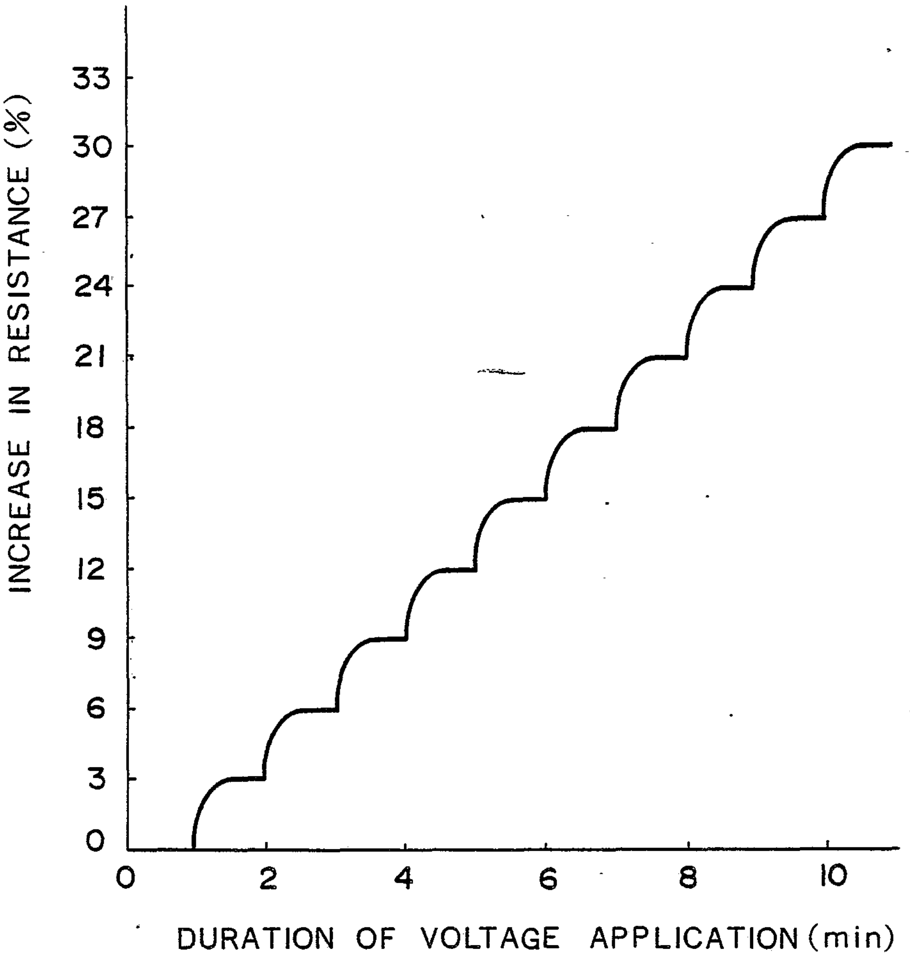

22
20
18
16
14
12
10
8
6
4
2
0
INCREASE IN RESISTANCE (%)
0
2
4
6
8
10
12
DURATION OF VOLTAGE APPLICATION (min)

FIG.4


INCREASE IN RESISTANCE (%)
33
30
27
24
21
18
15
12
9
6
3
0
0
2
4
6
8
10
DURATION OF VOLTAGE APPLICATION (min)