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METHOD OF TAILORING THIN FILM IMPEDANCE DEVICES

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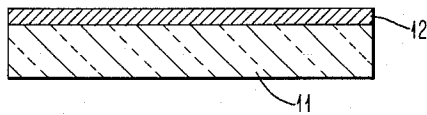


FIG. 1

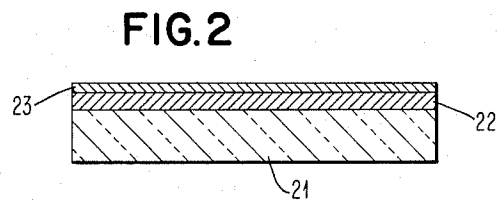


FIG. 2

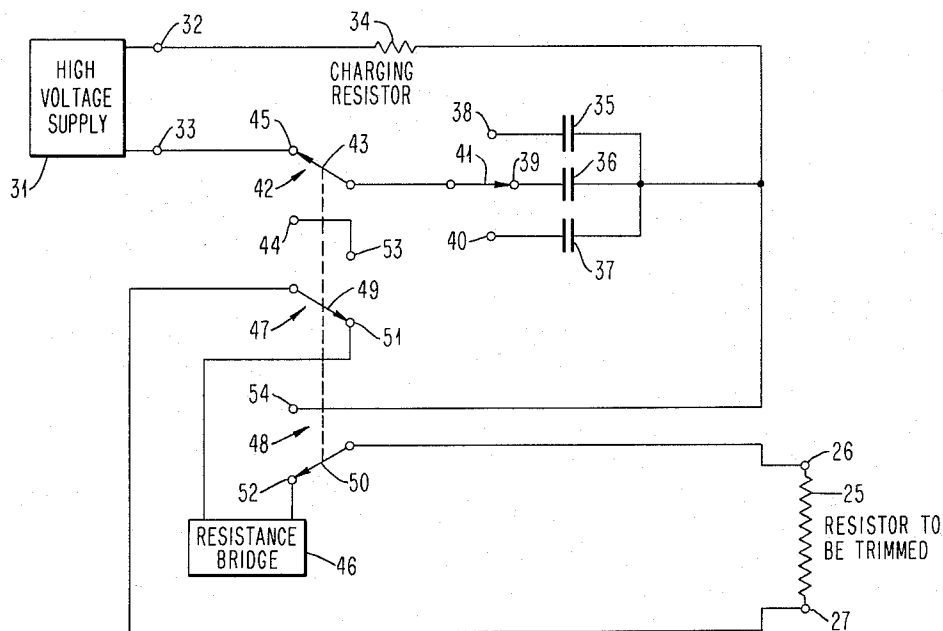


FIG. 3

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METHOD OF TAILORING THIN FILM IMPEDANCE DEVICES

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This invention relates to impedance devices and, more particularly, to the fabrication of thin film resistive devices with uniform, stable resistance characteristics.

Conventionally, thin film impedance devices, such as resistors, are formed by vacuum evaporation or sputtering a metallic thin film on a nonconductive substrate. In the case of a resistive device, when it is heated during normal operation, the electrical resistivity of the film changes. In order to prevent the occurrence of such changes, it is standard practice to stabilize the film by heating it for a period of time at a temperature greater than the maximum temperature that it is expected to encounter during its lifetime. Although the total change in resistance is a function both of the heating time and the temperature, heat is ordinarily applied for a period long enough for the resistance to approach a constant value. However, at the present state of the art, it is not possible to predict a stable value of resistance with any degree of certainty. Consequently, it is necessary to employ some method of trimming the individual resistors to adjust the resistance value of each within predetermined tolerance limits.

Ordinarily, the trimming method employed adjusts the geometry of the resistor without altering its sheet thickness or bulk resistivity. This is generally accomplished by gross removal of the resistive material, usually by mechanical abrasion, spiraling or grinding. Another method commonly employed, is to effect a change in the thickness of the film without changing the geometry of the structure or the bulk resistivity of the film. This is usually done by converting part of the film to an insulating oxide (by anodizing) although actual removal of surface material may also be accomplished by electrochemical etching.

Although both of these methods can produce satisfactory results, nevertheless, they are cumbersome, expensive and subject to limitations. For example, the method of mechanically trimming the excess portions of the thin film resistor by abrading or grinding is difficult to employ if the thin film resistor is formed in an integrated manner on a common nonconductive substrate. Although custom treatment of each resistor is possible, the method is restricted to resistors of relatively large physical size. Similarly, it is virtually impossible to anodize or etch individual resistors by different amounts on the same substrate. In addition, this method requires that all the metal in a thin film microcircuit, other than the resistor whose thickness is to be varied, must be carefully masked against contact with the anodizing or etching solution.

Accordingly, it is a primary object of the invention to provide a method of fabricating thin film impedance devices so as to stabilize them with uniform resistance characteristics within specified tolerance limits.

It is another object of the invention to provide a new method of tailoring thin film resistors by adjusting the

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bulk resistivity of the film and without varying the thickness or geometry of the film.

It is a further object of the invention to provide a method of individually adjusting the resistivity characteristics of a thin film resistor formed with a plurality of such resistors on a common nonconductive substrate without affecting the neighboring resistors.

Briefly, the invention resides in the method of tailoring a thin film impedance device by changing the resistance characteristics of the device. This change in characteristics is accomplished by repeatedly heating the device for short periods of time to a temperature substantially higher than its normal stabilizing temperature so that small changes in the characteristics occur. In accordance with one aspect of the invention, this local heating of the device is accomplished by passing impulses of electric current through the resistor for controlled periods of time. Alternatively, the heating may be performed by a hot gas emitted for short periods of time from a well-defined jet.

It is also within the purview of the invention to fabricate a thin film resistor in layers so that an inner layer having a high degree of thermal stability is provided on a nonconductive substrate and an outer layer having a low degree of thermal stability is deposited on the inner layer. Thereafter, changes in the resistor due to tailoring only occur in the outer layer and "hot spots" are avoided in the composite resistor.

A feature of the invention enables the resistance characteristics of individual resistors to be adjusted without affecting the characteristics of neighboring resistors formed on the same substrate.

Another feature of the invention permits measurement of the resistance of the thin film resistor to be made alternately with the periodic application of heat to the resistor.

A further feature of the invention enables it to be performed in an air atmosphere, a vacuum or an inert gas atmosphere.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments of the invention, as illustrated in the accompanying drawings; wherein:

FIGURE 1 is a sectional view of one form of thin film device which may be tailored according to the method of the invention;

FIGURE 2 is a sectional view of a second form of thin film device which may be tailored according to the method of the invention; and,

FIGURE 3 is a schematic diagram of a circuit which may be employed in practicing the invention.

It is well known in the art that thin film impedance devices may be fabricated by a number of methods. Referring to FIGURE 1, one of the conventional methods for fabricating a thin film resistor provides for a metallic film 12 to be deposited on a nonconductive substrate 11. The substrate 11 may be formed of a suitable insulator, such as a conventional glass or ceramic, and the metallic material may comprise pure tantalum which is deposited on the substrate to a thickness approximating 500 Angstrom units by vacuum evaporation or sputtering in an inert gas (e.g. argon) atmosphere. The substrate serves primarily to provide mechanical support for the resistor, and, therefore, it should have a thickness sufficient to

accomplish this purpose. Although such a thickness is readily ascertainable by one skilled in the art, for illustrative purposes, it may be stated that a substrate having a thickness approximating .020 inch has been found to provide ample mechanical support for a resistor. After depositing the metallic film on the substrate, the resistor is stabilized to a constant value of resistance by heating it for about fifty hours in an air atmosphere at a temperature above its normal operating temperature. In practice, it has been found that this normal stabilizing temperature may be approximately 250° C.

Ordinarily, the next step in the process of fabricating a thin film resistor requires that it be tailored in order to stabilize the value of resistance within certain predetermined tolerance limits. As previously mentioned, the tailoring has been accomplished in the past by some form of mechanical trimming or by anodizing the metallic film. In accordance with this invention, tailoring is performed by adjusting the bulk resistivity of the resistor to a predetermined value of resistance.

A preferred version of performing the invention provides for the resistive film 12 to be heated by subjecting it to instantaneous overload impulses or pulses of electric current for extremely short periods of time. The schematic diagram of FIGURE 3 is an example of one form of apparatus which may be employed alternately to provide impulses of electric current to the resistor and to connect it to a resistance measuring bridge. In this manner, the value of resistance may be checked after each application of heat to the resistor.

In the specification and the appended claims, the term "pulse" is employed in accordance with its conventional meaning to describe an amplitude variation in a signal which includes a departure from a given value and a subsequent return to such value after a period of time. The term "impulse," on the other hand, is employed to indicate a single amplitude variation in a signal. Accordingly, the term "impulse" is considered to encompass the term "pulse," and, therefore, the pulses may be supplied in a particular form, such as, rectangular shape or sine wave, for imparting heat to the thin film resistor.

Referring again to FIGURE 3, the circuit may be standardized to comprise a heating portion and a measuring portion. The resistor to be tailored 25 is connected into the circuit at the terminals 26-27. The heating portion of the circuit includes a high voltage supply 31 connected to the terminals 32 and 33. A series circuit is formed from the terminal 32 through a charging resistor 34, one of the capacitors 35, 36, 37, its associated output terminal 38, 39, 40, the movable contact 41, and the switch 42. Switch 42 is a double pole single throw switch including the switch arm 43 and the poles 44-45. Thus, when the switch arm 43 is in contact with the terminal 45 and the movable contact 41 is in contact with one of the capacitor output terminals, for example terminal 39, the capacitor 36 is charged from the supply 31 through the resistor 34. Concurrently with the charging of capacitor 36, the resistor 25 is measured by the measuring portion of the circuit, including a resistance bridge 46, through the switches 47 and 48. The switches 47 and 48 are also of the double pole single throw type and, as shown, are ganged with the switch 42. Thus, when arm 43 contacts pole 45, the arms 49-50 of the switches 47-48 contact poles 51-52, respectively.

In order to apply an impulse of electric current to the resistor 25, the switch arms 43, 49, 50 need only be moved to the opposite poles, that is, the arm 43 contacts the terminal 44 and the arms 49-50 contact the terminals 53-54, respectively. In this position, the capacitor 36 is discharged sending an impulse of electric current through the resistor 25. Although mechanical switches are shown as being employed in the circuit of FIGURE 3 for alternately supplying impulses of electric current to the resistor 25 and for connecting this resistor to a resistance bridge, it is readily apparent that electronic

switching elements may be employed for accomplishing this function.

The impulses supplied by this circuit are sufficient to provide the instantaneous pulsations of heat necessary to tailor thin film resistors. The duration of the current impulse depends on the resistance value of the resistor. Consequently, dependent on this resistance value, preselection is made of the time constant of the resistive-capacitive circuit comprising the resistor 34 and the capacitor connected in the circuit; the capacitors 35-37 being chosen to have different values of capacitance. Ordinarily, this period of time should approximate a few milliseconds and should not exceed one hundred milliseconds. By employing the apparatus of FIGURE 3 in practice, it has been found that impulses of approximately one millisecond for resistors of the order of 5,000 ohms and measuring .250 x .010 inch produces satisfactory results. Thus, as shown in tabular form below by suitably selecting the parameters of the supply 31 and the capacitor, an average percent increase in resistivity that approximates .06 percent per pulse has been achieved.

Resistance, ohms	Capacity, microfarads	Voltage, volts	Percent Increase per pulse
5, 276	2	470	0.068
5, 383	2	480	0.076
5, 710	2	480	0.061
5, 096	16	320	0.075
5, 218	16	320	0.061
5, 675	16	330	0.048

The tabular results presented above were obtained by tailoring resistors in a vacuum of the order of 5×10^{-7} mm. of mercury. Tailoring may also be performed in an air atmosphere or in an inert gas atmosphere.

As previously mentioned, the purpose of the thin film stabilization prior to tailoring is to vary the resistivity of the film until it approaches a constant value. Whether or not the resistance increases or decreases on heating depends on a number of factors. Deposited films are highly disordered resulting in a resistivity many times greater than that of the bulk metal. This resistivity is reduced on heating if the temperature is high enough for an appreciable amount of annealing or ordering to take place. In many metals the characteristic annealing temperature may be so high that it is rarely reached in practice. Consequently, in such cases, the effect of heating a resistor above its normal stabilizing temperature is to increase the film resistivity. This is believed to be due to the oxidation of the film, both at its surface and along its grain boundaries. Oxidation along the grain boundaries is the more important and may be due to the entrance of oxygen into the film from outside and then diffusing into the film, or to oxygen trapped inside the film during its deposition and subsequently precipitating at the boundaries. Thus, as indicated above, the resistivity of such films increases whether heated in an air atmosphere, a vacuum or an inert gas atmosphere. However, when tailoring by heating is performed in air, there is a tendency for nonprotective surface oxides to develop on the resistors. This surface oxide may ultimately lead to the destruction of the film, particularly if the total increase in resistance is greater than 8 to 10%.

Accordingly, it is within the purview of this invention to provide for the elimination of "hot spots." One method of accomplishing this is to fabricate the resistors in the form of a double layer of material. As shown in FIGURE 2, a first layer 22 of resistive material having a high thermal stability of approximately 0.01% per hour at 250° C. is deposited on a nonconductive substrate 21. This layer of material can be tantalum which is deposited to a thickness approximating 500 Angstrom units by sputtering in an argon atmosphere containing 0.5 to 0.05% oxygen. Thereafter, this layer is heated

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for about 15 minutes to a temperature of approximately 600° C. A second layer 23 having a thickness approximating 50 Angstrom units is deposited on the first layer. It consists of a resistive material having a low thermal stability of approximately 1 to 10% per hour at 250° C., for example, tantalum which is sputtered on the first layer in a substantially pure argon atmosphere. Thereafter, the double layer film is stabilized to a constant value of resistance by heating in an air atmosphere at approximately 250° C. for 25 to 50 hours.

Tailoring of the composite structure may be performed in the same manner as described for a single layer resistor. The changes in bulk resistivity produced by tailoring occur almost exclusively in the layer 23. If weak spots do develop in this layer during the tailoring operation, they are shunted by the lower layer and thus do not behave as "hot spots" with respect to the composite resistor as it has been found that the layer 22 carries about 80% of the current which flows through the resistor.

It is readily apparent that the method of this invention provides for the individual treatment of resistors to bring them within predetermined tolerance limits. The tailoring may be accomplished by merely connecting the resistor into a standard circuit and thus the method is readily adaptable for use in fabricating resistors formed on a common or integrated substrate. It eliminates the disadvantages of mechanical trimming and does not require premasking of all other elements in a microcircuit as required in the anodizing or etching methods of trimming. Moreover, the method of the invention provides a greater degree of control of the resistivity of the resistor, since it is readily possible to adjust the values of the resistors to 0.1% of a predetermined desired value. In addition, it is obvious that the method of the invention is not limited to the tailoring of thin film resistors, but rather, it also extends to the tailoring of the resistance characteristics of other thin film impedance devices, such as inductors. Similarly, it is obvious that tailoring may be accomplished by means other than impulses or pulses of electrical current. For example, hot gas at a desired temperature may be directed from a well-defined jet at the film for controlled periods of time.

While this invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A method of tailoring the resistance of a thin film impedance device, comprising:

heating the film of the impedance device to a temperature above its normal stabilizing temperature by applying at least one discrete electrical impulse to the film for a predetermined period of time equal to or less than one hundred milliseconds to modify its bulk resistivity from its initial value to a predetermined desired value.

2. A method of tailoring the resistivity characteristics of a thin film resistive device, comprising:

heating the film of the resistive device to a temperature above its normal stabilizing temperature by applying at least one discrete electrical impulse to the film for a predetermined period of time equal to or less than one hundred milliseconds to modify its bulk resistivity from its initial value to a predetermined desired value.

3. The method of claim 2 wherein the tailoring is performed in an air atmosphere.

4. The method of claim 2 wherein the tailoring is performed in a vacuum.

5. The method of claim 2 wherein the tailoring is performed in an inert gas atmosphere.

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6. A method of tailoring the resistivity characteristics of a thin film resistive device, comprising:

heating the film of the resistive device to a temperature above its normal stabilizing temperature by applying at least one discrete electrical impulse to the film for a predetermined period of time equal to or less than one hundred milliseconds to increase its bulk resistivity from its initial value to a predetermined desired value.

7. In a method of fabricating a thin film resistor in which the resistor is formed of two distinct layers of resistive material having a first layer with a high degree of thermal stability deposited on a non-conductive substrate and a second layer with a low degree of thermal stability deposited on the first layer, comprising: heating the combined layers of resistive material to a temperature above the normal stabilizing temperature of the materials by applying at least one discrete electrical impulse to the film for a predetermined period of time equal to or less than one hundred milliseconds to modify the bulk resistivity of the resistor from its initial value to a predetermined desired value, whereby when the heat is applied, the modification of bulk resistivity occurs almost exclusively in the second layer due to the differences in said degrees of thermal stability for the layers.

8. The method of claim 7, wherein the impulse of electric current is applied in a vacuum.

9. The method of claim 7, wherein the impulse of electric current is applied in an air atmosphere.

10. The method of claim 7, wherein the impulse of electric current is applied in an inert gas atmosphere.

11. A method of fabricating a resistor of the thin film type, comprising:

forming a stabilized layer of resistive material on a nonconductive substrate,

heating the material to a temperature above its normal stabilizing temperature by applying at least one discrete electrical impulse to the material for a predetermined period of time equal to or less than one hundred milliseconds to modify the bulk resistivity of the material from its initial value to a predetermined desired value,

and alternately measuring the resistance of the material until said desired value is reached.

12. A method of fabricating a resistor of the thin film type, comprising:

forming one stabilized layer of resistive material having high thermal stability characteristics on a non-conductive substrate,

forming a second stabilized layer of resistive material having low thermal stability characteristics on the one layer,

and imparting at least one impulse of heat to the layers for a period of time equal to or less than one hundred milliseconds and to a temperature above the normal stabilizing temperature of the resistive material to adjust uniformly the bulk resistivity of the combined resistive material from its initial value to a predetermined desired value whereby the different thermal stability characteristics of the layers cause the bulk resistivity modification to occur almost exclusively in the second layer.

13. A method of fabricating a thin film resistor, comprising:

sputtering a first layer of resistive material having a high degree of thermal stability on a nonconductive substrate in an inert gas atmosphere containing 0.5 to 0.05% oxygen,

heating the resistive material to a temperature of about 600° C. for approximately fifteen minutes,

sputtering a second layer of resistive material having a low degree of thermal stability on the first layer of resistive material in a substantially pure inert gas atmosphere,

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heating the two layers of resistive material in an air atmosphere to a temperature of about 250° C. for a period of time between 25 and 50 hours, and imparting at least one impulse of heat to the layers of resistive material for a period of time equal to or less than one hundred milliseconds to increase the bulk resistivity of the combined resistance materials from its initial value to a predetermined desired value whereby the different thermal stability characteristics of the layers cause the bulk resistivity modification to occur almost exclusively in the second layer.

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