March 27, 1962 R. SCHÖFER ETAL 3,027,529

RESISTOR WITH HIGH POSITIVE TEMPERATURE COEFFICIENT

Filed April 28, 1959 2 Sheets-Sheet 1

Fig.1

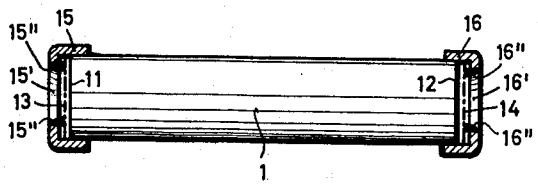


Fig.2

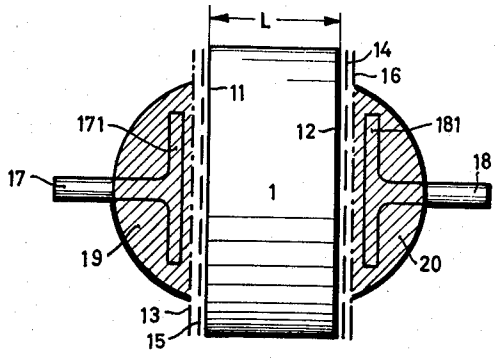
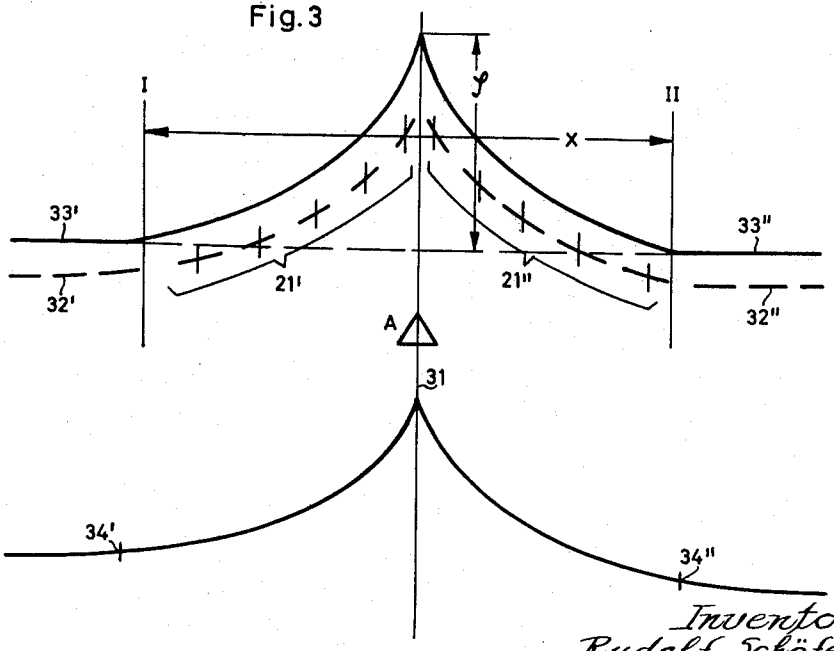


Fig.3



Inventors.
Rudolf Schöfer,
Walter Heywang &
Erich Fenner.
By
Atty.

March 27, 1962 R. SCHÖFER ETAL 3,027,529

RESISTOR WITH HIGH POSITIVE TEMPERATURE COEFFICIENT

Filed April 28, 1959 2 Sheets-Sheet 2

Fig.4

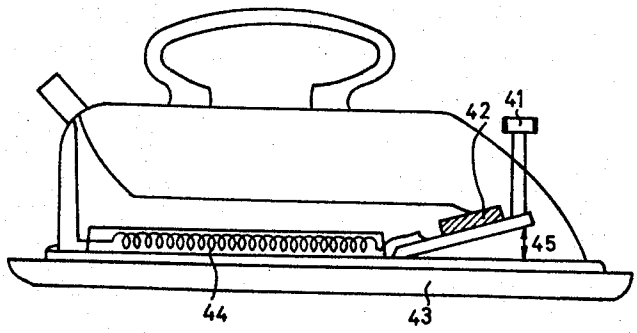
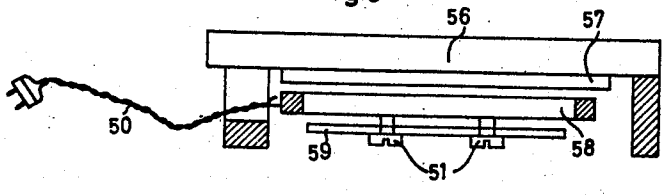


Fig.5



Inventors.
Rudolf Schöfer,
Walter Heywang, &
Erich Fenner
By. [signature]
Atty.

United States Patent Office 3,027,529
Patented Mar. 27, 1962

3,027,529
RESISTOR WITH HIGH POSITIVE TEMPERATURE COEFFICIENT

Rudolf Schöfer, Walter Heywang, and Erich Fenner, Munich, Germany, assignors to Siemens & Halske Aktiengesellschaft Berlin and Munich, a corporation of Germany

Filed Apr. 28, 1959, Ser. No. 809,478
Claims priority, application Germany Apr. 30, 1958
11 Claims. (Cl. 338—28)

This invention is concerned with a resistor having a high positive temperature coefficient of resistance, which may be considered in the nature of an improvement on the resistor disclosed in the copending application Serial No. 734,818, filed May 13, 1958, now abandoned, owned by the assignee also named in the present application.

The resistor described in the above noted copending application has a positive temperature coefficient of resistance within the entire temperature range or, preferably, only within the upper part of the operating temperature range, and is characterized by the following features, namely (*a*) the resistor consists of ferromagnetic material having a Curie temperature, above which the material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, especially at or below the lower limit of the range in which the resistor shall have a positive temperature coefficient of resistance, and preferably below 20° C.; (*b*) the material is made conductive by impurity centers, preferably n-conductive, whereby the spacing E of the donors from the line band and of the acceptors from the valence band is smaller, especially considerably smaller than half the width E_0 of the prohibited zone between the valence band and line band; and (*c*) the intrinsic conductivity or another impurity conductivity of the material is low, being particularly negligibly low as compared with impurity center conductivity, at least in a part of the operating temperature range in which the resistor has a positive temperature coefficient.

It was found in the production of such resistors that the resistance value often exhibits an undesired voltage dependence. The object of the present invention is to eliminate this voltage dependence or to reduce it to a point at which it is not disturbing. The copending application Serial No. 734,818 states in this connection that the resistor body, after the contacting thereof, is to be momentarily placed on high voltage, that is, that it be formed by a strong current surge.

The present invention is based upon thoughts and investigations concerning the possible reasons for the dependence of the value of the total resistance lying between the two current leads, on the polarization and/or on the magnitude of the voltage at the terminals. It must be considered in this connection that several reasons for the voltage dependence of the total resistance value are involved in the case of resistor bodies consisting of sintered ferroelectric crystallites, namely, as a volume effect, the voltage dependence of the transistion resistance between the adjoining crystallites in the resistor body as such; secondly, border layer effects of the semiconductor, for example, the formation of blocking or barrier layers in the marginal layer of the semiconductor which are caused by impurity centers of the semi-conductor located upon or closely to the surface thereof or by contaminations, for example, due to adsorbing oxygen; and, third, as surface border effect, a rectifying action between the resistor material which has been made conductive and the contact metal serving for the current connection, which is provided, for example, vaporized upon the semiconducting resistor material for the contacting thereof.

The various objects and features of the invention will

appear in the course of the description which is rendered below with reference to the accompanying drawings, in which:

FIG. 1 shows an embodiment of the invention;

FIG. 2 indicates another embodiment;

FIG. 3 is a graph to illustrate an *n*-doped titanate and the formation of the potential wall; and

FIGS. 4 and 5 show examples of electrically heated appliances using a semiconductor according to the invention.

The invention proposes to reduce the voltage dependence of the total resistance value of such resistors or to make it negligibly low at room temperature, by placing the contacts upon the material of the resistor (FIG. 1) substantially free of barrier or blocking layer, especially, to vaporize the contacts thereon. The material for the contacts is for this purpose selected so that it does not form a barrier or blocking layer with the resistor material; more particularly, in the case of a resistor sintered of ferroelectric crystallite particles made n-conductive, the current supply contacts will consist of a base metal, preferably aluminum or zinc or of an alloy containing at least a high proportion of one of these metals. The surface parts of the ceramic material serving for the contacting are moreover prior to or if desired incident to the contacting preferably particularly treated as compared with the interior particles of the resistor body, especially mechanically treated, for example, they are made to be well conductive by solder rubbing or by sanding or by electrical or chemical treatment applied prior to vaporizing metal thereon. The purpose of this pretreatment is to provide a clean surface free of troublesome conditions. This may be obtained, for example, by glow treatment or by chemical reduction. The treatment may be such as to affect not only the surface but penetrating to some depth the marginal layer of the resistor material.

In order to keep as small as possible the above mentioned varistor-like volume effect caused by the transition resistances between the crystallites of the sintered resistor body, it is furthermore proposed that the resistor material be sintered at suitable high temperature for a sufficient time so as to avoid these transition resistances as far as possible. In the event that an impermissible voltage dependence of the specific resistance cannot be avoided in the production of the resistor body, by suitable selection of the sintering conditions, the volume effect may be subsequently reduced by forming operations. For example, as explained in the copending application Serial No. 734,818, a sufficiently voltage-independent resistor may be produced by first sintering the resistor body without regard to the voltage dependence of its resistance, thereupon contacting the resistor body in the manner explained above, and thereafter passing through the resistor a strong current surge which reduces the voltage dependence of the transition resistances between the crystallites and therewith the conductivity of the resistor body to a tolerable point, by effecting in a manner welding together of the individual crystallites.

Since a reduction of the volume resistance could in connection with the above noted treatment be observed—if at all—only at high field strength, while the resistance remained at lower field strength practically independent of the voltage applied, it is possible by providing suitable dimensions of the resistor body to produce for any given voltage a resistor with any desired resistance value, which is practically free of varistor effects, by making the spacing between the two resistor contacts relatively great, therewith the field strength low, and making the cross-sectional area of the resistor body correspond to the desired capacitance and the length of the current path in the resistor body.

The surface treatment is in a particularly advantageous

embodiment carried out by subjecting the surface to a glow effect. For this purpose, the semiconductor is suitably disposed in a vacuum vessel, at relatively low gas pressure, opposite an electrode and the surface parts of the semiconductor body which are subsequently to be contacted are brought to a glowing condition by the connection of an alternating voltage or, preferably, a direct voltage, which becomes effective between the resistor body and the electrode. When using a direct voltage, it is advisable to place the semiconductor on the positive pole of the voltage source. The resistor material is preferably subjected to a strong glow effect, for example, at a current density from about 10 to 30 milliamperes per square centimeter, for example, at roughly 3000 to 5000 volt, so as to liberate the surface to be metallized also from adhering residual gas or other contaminations such as deposited hydrogen. The contact metal which does not form a blocking layer with the semiconductor is thereupon applied, advantageously by vaporization in the same vacuum vessel at further reduced gas pressure. The contact metals to be used in the case of *n*-doped ferroelectric resistor materials are preferably base metals with a normal potential below that of silver, especially below that of copper, for example, Al or Zn, which are particularly suitable. The use of noble metals as contact materials is, however, not inherently excluded.

The current connections are preferably mechanically secured on the semiconductor body; for example, in the case of rod-shaped resistor bodies, in the form of caps attached thereto by press fit or in the form of clasps embracing the corresponding body. An example is illustrated in FIG. 1.

Referring to FIG. 1, numeral 1 indicates the resistor body made of sintered ferroelectric crystallites. Its ends 11, 12 are cleaned as provided by the invention, for example, by electrical or chemical pretreatment. The contact metal is vaporized upon these end surfaces (see dash lines 13 and 14), such contact metal being preferably identical metal or identical alloy at the two ends. If the current supply terminals were connected directly to these metallic layers 13, 14, the latter, in the use of the resistor, would be subjected to considerable stress and it is, therefore, advantageous to avoid such stress that would occur, for example, in soldering the resistor in place in a given apparatus. For this purpose, metal caps 15, 16 are placed at the resistor ends with press fit, such metal caps being provided with openings 15' and 16' formed therein. The margins of these openings are directly soldered (15'', 16'') to the vaporized metal layers 13, 14, thereby providing a satisfactory electrical contact between respective contact layers 13, 14 and the caps 15, 16.

Pure tin is particularly to be recommended as the solder for connecting the caps 15, 16, consisting, for example, of copper, with the vaporized layers 13, 14, since the resistor must frequently be heated to relatively high temperatures of 200° C. or thereabout to bring it to its maximum specific resistance. This means, generally speaking, that the melting point of the solder used must lie considerably above the Curie point of the ferroelectric material of the resistor 1. In order to facilitate the soldering in place of the caps and the current connections to the contact layers of the resistor 1, it is furthermore proposed to coat the vaporized base metal layers which consist, for example, of aluminum, chemically or electrochemically treated, for example, in a galvanic bath or by burning-in of silver, with a copper or especially a silver layer, to which can be easily soldered the caps 15, 16. However, in the burning-in of silver, the alloying of the silver into the base metal layer must be avoided, particularly by the application of relatively low temperatures, because the good contact properties of the base metal would otherwise deteriorate.

It is in many cases, especially in the case of a disk-shaped embodiment of the resistor 1, as shown in FIG. 2, advisable to use instead of caps which are mechanically fastened to the resistor body, solderable material provided chemically or electrochemically upon the base metal layers and to solder the current leads 17, 18 by means of high melting solder 19, 20, directly to the layers 15, 16 consisting of solderable material.

In FIG. 2, numeral 1 again indicates the resistor body of a length L which is in this case disk-shaped. Its surfaces 11, 12 are pretreated according to the invention or, for example, coated with base metal 13, 14 by a rubbing operation. It is also possible, after "freshening" the surface layers 11, 12 for removal of surface conditions, to vaporize a base metal thereon, for example, aluminum 13, 14. These vaporized layers 13, 14 form very good barrier-free contacts with the surfaces 11, 12 of the ceramic resistor and are provided with solderable metal layers 15, 16 which are placed in position chemically or electrochemically.

The current leads 17, 18 are thereupon over a wide area directly soldered to the reinforcing layers 15, 16, consisting preferably of silver, by means of solder 19, 20, consisting of pure tin. The current leads 17, 18 are for this purpose by stamping or the like provided with disk-shaped enlargements 171, 181 at their ends facing the layers 15, 16.

Experiments have shown that the method according to the invention does not only avoid the appearance of blocking or barrier layers; the resistors also have a particularly low minimum value of specific resistance which exhibits in the case of barium titanate, made conductive, always values below 100 ohms per centimeter. The rise of the resistance value depending upon the temperature thereby becomes considerably steeper.

As already mentioned above, rubbing solder may be used in place of the electrical or chemical pretreatment. Solders of this kind may be, for example, indium-amalgam alloys; solder composed of 40 parts Bi, 25 parts Pb, 10 parts Sn, 10 parts Cd, preferably with an addition of 15 parts indium is suitable for this purpose. Such rubbing solders are however unsuitable for mass production of resistors demanding clear-cut transition resistance between the resistor body and the metal, since the corresponding process is substantially based upon mechanical destruction of the surface layer of the ceramic body and since such surface destruction can hardly affect the entire contact surface incident to the corresponding mechanical procedure.

It was found that even upon using the means noted in the copending application Serial No. 734,818 or the means previously noted herein, for the elimination of the voltage dependency, that voltage dependency is frequently present at sufficiently high field strength. To eliminate this voltage dependency, the dimensions of the resistor are to be such that, up to the maximum operating voltage, the field strength in the resistor material must not exceed the value at which the resistor body remains substantially free of the varistor effect.

A further object and feature of the invention is concerned with the provision of a resistor, particularly consisting of a material having at high field strength a voltage dependent resistance value but being free of this varistor effect at lower field strengths, in which the particle size of the preponderant part of the ceramic resistor body, as it appears particularly in an electron microscope picture, is about 1–20 microns and, especially, the smaller the greater the field strength is to be in the operating condition of the resistor body, but in no case smaller than about 1–2 microns. The particles of the ceramic resistance material shall also be as uniform as possible, that is, they should deviate little, that is, ±20–25% from the mean particle size of the major part of the ceramic resistor body. The "size" of the particle is, for reasons to be presently explained, understood to mean the length of the particle in the direction of the current path in the resistor.

The selection, in accordance with the invention, of the

particle size, and the use of particles of uniform size, in the production of the resistor material, provides the advantage of producing a resistor which, up to the desired maximum field strength, will have a resistance value which is substantially independent of voltage. This effect may be explained by the presence, in the resistor material, despite the eventually effected formation, of surface states at the particle borders, which lead to the formation of a potential wall and therewith to the varistor effects.

FIG. 3 shows in schematic manner an *n*-doped titanate and the formation of such a potential wall. The vertical line **31** indicates the particle border, for example, of two intersintered barium titanate bodies. References **32'** and **32''** represent the donor parts of two particles I and II lying closely to the lower border **33'** and **33''** of the conductivity band of the barium titanate. The upper limit of the valence band of those titanates is indicated at **34'** and **34''**. At the particle border there is at A an acceptor part which, due to its energetically low position leads to a discharge of the neighboring donors **21'**, **21''**, such donors accordingly forming a space charge zone and tending to bend the conductivity bend upwardly. The height of this bend is indicated by φ. The height of the potential wall thus designated by φ, being now within the range of the Curie temperature due to the very strong temperature dependence of the dielectric constant (e), is to a high degree temperature dependent. It rises, for example, in the case of barium titanate at an assumed acceptor density at the particle borders, of 10^{12}–10^{13}/cm.^{2} and at a donator density of about 10^{16}–10^{17}/cm.^{3} from about 0.1 volt at 20 C. to about 1 volt at 200° C.

A low voltage dependence of the resistance value occurs in the case of such potential walls, when the potential wall is by the electrons flowing in the line band substantially not overcome by the wave-mechanical tunnel effect but only thermally. However, in order to achieve this, as taught by the invention, the maximum field strength (E_{max}) at which the resistor is operated, must not be appreciably greater, at the particle borders, even at the lowest operating temperatures, than the quotient formed by the height of the potential wall divided by the particle size d. If possible, this maximum field strength shall be equal to or smaller than this quotient. Expressed differently, this means, that the voltage drop at the individual particle borders, represented by the equation

$$\frac{U}{L} \cdot d$$

(U=max. operating voltage at the resistor; L=length of current path in the resistor; d=particle "size" measured in the direction of the current path) shall at the most be equal to the height φ of the potential wall.

Accordingly, there will apply the equation

$$\frac{U}{L} \text{ max.} - E_{max} \leq \frac{\varphi}{d} \text{ min.}$$

wherein d is the average value (average particle diameter d of the resistor material) and φ min. the height φ of the potential wall at the lowest operating temperature.

It might be assumed from this equation that it is merely necessary to make the particle size small as desired so as to secure the voltage independence of the resistance of the resistor material up to any desired field strengths E_{max}. This assumption is, however, wrong because it does not take into account the fact that the particles must be larger than the width x of the potential wall noted in the figure. If they are smaller, the size φ of the potential wall, as will be realized upon reflection, will with otherwise identical conditions also be reduced, namely, approximately quadratic with the particle size d, and the permissible maximum field strength will again decrease. The optimum desired in accordance with the invention is at a point at which the average size d of the particles, measured in the direction of the length of the current path, is about equal to the value x of the width of the potential wall. At such dimensioning of the particle size, the operating field strength E of the resistor will be at a maximum, that is, the length of the current path can be short at a given operating voltage.

These considerations also show the advantages that will result when the particle sizes in the resistor are as uniform as possible, that is, when they fluctuate in the essential part of the resistor only negligibly about the average particle size; for, strong deviations upwardly or downwardly of the average particle size signify that the maximum field strength at which the resistance value is substantially still voltage-independent, is reduced either responsive to the value φ of the potential wall becoming too small (in the case of particles which are too small) or responsive to the voltage of the individual particle borders becoming too high (in the case of particles which are too large). The optimum particle size d is present, and in accordance with the invention shall be realized as closely as possible, when it is equal to the quotient of the term density (acceptor density A) on the surface of the particles divided by the impurity density (donor density D) in the resistor material ($d=A:D$).

It will be apparent from the foregoing considerations that it is in the production of the resistor essential that the particle sizes in the finished resistor, that is, the particle diameters d measured substantially in the direction of the current flowing through the resistor, correspond to the requirements. The particle diameters transverse of the direction of flow of the operating current are of lesser importance since the phenomena taking place at the particle borders lying approximately parallel to paths of the operating current influence the voltage dependence of the resistance value only inconsiderably or not at all.

It is accordingly possible by the determination of the particle sizes and by the use of particles of approximately the same size, to make the maximum operating voltage of the resistor high, that is, to keep the length of the current path in the resistor short; and it is for this reason advantageous to produce disk-shaped resistors to be contacted barrier-free as far as possible in the manner as explained with reference to FIG. 2. The donor density of the ceramic material 1 may in this case amount to 10^{16} impurity centers per cubic centimeter and the acceptor density at the particle borders to about 10^{12} to 10^{13} impurity centers per square centimeter; moreover, since the particle sizes are to fluctuate substantially only slightly about the optimum value, the particles to be used in this case will have a size from about 5 to 8 microns.

Instead of choosing an optimum particle size, it is possible to proceed in accordance with the previously noted formula

$$d=\frac{A}{D}$$

so as to obtain, with a given particle size d, a field strength as high as possible by selecting the donor density correspondingly. In the above mentioned example, this means that, with a particle size varying from 5 to 8 microns and an acceptor density A from about 10^{12} to 10^{13} impurity centers per square centimeter, the donor density D in the Perowskit is to be made approximately equal to 10^{16} impurity centers per cm.^{3}; that is, to dope the Perowskit with about 10^{16} donors per ccm.

The technical problem attending a relay-free temperature stabilization, for example, micro-thermostats for temperature sensitive structural parts, for example, oscillating quartz elements, or for power-stabilized heating devices to be used within a wide voltage range (for example, immersion heaters for 110–220 v.) or for heating elements with regulatable terminal temperature (for example, flat irons), may in accordance with the invention be solved in simple manner by the use of resistors as described herein.

The positive temperature coefficient of these resistors is particularly suitable for a relay-free and trouble-free automatic temperature stabilization of electrically heated

appliances. Among the many possible applications, the invention suggests as example a circuit arrangement comprising a temperature dependent resistor the resistance value of which increases strongly with rising temperature, that is, by approximately one tens power at about 20° temperature rise (thermistor), such resistor being either connected serially with the heating resistor or serving by itself as heating resistor.

The heating of the corresponding appliance therefore is effected, for example, in customary manner by a heating coil the resistance of which changes but little with the temperature, the current flowing through such heating coil being conducted through a resistor embodying the described features, which is disposed in more or less fixed heat exchange with the device to be heated. The resistance of such resistor will steeply rise when the temperature reaches the terminal value and will thus reduce the heating current.

The terminal temperature can be varied as desired by variation of the heat exchange relationship, for example, variation of the spacing between the resistor and the object to be heated. The current will immediately strongly increase when heat is drawn from the appliance, until the "switching-off" temperature is reached. With relatively small heat withdrawal, the "idling current" will be correspondingly low, for example, in the case of an inactive heating plate, it will amount to a few milliamperes. The magnitude of the voltage of the supply current (110 v.–220 v.) has due to the steepness of the resistance rise practically no effect on the terminal temperature.

The heating of the appliance may, however, be effected directly by the heat developed by such resistor. The ceramic body of the resistor thereby takes the place of the heating coil. The prerequisite for this entirely new kind of heating is, that the low cold resistance of the resistor is so high that the current consumption and therewith the speed of heating up of the appliance is not too great. For example, if a current of 2 amperes is to be obtained at 220 v., the cold resistance of the resistor must be 110 ohms. Resistors with, for example, rectangular cross section and having such cold resistance, can be easily produced. They are, for example, pressed against the underside of a plate to be heated with interposition of a thin insulating mica layer. The better the heat exchange contact is, the quicker will the plate assume the temperature at which the resistor will cut down the current. The current taken up by the resistor rods regulates itself automatically so that the assumed wattage is equal to the heat energy given off. Accordingly, the higher the supply voltage, the weaker will be the current.

In the corresponding circuit arrangement, the setting of the desired terminal temperature can be effected by the setting of the heat exchange transition of the resistor with respect to the body the temperature of which is to be regulated. Accordingly, in this temperature regulation, the amount of heat passing from the resistor to the appliance is adjustable at the amount of heat generated therein, that is, the spacing between the resistor and, for example, the plate to be heated, is variable. Since the required regulation operations are effected in steady manner, they do not entail disturbing high frequency effects and the corresponding appliances require no interference protection. Thermal overloading which limits the life of customary heating elements is due to the automatic temperature limitation practically excluded.

Explanations as to the use of a resistor according to the invention will now be supplied with reference to embodiments illustrated in FIGS. 4 and 5.

FIG. 4 shows a flat iron comprising a circuit arrangement for temperature control and limitation according to the invention. The heating resistor **44** is disposed in series with the resistor **42**. The spacing **45** between the resistor **42** and the plate **43** to be heated can be adjusted by means of the device **41**, thereby effecting adjustment of the desired terminal temperature. Disk-shaped configuration of the resistor **42** is in this case particularly favorable.

FIG. 5 illustrates a heating plate **56** provided with a heating resistor formed of a plurality of parallel disposed rod-shaped resistor rods **58**. Numeral **57** indicates a mica layer serving for insulation purposes. Screws **51** extending through a pressure plate **59** are provided for pressing the resistor rods **58** against the mica layer **57** on the underside of the plate **56** to be heated, thus providing for as good a heat exchange contact as possible so that the temperature of the plate **56** will practically be equal to that of the rods **58**. Numeral **50** indicates a cord having a plug for connecting the device to a suitable current source.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

We claim:

1. In a resistor having a resistor body which has at least in the upper region of the operating temperature range a positive temperature coefficient of the resistance value, said resistor body being made of ferroelectric material with a Curie temperature, above which such material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, said material being conductive by impurity centers included therein, whereby the respective spacing of the donors from the line band and of acceptors from the valence band is considerably smaller than one half of the width of the prohibited zone between the valence band and the line band while the intrinsic conductivity or conductivity due to the presence of other impurity centers is lower and especially negligibly low as compared with the conductivity which is due to the presence of said first named impurity centers; a device for achieving negligibly low voltage dependence of the total resistance value, said device comprising current lead contacts placed barrier-free upon said resistor body and being made of a common metal selected from the class of metals consisting of aluminum and zinc or of an alloy with a high content of at least one of said common metals.

2. A resistor according to claim 1, wherein the resistor body is made of n-conductive barium titanate the specific resistance of which is at a temperature below the Curie temperature of the ferroelectrical basic material less than 100 ohms per centimeter.

3. A resistor according to claim 1, having a rodlike resistor body, comprising a contact layer disposed practically voltage independent upon said rodlike resistor body, and a mechanically strong metal contact part which is metallically connected with said contact layer.

4. A resistor according to claim 1, wherein said current lead contacts are reinforced by a layer of silver.

5. A resistor according to claim 1, comprising current lead means and contact layers which are mechanically and electrically firmly interconnected by solder consisting of pure tin the melting temperature of which lies considerably above the Curie point of the ferroelectric basic material of the crystal particles of the resistor body, particularly above the temperature at which the resistor material assumes in operation its maximum resistance value.

6. A resistor having a resistor body which has at least in the upper region of the operating temperature range a positive temperature coefficient of the resistance value, said resistor body being made of ferroelectric material with a Curie temperature, above which such material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, said material being conductive by impurity centers included therein, whereby the respective spacing of the donors from the line band and of acceptors from the valence band is considerably smaller than one half of the width of the prohibited zone between the valence band and the

line band while the intrinsic conductivity or conductivity due to the presence of other impurity centers is lower and especially negligibly low as compared with the conductivity which is due to the presence of said first named impurity centers, wherein the dimensions, with respect to length of current path and cross-sectional area thereof, are selected so that the field strength appearing in said resistor body remains so low that voltage dependence which is unavoidable in high resistance condition thereof cannot become effective.

7. A resistor having a resistor body which has at least in the upper region of the operating temperature range a positive temperature coefficient of the resistance value, said resistor body being made of ferroelectric material with a Curie temperature, above which such material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, said material being conductive by impurity centers included therein, whereby the respective spacing of the donors from the line band and of acceptors from the valence band is considerably smaller than one half of the width of the prohibited zone between the valence band and the line band while the intrinsic conductivity or conductivity due to the presence of other impurity centers is lower and especially negligible low as compared with the conductivity which is due to the presence of said first named impurity centers, wherein the particle size (d) of the preponderant part of the resistor body is approximately equal to the quotient from surface term density (A) to the impurity center density (D), amounting to

$$\left(d \approx \frac{A}{D}\right)$$

8. A resistor having a resistor body which has at least in the upper region of the operating temperature range a positive temperature coefficient of the resistance value, said resistor body being made of ferroelectric material with a Curie temperature, above which such material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, said material being conductive by impurity centers included therein, whereby the respective spacing of the donors from the line band and of acceptors from the valence band is considerably smaller than one half of the width of the prohibited zone between the valence band and the line band while the intrinsic conductivity or conductivity due to the presence of other impurity centers is lower and especially negligibly low as compared with the conductivity which is due to the presence of said first named impurity centers, wherein the particle size of the preponderant part of the resistor body amounts to about 1 micron to 20 microns.

9. A resistor having a resistor body which has at least in the upper region of the operating temperature range a positive temperature coefficient of the resistance value, said resistor body being made of ferroelectric material with a Curie temperature, above which such material loses its permanent polarization, lying at least below the upper limit of the operating temperature range, said material being conductive by impurity centers included therein, whereby the respective spacing of the donors from the line band and of acceptors from the valence band is considerably smaller than one half of the width of the prohibited zone between the valence band and the line band while the intrinsic conductivity or conductivity due to the presence of other impurity centers is lower and especially negligibly low as compared with the conductivity which is due to the presence of said first named impurity centers, wherein the surface of the resistor body is for barrier-free contacting thereof cleaned by the application of a pretreatment selected from the class of treatments consisting of electrical treatment, especially a glow discharge, and chemical treatment.

10. A resistor according to claim 9, wherein said resistor body is positively poled for the application of the glow discharge.

11. A resistor according to claim 9, wherein the glow discharge is effected by the use of alternating voltage.

References Cited in the file of this patent

UNITED STATES PATENTS

2,501,322	Ferguson et al.	Mar. 21, 1950
2,710,329	Herterick	June 7, 1955
2,819,373	Allman	Jan. 7, 1958
2,864,713	Lewis	Dec. 16, 1958
2,870,307	Milliken et al.	Jan. 20, 1959
2,911,370	Kulcsar	Nov. 3, 1959