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(54) Making electrical contact between metals and resistive elements.

(57) In an electrical device comprising first and second members having different resistivities, a thin contact layer of intermediate resistivity is provided between the first and second members. The contact layer, (which may comprise a conductive polymer) is intimately bonded to the member of highest resistivity (which may comprise a second conductive polymer) e.g., by a printing process. The member of lowest resistivity may comprise a third conductive polymer, in which case it may be intimately bonded to the intermediate contact layer, e.g., by a printing process, or it may comprise a metallic member, in which case good electrical contact may be made merely by pressing the metallic member against the contact layer even when the contact area is large and/or long, and even when the pressure is sufficiently low to permit, if necessary, relative movement of the metallic member and the contact layer without disrupting the bond between the contact layer and the resistive element. A preferred device comprises four or more members of different resistivities. The members are arranged adjacent each other in order of decreasing resistivity. The least resistive member preferably comprises a metal and the other members conductive polymer materials.

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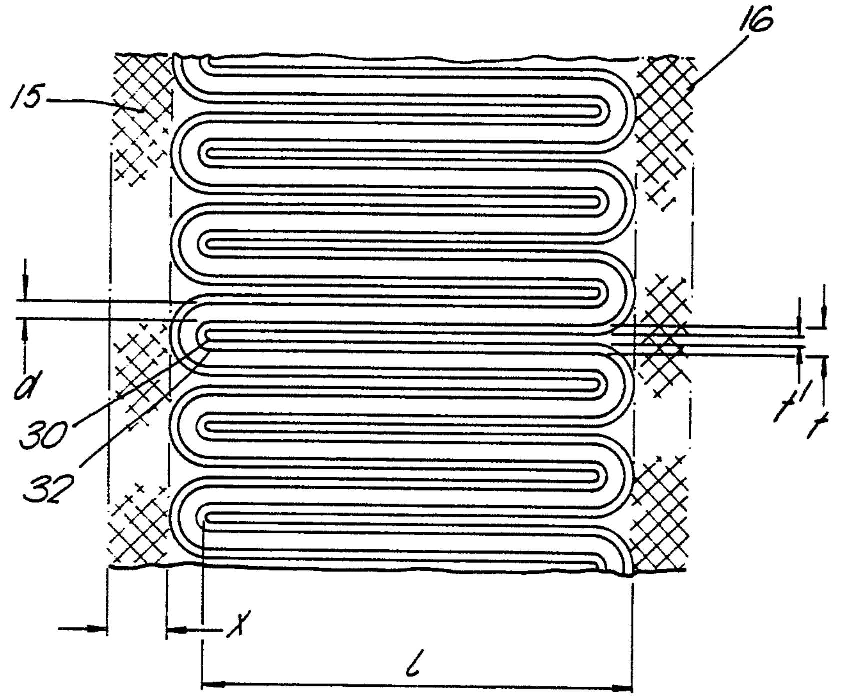
Fig. 5.



MAKING ELECTRICAL CONTACT BETWEEN METALS AND RESISTIVE ELEMENTS

This invention relates to electrical devices comprising conductive members having different resistivities.

Many electrical devices, particularly heaters, comprising conductive members having different resistivities are known. Such devices may comprise, for example, a metallic member used in conjunction with a resistive element such as a conductive polymer, i.e. a mixture comprising a conductive filler and an organic polymer (this term being used to include polysiloxanes), the filler being dispersed in the organic polymer or otherwise held together by the organic polymer, or a ceramic. The conductive polymer may exhibit PTC behavior. Documents describing conductive polymer compositions and devices comprising them include U.S. Patents Nos. 2,952,761, 2,978,665, 3,243,753, 3,351,882, 3,571,777, 3,757,086, 3,793,716, 3,823,217, 3,858,144, 3,861,029, 3,950,604, 4,017,715, 4,072,848, 4,085,286, 4,117,312, 4,177,376, 4,177,446, 4,188,276, 4,237,441, 4,242,573, 4,246,468, 4,250,400, 4,252,692, 4,255,698, 4,271,350, 4,272,471, 4,304,987, 4,309,596, 4,309,597, 4,314,230, 4,314,231, 4,315,237, 4,317,027, 4,318,881, 4,327,351, 4,330,704, 4,334,351, 4,352,083, 4,388,607, 4,398,084, 4,413,301, 4,425,397, 4,426,339, 4,426,633, 4,427,877, 4,435,639, 4,429,216, 4,442,139, 4,459,473, 4,481,498, 4,476,450, and 4,502,929; J. Applied Polymer Science 19, 813-815 (1975), Klason and Kubat; Polymer Engineering and Science 18, 649-653 (1978), Narkis et al; and commonly assigned U.S. Serial Nos. 601,424 now abandoned, published as German OLS No. 1,634,999; 732,792 (Van Konynenburg et al), now abandoned, published as German OLS No. 2,746,602; 798,154 (Horsma et al), now abandoned, published as German OLS No. 2,821,799; 134,354 (Lutz); 141,984 (Gotcher et al), published as European Application No. 38,718; 141,988 (Fouts et al), published as European Application No. 38,718, 141,989 (Evans), published as European Application No. 38,713, 141,991 (Fouts et al), published as European Application No. 38,714, 150,909 (Sopory), published as UK Application No. 2,076,106A, 184,647 (Lutz), 250,491 (Jacobs et al) published as European Application No. 63,440, 272,854 and 403,203 (Stewart et al), published as European Patent Application No. 67,679, 274,010 (Walty et al), 300,709 and 423,589 (Van Konynenburg et al), published as European Application No. 74,281, 369,309 (Midgley et al), 483,633 (Wasley), 493,445 (Chazan et al), published as European Patent Application Publication No. 128,664, 606,033, (Leary et al), published as European Application No. 119,807, 509,897 and 598,048 (Masia et al) published as European Application Publication No. 133,748, 524,482 (Tomlinson et al) published as European Application Publication No. 134,145, 534,913 (McKinley), 535,449 (Cheng et al) published as European Application No. 138,424, 84,306,456.9, 552,649 (Jensen et al) published as European Application No. 144,187 and 904,736, published as UK Patent Nos. 1,470,502 and 1,470,503. The application contemporaneously filed with this application (our reference MP0959-COM) corresponding to U.S. Serial No. 650,918 and European Patent Application No. 85300415.8 corresponding to U.S. Serial No. 573,099 (MP0897, Batliwalla et al). The disclosure of each of the patents, publications and applications referred to above is incorporated herein by reference.

Care is required to ensure satisfactory electrical contact, with a minimum of contact resistance, between two members of different resistivities. This is especially true when a large and/or long contact area is needed, as for example in strip heaters and large sheet heaters, where contact is to be made, for example, between a metallic member and a resistive element composed of a conductive polymer. Methods have been proposed for achieving such contact between a metallic member and a resistive element. Some of those methods involve heating the metallic member and the conductive polymer in contact therewith at a temperature above the melting point of the conductive polymer; the molten conductive polymer can be contacted with a suitably preheated metallic member, and/or the metallic member and conductive polymer can be heated after they have been brought into contact. It is also known to coat the metallic member with a highly conductive polymer, e.g., containing a relatively high concentration of silver or graphite, before contacting it with the conductive polymer of the resistive element. Other proposed methods involve the use of conductive adhesives, staples or rivets (or other low resistance connection member).

We have now discovered that if a thin contact layer, composed of a material whose resistivity is between that of two conductive members having different resistivities is sandwiched between the two conductive members and is bonded to the surface of the highest resistivity member, improved electrical contact between the said two members is achieved.

A first aspect of the present invention provides an electrical device which comprises:

(1) a resistive element composed of a first material which has a resistivity at 23°C of 1 to 500,000 ohm.cm;

(2) a contact layer which is directly bonded to a surface of the resistive element, and is composed of a second conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the first material; and

(3) a further member which is composed of a third conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the second material, preferably a metal, said further member being in direct physical contact with the contact layer and being maintained in such contact substantially only by means of pressure over a connection area which is at least 1.61 cm^3 (0.5 $inch^2$) in area or which has at least one dimension greater than 2.54 cm (1 inch),

the components of the device being positioned such that the device can be connected to a source of electrical power so that an electrical path exists from the further member to the resistive element through the contact layer.

With such an arrangement good electrical contact between the resistive element and the further member, that is the lowest resistivity member, can be achieved merely by pressing the further member against the contact layer, even when the connection area is large and/or long and even when the pressure is sufficiently low to allow the further member to be moved relative to the contact layer. In one preferred embodiment the further member provides a connection means for connection, for example to a power supply.

A second aspect of the present invention provides an electrical device which comprises:

(1) a resistive element composed of a first conductive material, which has a resistivity at 23°C of 1 to 500,000 ohm.cm;

(2) a contact layer which is supported by and bonded to a surface of the resistive element, and is composed of a second conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the first material; and

(3) a further member which is composed of a third conductive material having a resistivity at 23°C greater than $1x10^{-5}$ ohm.cm but less than the resistivity at 23°C of the second material, the further member being in direct physical contact with, and preferably being bonded to, the contact layer,

the components of the device being positioned such that the device can be connected to a source of electrical power so that an electrical path exists from the further member to the resistive element through the contact layer.

A third aspect of the present invention provides an electrical device which comprises

(1) a laminar resistive element composed of a first conductive material having a resistivity at 23°C of 1 to 500,000 ohm.cm and comprising spaced apart substantially flat surfaces, which flat surfaces are in the same plane;

(2) interdigitated contact layers, composed of a second conductive material having a resistivity at 23°C which is less than the resistivity of the first material, the contact layers being directly bonded to respective ones of the substantially flat surfaces; and

(3) interdigitated further members composed of a third conductive material having a resistivity at 23°C greater than $1x10^{-5}$ ohm.cm but less than the resistivity at 23°C of the second material, the further members being bonded to respective ones of the contact layers to provide a plurality of interdigitated electrodes, which are positioned and shaped such that when they are connected to a source of electrical power, they cause current to flow between them, through and in the plane of the resistive element.

In the devices of the invention, there is preferably no direct physical contact between the resistive element and the further member.

The resistive element in the devices of the invention is preferably composed of a conductive polymer. When the device is a heater, the conductive polymer preferably exhibits PTC behavior, thus rendering the heater self-regulating. The preferred range of resistivity at 23°C depends upon the dimensions of the heater and the power supply to be used, e.g. 5 to 50 ohm.cm for voltages up to 6 volts DC, 50 to 500 ohm.cm for 4 to 60 volts DC, 500 to 10,000 ohm.cm for 110 to 240 volts AC and 10,000 to 100,000 ohm.cm for voltages greater than 240 volts AC. The conductive filler in the conductive polymer usually comprises, and preferably consists essentially of, carbon black.

The contact layer preferably also is composed of a conductive polymer. The contact layer can exhibit PTC, substantially ZTC or NTC behavior in the operating temperature range of the device. The ratio of the resistivity of the resistive layer material to the resistivity of the contact layer material is preferably at least 20:1, preferably at least 100:1, especially at least 1000:1, or even higher, e.g. at least 100,000:1. The contact layer can be applied to the resistive layer by printing a conductive ink thereon, or through use of polymer thick film technology, or by a process comprising an etching step, or in any other way. The contact layer can be present only between the most conductive member and the resistive element, or can extend beyond the connection member, in which case it may act as a preferential current carrier.

In the device according to the first aspect of the present invention, wherein the lowest resistivity member is preferably metal and preferably functions as a connection means, it is preferred that the contact layer extends beyond the lowest resistivity member in which case the contact layer can provide one or more electrodes which extend beyond the connection member.

The electrodes provided by the contact layer are preferably arranged in a manner similar to that disclosed in our copending, Application No. 85300415.8 filed 85/01/22 corresponding to U.S. Serial No. 573,099 (MPO897), the disclosure of which is incorporated herein by reference, i.e. there are a plurality of ribbon-shaped electrodes which are dimensioned and positioned on a surface of the resistive heating element (in our case the highest resistivity layer) so that

(a) when current passes between the electrodes, a substantial proportion of the current is parallel to the faces of the resistive element, and

(b) the ratio of the average width of the electrodes, measured parallel to the faces of the resistive element, to the average distance between adjacent electrodes between which current passes, measured parallel to the faces of the resistive element, is at least 0.01:1, particularly at least 0.1:1.

Preferably the electrodes are so positioned and dimensioned that, at all points, the distance between adjacent electrodes between which current passes, measured parallel to the faces of the resistive element, is not more than three times the average distance between adjacent electrodes between which current passes, measured parallel to the faces of the resistive element. It is particularly preferred that the ratio of the average width of the electrodes to the average distance between the electrodes between which current passes is from 0.4:1 to 5:1, especially an arrangement in which the electrodes comprise a plurality of parallel bars which are preferably spaced apart from each other by substantially the same distance. Preferably adjacent electrodes are less than 1 inch apart. When the resistive element is conductive polymer which has been melt-extruded, the electrodes are preferably arranged so that the current flows along the direction of extrusion.

In the device according to the second aspect of the present invention, wherein the further member has a resistivity greater than $1x10^{-5}$ ohm.cm, and is therefore non-metallic, it is preferred that the contact layer has the same configuration as, and extends slightly beyond, the further member, so that there is no direct contact between the further member and the resistive element. In this case the further member, may itself provide one or more electrodes. The devices of the present invention each provide three components arranged relative to each other so that an electrical path can exist from the component having the lowest resistivity of the three components to the component having the highest resistivity of the three components through the other, intermediate resistivity component. The devices may comprise more than three components of different resistivity. Where there are more than three components, the components are preferably arranged sequentially in order of their resistivity, so that the electrical contact between any two components is improved by the presence of an intermediate resistivity layer between them. For example, a preferred electrical device comprises four components of different resistivities in which the component having the lowest resistivity of the four comprises a metal connection member for connection to an electrical power source. It contacts a second higher resistivity member, which preferably extends beyond the connection member to provide electrodes, and in turn contacts a third higher resistivity layer, which preferably has the same configurations, but extends slightly beyond the second layer. The third layer in turn contacts a higher resistivity layer which preferably provides a substrate resistive element. The device according to the third aspect of the invention comprises four members of sequentially increasing resistivity.

By arranging one or more intermediate resistivity layers between the members of different resistivities in this way, good electrical contact may be achieved between members having resistivities differing by 10^{10} ohm.cm, and even up to 10^{12} ohm.cm.

In preferred devices according to the invention, particularly in preferred devices according to the first aspect of the present invention, the contact layer preferably comprises a conductive polymer in which the conductive filler consists of or contains a metal, preferably silver, or a mixture of silver with graphite or silver with graphite and carbon black. In this case the contact layer preferably has a resistivity in the range $2.5x10^{-5}$ to $1x10^{-3}$ ohm.cm. In other preferred devices according to the invention, particularly in devices according to the second aspect of the present invention, the contact layer preferably comprises a conductive polymer in which the conductive filler consists of graphite and/or carbon black, or a mixture of graphite and/or carbon black with a metal, for example silver, wherein there is more graphite and/or carbon black than silver. In this case the contact layer preferably has a resistivity in the range $0.5x10^{-2}$ to 0.1

ohm.cm.

Preferred features of the further member in devices according to the invention are now discussed. Particularly in devices according to the first aspect of the present invention, wherein the further member preferably provides a connection member, that member is preferably composed of at least one metal, e.g. copper, which is usually preferred for reasons of economy, aluminum, nickel, silver or gold, or a coating of one metal on another, e.g. nickel-coated or tin-coated copper, and is usually a wire or sheet or tape, and may be straight or bent or folded. Generally there are two or more connection members in each device, the members being connectable to a power supply to cause current to pass through the resistive element. Often the connection area between each connection member and a contact layer is at least 0.5 $inch^2$ preferably at least 5 $inch^2$, e.g. at least 10 $inch^2$, in area and can be very much more. The connection area often has at least one dimension greater than 0.5 $inch^2$, preferably greater than 1 inch and can be much more, e.g. at least 5 inch. Preferably the connection member makes substantially continuous contact with the contact layer, but this is not essential.

In the devices according to the invention and particularly in devices according to the second aspect of the present invention wherein the further member has a resistivity greater than $1x10^{-5}$, and is therefore non-metallic, that member is preferably composed of a conductive polymer. The member can exhibit PTC, substantially ZTC or NTC behaviour in the operating temperature range of the device. In certain embodiments of devices according to the second aspect of the invention the ratio of the resistivity of the contact layer to the resistivity of the further member may be from as little as 5:1 to as much as 10,000:1, preferably it is in the range 10:1 to 1,000:1, for example 100:1.

The further member has a resistivity less than that of the contact layer but greater than $1x10^{-5}$ ohm.cm. Preferably the further member has a resistivity in the range $1x10^{-5}$ to $1x10^{-2}$ ohm.cm, more preferably in the range $1x10^{-4}$ to $1x10^{-3}$ ohm.cm. In a preferred embodiment the resistivity is about $5x10^{-4}$ ohm.cm.

Where the further member comprises a conductive polymer, it may be applied to the contact layer in the same way that the contact layer is applied to the resistive layer, that is by printing a conductive ink on the contact layer, through the use of polymer thick film technology, or by a process comprising an etching step or it may be applied in any other way.

Devices according to the first aspect of the invention include (i) sheet heaters, e.g. a sheet heater wherein the resistive element is a laminar element comprising spaced-apart substantially flat surfaces to which the contact layers are bonded and in particular include sheet heaters wherein the further members are connection members, the connection members having substantially flat surfaces which are pressed against the respective contact layers, and the contact layers extend beyond the areas of contact with the connection members to provide a plurality of electrodes; and (ii) strip heaters wherein the resistive element is in the form of a strip comprising spaced-apart concave surfaces to which the contact layers are bonded, and the connection members have substantially complementary convex surfaces which are pressed against the respective contact layers.

Devices according to the second aspect of the present invention include sheet heaters, wherein the further member itself provides a plurality of electrodes and wherein the contact layer is at least coextensive with the electrodes and preferably extends slightly beyond the electrodes. Preferably the contact layer has the same configuration as the electrodes. The contact layer and the electrodes are preferably each in the form of conductive inks that are applied sequentially to the resistive layer by a printing process.

Devices according to the second aspect of the invention preferably also include a metal connection member, for connection to an electrical power source. The connection member is preferably in contact with the electrodes, and preferably has all the preferred features attributed to the further member of the devices according to the first aspect of the invention.

In devices according to the second aspect of the invention, the resistive element is preferably a laminar element comprising spaced-apart substantially flat surfaces to which respective contact layers are bonded, to which, in turn, respective further members are bonded, the further members providing a plurality of electrodes, which, when connected to a source of electrical power, cause current to flow through the resistive element, preferably in the plane of the resistive element. Preferably the spaced apart, substantially flat surfaces are in the same plane, and the electrodes are interdigitated. The contact layers preferably have the same general configuration as the electrodes, but extend beyond the electrodes. In the case of interdigitated electrodes the contact layers are preferably from 1.5 to 3 times as wide as the electrodes, for example about twice as wide.

Devices according to the present invention preferably include a dielectric layer, covering and intimately bonded to at least part of the electrodes. Devices according to the invention, especially devices which are heaters, preferably also comprises a laminar polymeric insulating element which is adjacent to, but not secured to, the electrodes or dielectric layer (if present), or to the electrode bearing face of the resistive element. Preferably the insulating element is arranged in a manner described in the Patent Application filed contemporaneously with this application corresponding to U.S. Serial No. 650,918 (MP0959, Batliwalla et al), the disclosure of which is incorporated herein by reference.

In the device according to the first aspect of the present invention the connection area between the resistive element and the further member is at least 2.54 (1), preferably at least 12.70 square centimeters (5 square inches) in area. The connection area preferably has at least one dimension greater than 7.62 cm (3 inches).

An advantage of devices according to the invention is that they can be used in applications where it is necessary for the device to carry a current of at least 5, and in some situations at least 10 Amps.

In devices according to the second aspect of the present invention, particularly in sheet heaters, wherein the further members preferably provide a plurality of electrodes, for example interdigitated electrodes, on a surface of a laminar resistive element, and the respective contact layers provide an intermediate resistivity layer between the electrodes and the resistive element, the presence of the contact layers not only improves the electrical contact between the electrodes and resistive elements, but also significantly improves the voltage stability of the devices, as compared with devices in which there are no intermediate contact layers and the electrodes directly contact the resistive element. The voltage stability of a device indicates how the resistivity of the device changes with voltage. It is conventionally recorded in terms of a linearity ratio (LR), that is the ratio of the resistance at a low voltage (typically 30mV) to the resistance at a high voltage (typically 100V). Ideally, for a completely stable material the linearity ratio is 1. The improvement in the voltage stability in devices according to the second aspect of the invention, as compared to identical devices in which there is no intermediate resistivity layer between the electrodes and the resistive layer, is particularly substantial where the device has been subjected to in-rush currents or to temperature ageing.

A comparative test was carried out to show the improvement in voltage stability of a device according to the second aspect of the present invention (incorporating an intermediate resistivity layer between the electrodes and the resistive element), as compared to a comparative, control, device (with no intermediate resistivity layer), after submitting the devices to a cycling voltage treatment or an ageing treatment. In the test, comparative control devices (with no intermediate resistivity layer) were prepared by printing on a conductive polymer resistive element a single layer of interdigitated electrodes, comprising a vinyl based conductive ink containing silver graphite and carbon black, and devices according to the invention (with an intermediate layer) were prepared by sequentially printing onto an identical resistive element interdigitated contact layers, and respective interdigitated electrodes over each contact layer, the contact layer comprising a vinyl based conductive ink containing graphite and carbon black only and having a resistivity intermediate to that of the electrodes and the resistive element. In the control devices, the interdigitated electrodes were 0.16 cm (1/16 inch) wide and separated by 0.64 cm (1/4 inch). In the devices according to the invention the electrodes were again 0.16 cm (1/16 inch) wide, the contact layers were 0.32 cm (1/8 inch) wide, and adjacent contact layers were separated by 0.64 cm (1/4 inch).

Three sets of test and control devices were prepared. The first set of devices were maintained as virgin samples. The second set of devices were subjected to a cycling voltage input in which a current at 240 Volts was pulsed on and off at 15 minute second intervals. The pulsing was carried out at 21 °C (70 °F), for 250 cycles. The cycling represent the in-service treatment of the devices which are continually switched on and off and therefore subjected to so-called "in-rush" currents each time they are switched on. A third set of devices were powered continuously at 240V and aged for 1 week at 107 °C (225 °F). The resistivity of each set of devices was measured at 21 °C (70 °F) at 30mV and 100V continuous current, and the linearity ratio of each set calculated. The results are set out in the Table below.

Table

Linearity Ratio Control Samples	Linearity Ratio Test Sample

	(no intermediate layer)	(including intermediate resistivity layer)
Virgin samples	1.005	1.005
Cycled samples	1.036	1.006
Aged samples	1.034	1.008

As can be seen the linearity ratio of the control devices is significantly and detrimentally increased by the cycling and ageing treatments, while the linearity ratio of the test devices is only slightly increased.

Embodiments of the present invention will now be described by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a cross-section through a first sheet heater according to the invention,

Figure 2 is a plan view of the resistive element, contact layers and connection members of Figure 1,

Figure 3 is a cross-section through a strip heater of the invention;

Figure 4 is a cross-section through a second sheet heater according to the invention; and

Figure 5 is a plan view of the resistive element contact layers, further members, and connection members of Figure 4.

Referring now to the drawings, Figures 1 and 2 illustrate a heater which comprises a heating element comprising a laminar conductive polymer resistive element 11 having printed on the top surface thereof inter-digitated electrodes 12 and 13 which are composed of a conductive polymer composition containing a metal, e.g. silver, as the conductive filler and having substantially lower resistivity than the conductive polymer in element 11. Bus bars 15 and 16, composed of expanded metal mesh, are folded around marginal portions of the element 11 and the electrodes 12 and 13 respectively, the marginal portions of the electrodes providing the contact layers of the present invention. An insulating jacket is formed around the heating element and bus bars by a polymeric bottom sheet 17 and a polymeric top sheet 18. Sheet 17 is secured to the bottom of the resistive element, to the bottom of the bus bars and to edge portions of the top sheet by a substantially continuous layer of adhesive 21 (as shown), or by melt bonding (not shown). The top sheet is adjacent to, but not secured to, the bus bars, electrodes and resistive element. On top of the top sheet there is a metallic, e.g. copper, foil 19 which is maintained in position by an outer polymeric insulating sheet 20, whose marginal portions are secured to the marginal portions of the sheet 18 by adhesive layers 22 and 23 (as shown), or by melt bonding (not shown). As shown in Figure 2, the electrodes have a width t and a length l, and are separated by a distance d, and the bus bars have a width x. Typical values for these variables are

t 0.08 - 0.51 cm (0.03 - 0.2 inch)
l 6.35 - 15.24 cm (2.5 - 6.0 inch)
d 0.25 - 0.76 cm (0.1 - 0.3 inch)
x 1.02 - 2.04 cm (0.4 - 0.8 inch)

Figure 3 is a cross-section through a self-regulating strip heater having a constant cross-section along its length. An elongate strip 1 of PTC conductive polymer has concave edges which are coated with contact layers 2 and 3 of a ZTC conductive polymer whose resistivity at room temperature is several times less than that of the PTC conductive polymer. Elongate wires 5 and 6, which may be solid or stranded, are pressed against the contact layers 2 and 3 respectively by means of polymeric insulating jacket 7.

Figures 4 and 5 illustrate a heater similar to that shown in Figures 1 and 2 which comprises a heating element comprising a laminar conductive polymer resistive element 11. Printed on the top surface of the resistive element 11 is an interdigitated pattern of a resistive conductive polymer composition 30 which contains carbon black, or a mixture of graphite and carbon black, as the conductive filler, and has substantially lower resistivity than the conductive polymer in the element 11. Printed over the resistive pattern 30 are interdigitated electrodes 32 which are composed of a conductive polymer containing a metal e.g. silver, as the conductive filler and having lower resistivity than the conductive polymer in the resistive pattern 30. The configuration of the electrodes 32 is identical to that of the underprint layer 30, but the electrodes are narrower than the underprint layer. Thus the layer 30 extends between the electrodes 32 and the resistive element 11 and extends slightly beyond the electrodes 32. Bus bars 15 and 16, as used in the device of Figures 1 and 2 are provided. An insulating jacket in the form of a polymeric bottom sheet 17 and a polymer top sheet 18 which is secured by adhesive 21 or by a melt bond, is also provided as in the device illustrated in Figures 1 and 2, as is a metallic foil 19 which is held in place by polymeric insulating sheet 20 secured to sheet 18 by adhesive layers 22 and 23 or by a melt bond. The width t and length l, of the electrodes 32 are the same as those for the electrodes 12 and 13 illustrated in Figure 1. The width t′ and the separation distance d′ of the underprint layer 30 are

t′ 0.15 - 1.02 cm (0.06 - 0.4 inch) d′ 0.25 - 0.76 cm (0.1 - 0.3 inch(

The invention is further illustrated by the following Examples.

Example 1

A heater as illustrated in Figures 1 and 2 was made in the following way.

The ingredients listed below were compounded together and melt-extruded at 232°C (450°F) as a sheet 0.04 cm (0.0175 inch) thick.

Ingredient	% by weight
Polyvinylidene fluoride ("Kynar")	79.7
Carbon Black (Vulcan XC-72)	10.2
Fillers and other additives	10.1

The sheet was irradiated to a dose of 14 megarads, thus cross-linking the polymer. The resistivity of the cross-linked composition at 23°C was 3,500 ohm.cm. The sheet was then heated and split into strips 18.42 cm (7.25 inches) wide. An electrode pattern as illustrated in Figure 1 was deposited on the strips, by screen-printing a graphite-and-silver-containing composition onto the strip, followed by drying. The resistivity of the printed composition, after it had dried, was about 10^{-4} ohm.cm. The distance (d) between adjacent electrodes was 0.64 cm (0.25 inch); the width (t) of each electrode was 0.16 cm (0.0625 inch); and the length (l) of each electrode was 13.72 cm (5.4 inches).

Bus bars of nickel-coated copper expanded metal, 3.81 cm (1.5 inch) wide, were folded around the edges of the electrode-bearing strip, and the assembly laminated between (A) a bottom sheet of ethylene-chlorotrifluoroethylene copolymer ("Halar") 21.6 cm (8.5 inch) wide and 0.05 cm (0.020 inch) thick, coated on the whole of its top surface with a layer 0.005 cm (0.002 inch) thick of a silicone adhesive sold by Adhesives Research Corporation under the trade name "Arclad", and (B) a top sheet of ethylene-chlorotrifluoroethylene ("Halar") 21.6 cm (8.5 inch) wide and 0.025 cm (0.010 inch) thick, placed in contact with the printed electrodes, which was coated on 1.27 cm (0.5 inch) wide edge portions of its bottom surface with a layer 0.005 cm (0.002 inch) thick of the same adhesive. Lamination was carried out at 52°C (125°F) and 690 KPa (100 psi). There was no adhesive between the top sheet and the bus bars, or between the top sheet and the conductive polymer sheet, or between the top sheet and the electrodes. A sheet of copper, 0.005 cm (0.002 inch) thick and 18.24 cm (7.25 inch) wide, was placed on the exposed surface of the top sheet, and an outer sheet of ethylene-chlorotrifluoroethylene ("Halar"), 21.6 cm (8.5 inch) wide and 0.01 cm (0.005 inch) thick, was placed over the copper sheet and laminated [at 52°C (125°F) and 690 KPa (100 psi)] to the edge portions of the bottom sheet (but not the copper foil), through 1.27 cm (0.5 inch) wide layers of 0.005 cm (0.002 inch) thick "Arclad" adhesive on edge portions of the outer sheet. There was no adhesive between the outer sheet and the copper foil.

Example 2

A heater as illustrated in Figure 4 was made in a same way to the heater illustrated in Figures 1 and 2 as described in Example 1, except that before the electrode pattern was deposited on the strips, an underprint layer comprising a graphite containing composition, having a resistivity of about 0.1 ohm.cm, i.e., intermediate between the resistivity of the resistive element and the electrodes, was deposited on the strips by screen printing, and then dried. The electrodes were then screen printed directly to overlie the underprint layer. The interdigitated portions of the underprint layers were twice as wide as the electrodes. Thus the width (t) of each electrode was 0.16 cm (0.0625 inch) and the width (t′) of each of the interdigitated portions of the underprint layer was 0.32 cm (0.125 inch). The distance (d′) between adjacent interdigitated portions of the underprint layer was 0.64 cm (0.25 inch).

Claims

1. An electrical device which comprises

(1) a resistive element composed of a first material which has a resistivity at 23°C of 1 to 500,000 ohm.cm;

(2) a contact layer which is directly bonded to a surface of the resistive element, and is composed of a second conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the first material; and

(3) a further member which is composed of a third conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the second material, said further member being in direct physical contact with the contact layer and being maintained in such contact substantially only by means of pressure over a connection area which is at least 0.5 $inch^2$ in area or which has at least one dimension greater than 1 inch,

the components of the device being positioned such that the device can be connected to a source of electrical power so that an electrical path exists from the further member to the resistive element, through the contact layer.

2. A device according to claim 1 wherein the second material has a resistivity at 23°C which is from 10^{-6} to 10^3 ohm.cm and which is such that the ratio of the resistivity at 23°C of the first material to the resistivity at 23°C of the second material is at least 20:1, and wherein the further member is composed of a metal.

3. A device according to claim 1 or 2, which comprises at least two further members in the form of continuous elongate metallic connection members which can be connected to a power source to cause current to flow through the resistive element and which make substantially continuous contact with the resistive element through respective contact layers.

4. A device according to claim 1, 2, or 3, which is a sheet heater wherein the resistive element is a laminar element comprising spaced-apart substantially flat surfaces to which the contact layers are bonded, and the metallic members have substantially flat surfaces which are pressed against the respective contact layers, wherein the contact layers preferably extending beyond the area of contact with the metallic members to provide a plurality of interdigitated electrodes.

5. A device according to claim 3, which is a strip heater wherein the resistive element is in the form of a strip comprising spaced-apart concave surfaces to which the contact layers are bonded, and the metallic members have substantially complementary convex surfaces which are pressed against the respective contact layers.

6. An electrical device which comprises

(1) a resistive element composed of a first conductive material which has a resistivity at 23°C of 1 to 500,000 ohm.cm;

(2) a contact layer which is directly bonded to a surface of the resistive element, and is composed of a second conductive material having a resistivity at 23°C which is less than the resistivity at 23°C of the first material; and

(3) a further member which is composed of a third conductive material having a resistivity at 23°C greater than $1x10^{-5}$ ohm.cm but less than the resistivity at 23°C of the second material, the further member being in direct physical contact with the contact layer,

the component of the device being positioned such that the device can be connected to a source of electrical power so that an electrical path exists from the further member to the resistive element, through the contact layer.

7. A device according to claim 6, wherein second material has a resistivity at 23°C which is from $0.5x10^{-2}$ to 0.1 ohm.cm. and which is such that the ratio of the resistivity at 23°C of the second material to the resistivity at 23°C of the third material is in the range 5:1 to 10,000:1.

8. A device according to claim 6 or 7, wherein the further member is bonded to the contact layer.

9. A device according to claim 6, 7 or 8, wherein the resistive element is a laminar element comprising spaced-apart substantially flat surfaces to which respective contact layers are bonded, and wherein, to said contact layers are bonded respective further members, to provide a plurality of electrodes, which, when connected to a source of electrical power, cause current to flow through the resistive element.

10. A device according to claim 9, wherein the electrodes are such that current flowing between them is in the plane of the resistive element.

11. A device according to any preceding claim, wherein at least one of the first and second materials is a conductive polymer which comprises an organic polymer and, dispersed in the polymer, a particulate conductive filler, which filler preferably comprises at least one of silver, graphite and carbon black.

12. A device according to any preceding claim, wherein the first material is a conductive polymer which exhibits PTC behavior in the operating temperature range of the device.

13. A device according to any preceding claim, wherein there is no direct physical contact between the resistive element and the further member.

Fig.1.

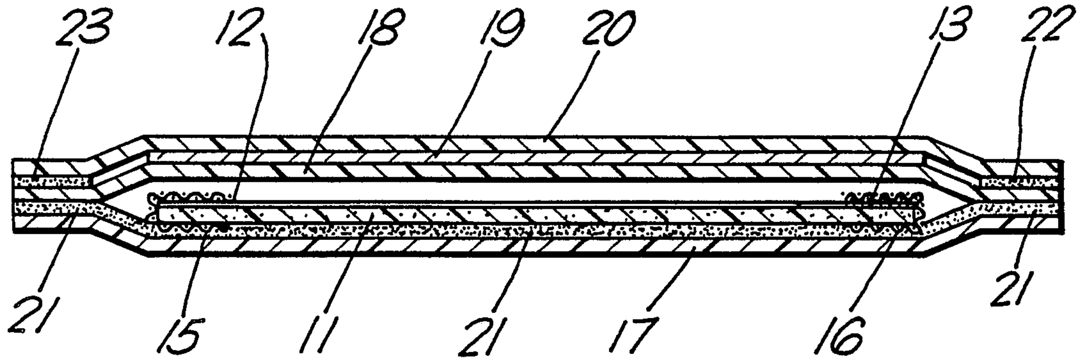


Fig.2.

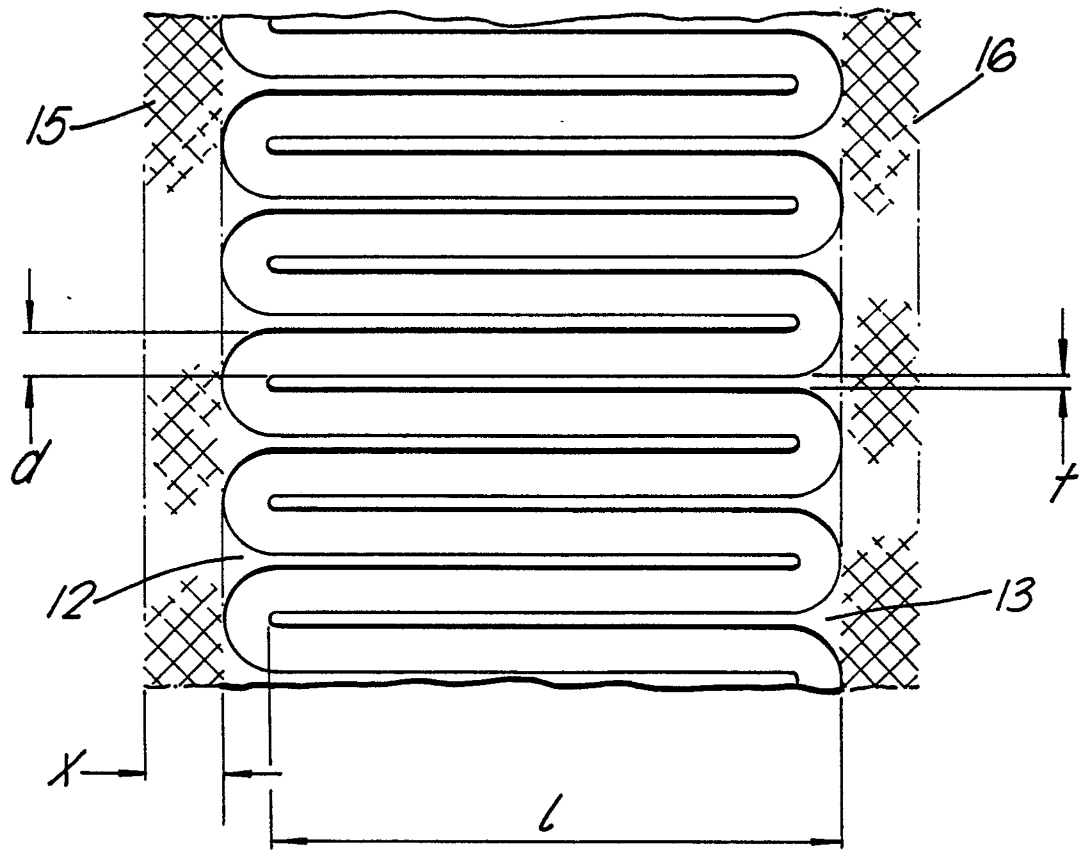


Fig . 3.

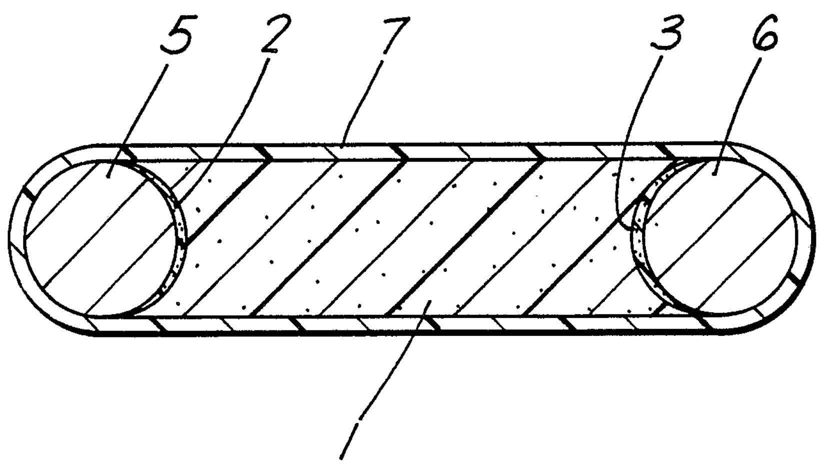


Fig . 4.

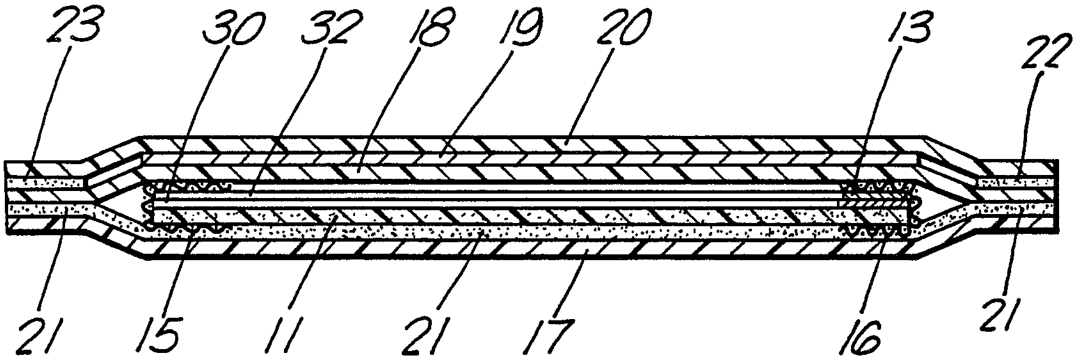


Fig. 5.