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(54) **Radiation cross-linking of PTC conductive polymers.**

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Description

This invention relates to the radiation cross-linking of PTC conductive polymers.

Conductive polymer compositions exhibiting PTC behavior, and electrical devices comprising them, have been described in published documents and in our earlier specifications. Reference may be made, for example, to 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, 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, 4,255,698, 4,272,471, 4,276,466 and 4,314,230; J. Applied Polymer Science *19*, 813—815 (1975), Klason and Kubat; Polymer Engineering and Science *18*, 649—653 (1978), Narkis et al; German OLS 2,634,999, 2,746,602, 2,755,076, 2,755,077, 2,821,799 and 3,030,799; European Published Applications Nos. 0028142, 0030479, 0038713, 0038714, 0038715 and 0038718; pending European Applications No. 81,301,767.0, 81,301,768.8 and 81,302,201.9; and pending U.S. Applications Nos. 176,300, 184,647, 254,352, 272,854 and 300,709. The disclosures of these patents, publications and applications are incorporated herein by reference.

It is known to cross-link PTC conductive polymers by radiation, and in practice the dosages employed have been relatively low, e.g. 10—20 Mrads. Higher dosages have, however, been proposed for some purposes. Thus OLS 2,634,999 recommends a dose of 20—45 Mrads; U.K. Specification No. 1,071,032 describes irradiated compositions comprising a copolymer of ethylene and a vinyl ester or an acrylate monomer and 50—400% by weight of a filler, e.g. carbon black, the radiation dose being about 2 to about 100 Mrads, preferably about 2 to about 20 Mrads, and the use of such compositions as tapes for grading the insulation on cables; US—A—3 351 882 discloses the preparation of electrical devices by embedding electrodes having a considerable area and an irregular surface, e.g. a metal mesh, in a resistor composed of a PTC conductive polymer, followed by cross-linking of the conductive polymer. The stated purpose of using electrodes of considerable area is to avoid excessive current concentrations and consequent damage to the conductive polymer. The stated purposes of the radiation are (a) to cross-link the conductive polymer adjacent the electrodes, so that the electrodes are firmly gripped, and (b) to cross-link the bulk of the conductive polymer so that it will resist softening. The cross-linking can be effected by radiation, and the patent discloses subjecting the entire resistor to a dose of 50 to 100 megarads of radiation of one or two million electron volt electrons. As shown by US—A—3 858 144 and 3 861 029, a dose of 2—15 megarads is sufficient to prevent softening of PTC conductive polymers, and higher doses are regarded as disadvantageous because they reduce crystallinity.

The higher the voltage applied to an electrical device comprising a PTC conductive polymer, the more likely it is that intermittent application of the voltage will cause the device to fail. This has been a serious problem, for example, in the use of circuit protection devices where the voltage dropped over the device in the "tripped" (i.e. high resistance) condition is more than about 200 volts. [Voltages given herein are DC values or RMS values for AC power sources]. We have now discovered that the likelihood of such failure can be substantially reduced by irradiating the conductive polymer so that it is very highly cross-linked.

In its first aspect, the invention provides a process for the preparation of an electrical device comprising (1) a cross-linked PTC conductive polymer element and (2) two electrodes which can be connected to a power source to cause current to flow through the PTC element, which process comprises cross-linking the PTC element by radiation, characterized in that the essential parts of the PTC element are irradiated to a dosage of at least 50 Mrads, subject to the proviso that if each of the electrodes has a substantially planar configuration, then one or both of the following conditions is fulfilled:

(a) the essential parts of the PTC element are irradiated to a dosage of at least 120 Mrads,

(b) the PTC element is irradiated in the absence of the electrodes and metal foil electrodes are secured to the PTC element after it has been cross-linked.

Our experiments indicate that the higher the radiation dose, the greater the number of "trips" (i.e. conversions to the tripped state) a device will withstand without failure. The radiation dose is, therefore, preferably at least 60 Mrads, particularly at least 80 Mrads, with yet higher dosages, e.g. at least 120 Mrads or at least 160 Mrads, being preferred when satisfactory PTC characteristics are maintained and the desire for improved performance outweighs the cost of radiation.

We have further discovered a method of determining the likelihood that a device will withstand a substantial number of trips at a voltage of 200 volts. This method involves the use of a scanning electron microscope (SEM) to measure the maximum rate at which the voltage changes in the PTC element when the device is in the tripped state. This maximum rate occurs in the so-called "hot zone" of the PTC element. The lower the maximum rate, the greater the number of trips that the device will withstand. Accordingly, the present invention provides, in a second aspect, an electrical device which comprises (a) a radiation cross-linked PTC conductive polymer element and (b) two electrodes which can be connected to a power source to cause current to flow through the PTC element, characterized in that if the device, while it is powered by a 200 volts DC power source and is in the tripped condition, is inspected by means of a scanning electron microscope using voltage contrast to determine the way in which the potential of the device changes between the electrodes, the maximum difference in voltage between two points separated by 10 microns is less than 4.2 volts, preferably less than 3 volts, particularly less than 2 volts, especially less than 1 volt, subject to the proviso that if each of the electrodes has a substantially planar configuration, the maximum difference is less than 3 volts.

The term "SEM scanning" is used herein to denote the following procedure. The device is inspected to see whether the PTC element has an exposed clean surface which is suitable for scanning in an SEM and which lies between the electrodes. If there is no such surface, then one is created, keeping the alteration of the device to a minimum. The device (or a portion of it if the device is too large, e.g. if it is an elongate heater) is then mounted in a scanning electron microscope so that the electron beam can be traversed from one electrode to the other and directed obliquely at the clean exposed surface. A slowly increasing current is passed through the device, using a DC power source of 200 volts, until the device has been "tripped" and the whole of the potential dropped across it. The electron beam is then traversed across the surface and, using voltage contrast techniques known to those skilled in the art, there is obtained a photomicrograph in which the trace is a measure of the brightness (and hence the potential) of the surface between the electrodes; such a photomicrograph is often known as a line scan. A diagrammatic representation of a typical photomicrograph is shown in Figure 1. It will be seen that the trace has numerous small peaks and valleys and it is believed that these are due mainly or exclusively to surface imperfections. A single "best line" is drawn through the trace (the broken line in Figure 1) in order to average out small variations, and from this "best line", the maximum difference in voltage between two points separated by 10 microns is determined.

When reference is made herein to an electrode "having a substantially planar configuration", we mean an electrode whose shape and position in the device are such that substantially all the current enters (or leaves) the electrode through a surface which is substantially planar.

The present invention is particularly useful for circuit protection devices, but is also applicable to heaters, particularly laminar heaters. In one class of devices, each of the electrodes has a columnar shape. Such a device is shown in isometric view in Figure 2, in which wire electrodes 2 are embedded in PTC conductive polymer element 1 having a hole through its centre portion.

In a second class of devices, usually circuit protection devices,

(A) the PTC element is in the form of a strip with substantially planar parallel ends, the length of the strip being greater than the largest cross-sectional dimension of the strip; and

(B) each of the electrodes is in the form of a cap having (i) a substantially planar end which contacts and has substantially the same cross-section as one end of the PTC element and (ii) a side wall which contacts the side of the PTC element. Such a device is shown in cross-section in Figure 3, in which cap electrodes 2 contact either end of cylindrical PTC conductive polymer element 1 having a hole 11 through its centre portion.

In a third class of devices, usually heaters,

(A) the PTC element is laminar; and

(B) the electrodes are displaced from each other so that current flow between them is along one of the large dimensions of the element.

In a fourth class of devices, each of the electrodes has a substantially planar configuration. Meshed planar electrodes can be used, but metal foil electrodes are preferred. If metal foil electrodes are applied to the PTC element before it is irradiated, there is a danger that gases evolved during irradiation will be trapped. It is preferred, therefore, that metal foil electrodes be applied after the radiation cross-linking step. Thus a preferred process comprises the

(1) irradiating a laminar PTC conductive polymer element in the absence of electrodes;

(2) contacting the cross-linked PTC element from step (1) with metal foil electrodes under conditions of heat and pressure, and

(3) cooling the PTC element and the metal foil electrodes while continuing to press them together.

PTC conductive polymers suitable for use in this invention are disclosed in the patents and applications referenced above. Their resistivity at 23°C is preferably less than 1250 ohm.cm, e.g. less than 750 ohm.cm, particularly less than 500 ohm.cm, with values less than 50 ohm.cm being preferred for circuit protection devices. The polymeric component should be one which is cross-linked and not significantly degraded by radiation. The polymeric component is preferably free of thermosetting polymers and often consists essentially of one or more crystalline polymers. Suitable polymers include polyolefins, e.g. polyethylene, and copolymers of at least one olefin and at least one olefinically unsaturated monomer containing a polar group. The conductive filler is preferably carbon black. The composition may also contain a non-conductive filler, e.g. alumina trihydrate. The composition can, but preferably does not, contain a radiation cross-linking aid. The presence of a cross-linking aid can substantially reduce the radiation dose required to produce a particular degree of cross-linking, but its residue generally has an adverse affect on electrical characteristics.

Shaping of the conductive polymer will generally be effected by a melt-shaping technique, e.g. by melt-extrusion or molding.

The invention is illustrated by the following Example

Example

The ingredients and amounts thereof given in the Table below were used in the Example.

TABLE

	Masterbatch			Final mix		
	g	wt%	vol%	g	wt%	vol%
Carbon black (Statex G)	1440	46.8	32.0	1141.5	33.7	26.7
Polyethylene (Marlex 6003)	1584	51.5	66.0	1256.2	37.1	55.2
Filler (Hydral 705)				948.3	28.0	16.5
Antioxidant	52.5	1.7	2.0	41.5	1.2	1.6

Notes:

Statex G, available from Columbian Chemicals, has a density of 1.8 g/cc, a surface area (S) of 35 m^2/g, and an average particle size (D) of 60 millimicrons.

Marlex 6003 is a high density polyethylene with a melt index of 0.3 which is available from Phillips Petroleum.

Hydral 705 is alumina trihydrate available from Aluminum Co. of America.

The antioxidant used was an oligomer of 4,4-thio bis (3-methyl-6-5-butyl phenol) with an average degree of polymerization of 3—4, as described in U.S. Patent Number 3,986,981.

After drying the polymer at 70°C and the carbon black at 150°C for 16 hours in a vacuum oven, the ingredients for the masterbatch were dry blended and then mixed for 12 minutes in a Banbury mixer turning at high gear. The mixture was dumped, cooled, and granulated. The final mix was prepared by dry blending 948.3 g of Hydral 705 with 2439.2 g of the masterbatch, and then mixing the dry blend for 7 minutes in a Banbury mixer turning at high gear. The mixture was dumped, cooled, granulated, and then dried at 70°C and 1 torr for 16 hours.

Using a cross-head die, the granulated final mix was melt extruded as a strip 1 cm wide and 0.25 cm thick, around three wires. Two of the wires were preheated 20 AWG (0.095 cm diameter) 19/32 stranded nickel-plated copper wires whose centers were 0.76 cm apart, and the third wire, a 24 AWG (0.064 cm diameter) solid nickel-plated copper wire, was centered between the other two. Portions 1 cm long were cut from the extruded product and from each portion the polymeric composition was removed from about half the length, and the whole of the center 24 AWG wire was removed, leaving a hole running through the polymeric element. The products were heat treated in nitrogen at 150°C for 30 minutes and then in air at 110°C for 60 minutes, and were then irradiated. Samples were irradiated to dosages of 20 Mrads, 80 Mrads or 160 Mrads. These samples, when subjected to SEM scanning, were found to have a maximum difference in voltage between two points separated by 10 microns of about 5.2, about 4.0 and about 2.0 respectively. Some of these samples were then sealed inside a metal can, with a polypropylene envelope between the conductive element and the can.

The resulting circuit protection devices were tested to determine how many test cycles they would withstand when tested in a circuit consisting essentially of a 240 volt AC power supply, a switch, a fixed resistor and the device. The devices had a resistance of 20—30 ohms at 23°C and the fixed resistor had a resistance of 33 ohms, so that when the power supply was first switched on, the initial current in the circuit was 4—5 amps. Each test cycle consisted of closing the switch, thus tripping the device, and after a period of about 10 seconds, opening the switch and allowing the device to cool for 1 minute before the next test cycle. The resistance of the device at 23°C was measured initially and after every fifth cycle. The Table below shows the number of cycles needed to increase the resistance to 1-1/2 times its original value.

Device irradiated to a dose of	Resistance increased to 1-1/2 times after
20 Mrads	40—45 cycles
80 Mrads	80—85 cycles
160 Mrads	90—95 cycles

Claims

1. A process for the preparation of an electrical device comprising (1) a cross-linked PTC conductive polymer element and (2) two electrodes which can be connected to a power source to cause current to flow

through the PTC element, which process comprises cross-linking the PTC element by radiation, characterized in that the essential parts of the PTC element are irradiated to a dosage of at least 50 Mrads, subject to the proviso that if each of the electrodes has a substantially planar configuration, then one or both of the following conditions is fulfilled:

(a) the essential parts of the PTC element are irradiated to a dosage of at least 120 Mrads,

(b) the PTC element is irradiated in the absence of the electrodes and metal foil electrodes are secured to the PTC element after it has been cross-linked.

2. A process according to Claim 1, characterized in that each of the electrodes has a columnar shape.

3. The process according to Claim 2 characterized in that the essential parts of the device are irradiated to a dosage of at least 60 Mrads, preferably at least 80 Mrads.

4. A process according to Claim 1 characterized in that

(A) the PTC element is in the form of a strip with substantially planar parallel ends, the length of the strip being greater than the largest cross-sectional dimension of the strip;

(B) each of the electrodes is in the form of a cap having (i) a substantially planar end which contacts and has substantially the same cross-section as one end of the PTC element and (ii) a side wall which contacts the side of the PTC element.

5. A process according to Claim 4 characterized in that the essential parts of the PTC element are irradiated to a dosage of at least 60 Mrads, preferably at least 80 Mrads.

6. A process according to Claim 1 characterized by the steps of

(1) irradiating a laminar PTC conductive polymer element in the absence of electrodes;

(2) contacting the cross-linked PTC element from step (1) with metal foil electrodes under conditions of heat and pressure; and

(3) cooling the PTC element and the metal foil electrodes while continuing to press them together.

7. A process according to Claim 6 characterized by irradiating the essential parts of the PTC element to a dose of at least 60 Mrads, preferably at least 80 Mrads.

8. A process according to any one of the preceding claims, characterized in that the essential parts of the PTC element are irradiated to a dosage of at least 120 Mrads, preferably at least 160 Mrads.

9. An electrical device which comprises (a) a radiation cross-linked PTC conductive polymer element and (b) two electrodes which can be connected to a power source to cause current to flow through the PTC element, characterized in that if the device, while it is powered by a 200 volts DC power source and is in the tripped condition, is inspected by means of a scanning electron microscope using voltage contrast to determine the way in which the potential of the device changes between the electrodes, the maximum difference in voltage between two points separated by 10 microns is less than 4.2 volts, preferably less than 3 volts, particularly less than 2 volts, especially less than 1 volt, subject to the proviso that if each of the electrodes has a substantially planar configuration, the maximum difference is less than 3 volts.

10. A device according to Claim 9 characterized in that each of the electrodes has a columnar shape and, when the device is subjected to said inspection, the maximum difference in voltage between two points separated by 10 microns is less than 4.0 volts.

11. A device according to Claim 9 characterized in that

(A) the PTC element is in the form of a strip with substantially planar parallel ends, the length of the strip being greater than the largest cross-sectional dimension of the strip;

(B) each of the electrodes is in the form of a cap having (i) a substantially planar end which contacts and has substantially the same cross-section as one end of the PTC element and (ii) a side wall which contacts the side of the PTC element; and

(C) when the device is subjected to said inspection, the maximum difference in voltage between two points separated by 10 microns is less than 4.0 volts.

Patentansprüche

1. Verfahren zur Herstellung einer elektrischen Einrichtung, umfassend (1) ein vernetztes PTC-leitfähiges Polymerelement und (2) zwei Elektroden, die an eine Stromquelle anschließbar sind, um durch das PTC-Element Strom fließen zu lassen, wobei das Verfahren eine Vernetzung des PTC-Elementes durch Strahlung umfaßt, dadurch gekennzeichnet, daß die wesentliche Teile des PTC-Elementes mit einer Dosis von mindestens 50 Mrad bestrahlt werden, unter der Voraussetzung, daß dann, wenn jede der Elektroden eine im wesentlichen ebene Konfiguration hat, dann eine oder beide der folgenden Bedingungen erfüllt sind:

(a) die wesentlichen Teile des PTC-Elementes werden mit einer Doses von mindestens 120 Mrad bestrahlt,

(b) das PTC-Element wird in Abwesenheit der Elektroden bestrahlt und Metallfolienelektroden werden an den PTC-Element befestigt, nachdem es vernetzt worden ist.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß jede der Elektroden eine säulenförmige Gestalt hat.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die wesentlichen Teile der Einrichtung mit einer Dosis von mindestens 60 Mrad, vorzugsweise mindestens 80 Mrad bestrahlt werden.

4. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß

(A) das PTC-Element in Form eines Streifens mit im wesentlichen ebenen parallelen Enden vorliegt, wobei die Länge des Streifens größer ist als die größte Querschnittsabmessung des Streifens;

(B) jede der Elektroden in Form einer Kappe vorliegt, die (i) ein im wesentlichen ebenes Ende, das mit dem PTC-Element in Kontakt steht und das im wesentlichen den gleichen Querschnitt hat wie das eine Ende des PTC-Elementes, und (ii) eine Seitenwand aufweist, die mit der Seite des PTC-Elementes in Kontakt steht.

5. Verfahren nach Anspruch 4, dadurch gekennzeichnet, daß die wesentlichen Teile des PTC-Elementes mit einer Dosis von mindestens 60 Mrad, vorzugsweise mindestens 80 Mrad bestrahlt werden.

6. Verfahren nach Anspruch 1, gekennzeichnet, durch die Schritte

(1) Bestrahlen eines laminaren PTC-leitfähigen Polymerelementes in Abwesenheit von Elektroden;

(2) Kontaktieren des vernetzten PTC-Elementes gemäß Schritt (1) mit Metallfolienelektroden unter Wärme- und Druckbeaufschlagung; und

(3) Kühlen des PTC-Elementes und der Metallfolienelektroden, während diese weiterhin zusammengedrückt werden.

7. Verfahren nach Anspruch 6, gekennzeichnet, durch die Bestrahlung der wesentlichen Teile des PTC-Elementes mit einer Dosis von mindestens 60 Mrad, vorzugsweise mindestens 80 Mrad.

8. Verfahren nach einem der vorherigen Ansprüche, dadurch gekennzeichnet, daß die wesentlichen Teile des PTC-Elementes mit einer Dosis von mindestens 120 Mrad, vorzugsweise mindestens 160 Mrad bestrahlt werden.

9. Elektrische Einrichtung, die (a) ein durch Strahlung vernetztes PTC-leitfähiges Polymerelement und (b) zwei Elektroden aufweist, die sich an eine Stromquelle anschließen lassen, um durch das PTC-Element einen Strom fließen zu lassen, dadurch gekennzeichnet, daß dann, wenn die Einrichtung, während sie von einer Stromquelle mit 200 Volt Gleichspannung versorgt wird und sich im ausgelösten Zustand befindet, mit einem Rasterelektronenmikroskop untersucht wird, das Spannungskontraste verwendet, um festzustellen, in welcher Weise sich das Potential der Einrichtung zwischen den Elektroden ändert, die maximale Spannungsdifferenz zwischen zwei Punkten, die 10 µm auseinanderliegen, weniger als 4,2 Volt, vorzugsweise weniger als 3 Volt, insbesondere weniger als 2 Volt, speziell weniger als 1 Volt beträgt, unter der Voraussetzung, daß dann, wenn jede der Elektroden eine im wesentlichen ebene Konfiguration hat, die maximale Differenz weniger als 3 Volt beträgt.

10. Einrichtung nach Anspruch 9, dadurch gekennzeichnet, daß jede der Elektroden eine säulenförmige Gesalt hat und, wenn die Einrichtung der Untersuchung unterworfen wird, die maximale Spannungsdifferenz zwischen zwei Punkten, die 10 µm auseinanderliegen, weniger als 4,0 Volt beträgt.

11. Einrichtung nach Anspruch 9, dadurch gekennzeichnet, daß

(A) das PTC-Element in Form eines Streifens mit im wesentlichen ebenen parallelen Enden vorliegt, wobei die Länge des Streifens größer ist als die größte Querschnittsabmessung des Streifens;

(B) jede der Elektroden die Form einer Kappe hat, die (i) ein im wesentlichen ebenes Ende, das mit dem PTC-Element in Kontakt steht und im wesentlichen den gleichen Querschnitt hat wie das eine Ende des PTC-Elementes, und (ii) eine Seitenwand aufweist, die mit der Seite des PTC-Elementes in Kontakt steht; und

(C) wenn die Einrichtung der Untersuchung unterworfen wird, die maximale Spannungsdifferenz zwischen zwei Punkten, die 10 µm auseinanderliegen, weniger als 4,0 Volt beträgt.

Revendications

1. Procédé pour la préparation d'un dispositif électrique comprenant (1) un élément en polymère conducteur CPT réticulé et (2) deux électrodes qui peuvent être connectées à une source d'énergie pour faire circuler un courant à travers l'élément CPT, lequel procédé comprend une réticulation de l'élément CPT par irradiation, caractérisé en ce que les parties essentielles de l'élément CPT sont irradiées à un dosage d'au moins 50 Mrads, à condition que, si chacune des électrodes possède une configuration sensiblement plane, l'une des conditions suivantes ou les deux soient alors remplies:

(a) les parties essentialles de l'élément CPT sont irradiées à un dosage d'au moins 120 Mrads,

(b) l'élément CPT est irradié en l'absence d'électrodes et des électrodes en feuille métallique mince sont fixées à l'élément CPT après qu'il a été réliculé.

2. Procédé selon la revendication 1, caractérisé en ce que chacune des électrodes possède une forme en colonne.

3. Procédé selon la revendication 2, caractérisé en ce que les parties essentielles du dispositif sont irradiées à un dosage d'au moins 60 Mrads, avantageusement d'au moins 80 Mrads.

4. Procédé selon la revendication 1, caractérisé en ce que

(A) l'élément CPT se présente sous la forme d'une bande ayant des extrémités parallèles sensiblement planes, la longueur de la bande étant supérieure à la dimension la plus grande, en section transversale, de la bande;

(B) chacune des électrodes se présente sous la forme d'une chapeau ayant (i) une extrémité sensiblement plane qui est en contact avec une extrémité de l'élément CPT et qui possède sensiblement la même section transversale que cette extrémité de l'élément CPT, et (ii) une paroi latérale qui est en contact avec le côté de l'élément CPT.

5. Procédé selon la revendication 4, caractérisé en ce que les parties essentielles de l'éléments CPT sont irradiées à un dosage d'au moins 60 Mrads, advantageusement d'au moins 80 Mrads.

6. Procédé selon la revendication 1, caractérisé par les étapes qui consistent

(1) à irradier un élément en forme de lamelle en polymère conducteur CPT en l'absence d'électrodes;

(2) à mettre en contact l'élément CPT réticulé provenant de l'étape (1) avec les électrodes en feuille métallique mince dans des conditions de chaleur et de pression; et

(3) à refroidir l'élément CPT et les électrodes en feuille mètallique mince pendant que l'on continue de les presser ensemble.

7. Procédé selon la revendication 6, caractérisé en ce qu'il consiste à irradier les parties essentielles de l'élément CPT à une dose d'au moins 60 Mrads, avantageusement d'au moins 80 Mrads.

8. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les parties essentielles de l'élément CPT sont irradiées à un dosage d'au moins 120 Mrads, avantageusement 160 Mrads.

9. Dispositif électrique qui comprend (a) un élément en polymère conducteur CPT réticulé par irradiation et (b) deux électrodes qui peuvent être connectées à une source d'énergie pour faire circuler un courant à travers l'élément CPT, caractérisé en ce que, si le dispositif, pendant qu'il est alimenté par une source d'énergie à courant continu, 200 volts, et se trouve dans la conditions déclenchée, est inspecté au moyen d'un microscope électronique à balayage utilisant un contraste de tension pour déterminer la façon dont le potentiel du dispositif change entre les électrodes, la différence maximale de tension entre deux points séparés de 10 micromètres est inférieure à 4,2 volts, avantageusement inférieure à 3 volts, en particulier inférieure à 2 volts, et spécialement inférieure à 1 volt, à condition que, si chacune des électrodes possède une configuration sensiblement plane, la différence maximale soit inférieure à 3 volts.

10. Dispositif selon la revendication 9, caractérisé en ce que chacune des électrodes présente une forme en colonne et, lorsque le dispositif est soumis à ladite inspection, la différence maximale de tension entre deux points séparés de 10 micromètres est inférieure à 4,0 volts.

11. Dispositif selon la revendication 9, caractérisé en ce que

(A) l'élément CPT se présente sous la forme d'une bande à extrémités parallèles sensiblement planes, la longueur de la bande étant supérieure à la dimension la plus grande, en section transversale, de la bande;

(B) chacune des électrodes se présente sous la forme d'un chapeau ayant (i) une extrémité sensiblement plane qui est en contact avec une extrémité de l'élément CPT et qui présente sensiblement la même section transversale que cette extrémité de l'élément CPT et (ii) une paroi latérale qui est en contact avec le côté de l'élément CPT; et

(C) lorsque le dispositif est soumis à ladite inspection, la différence maximale de tension entre deux points séparés de 10 micromètres est inférieure à 4,0 volts.

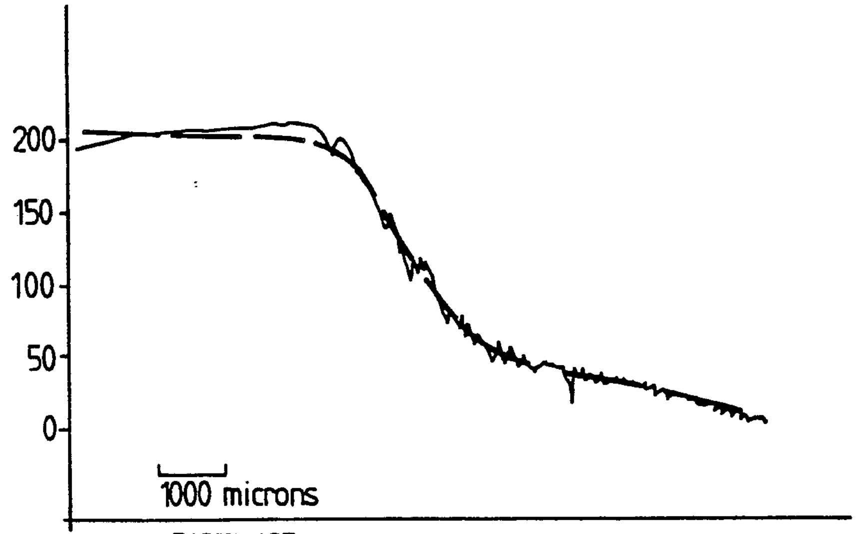

Fig.1

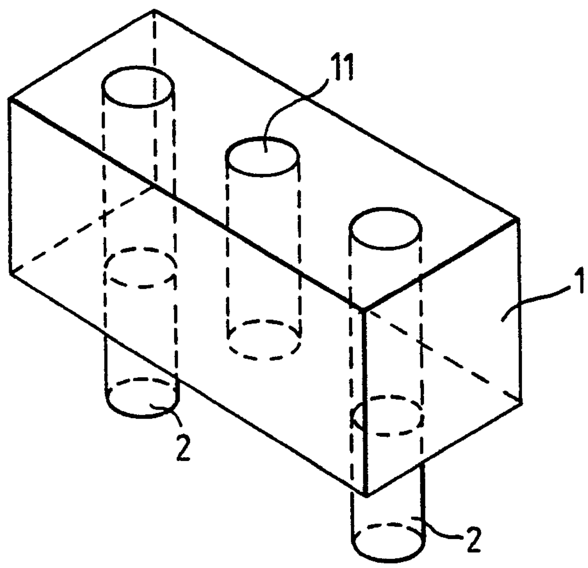

Fig.2

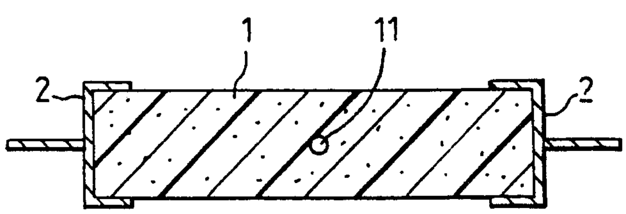

Fig.3