United States Patent [19]

Harnden, Jr.

[11] **3,818,411**

[45] **June 18, 1974**

[54] **METAL OXIDE VARISTOR WITH SELECTIVELY POSITIONABLE INTERMEDIATE ELECTRODE**

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[73] Assignee: **General Electric Company**, Syracuse, N.Y.

[22] Filed: **June 7, 1973**

[21] Appl. No.: **367,963**

Related U.S. Application Data

[62] Division of Ser. No. 188,984, Oct. 13, 1971, Pat. No. 3,768,058.

[52] **U.S. Cl.** **338/20**, 338/92

[51] **Int. Cl.** **H01c 7/10**

[58] **Field of Search** 338/18, 20, 21, 52, 92

[56] **References Cited**

UNITED STATES PATENTS

2,935,712	5/1960	Oppenheim et al.	338/20
3,456,228	7/1969	Wright	338/92 X
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3,768,058	10/1973	Harnden, Jr.	338/20

Primary Examiner—C. L. Albritton

Attorney, Agent, or Firm—Robert J. Mooney

[57] **ABSTRACT**

A metal oxide varistor is disclosed formed of a varistor body having an alpha in excess of 10 in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter. First and second electrodes are laterally spaced along the varistor body, and a third electrode is located between and spaced from the first and second electrodes. The third electrode may be slidably mounted on the varistor body or may be in the form of discrete, spaced elements fixedly attached to the surface of the varistor body.

7 Claims, 7 Drawing Figures

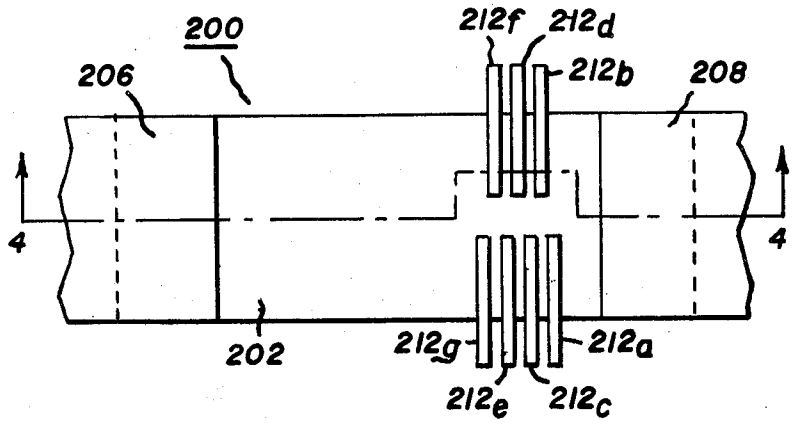


FIG. 1.

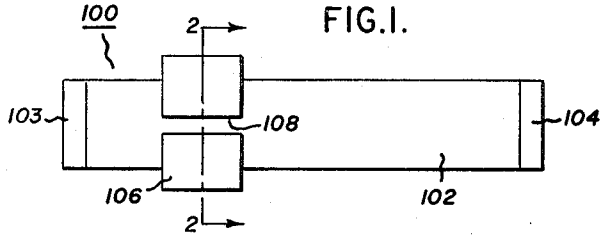


FIG. 2.

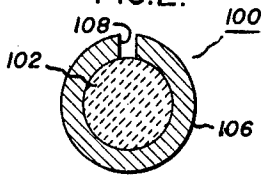


FIG. 3.

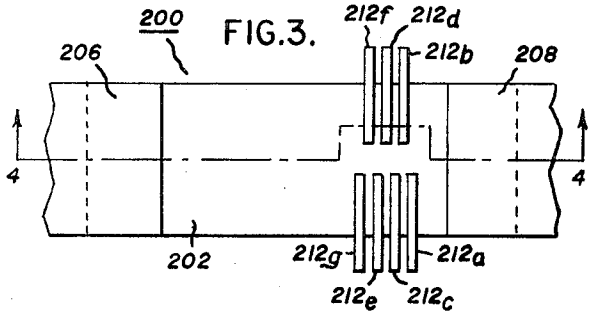


FIG. 4.

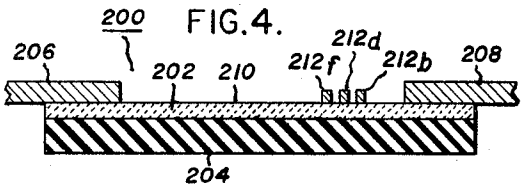


FIG. 5.

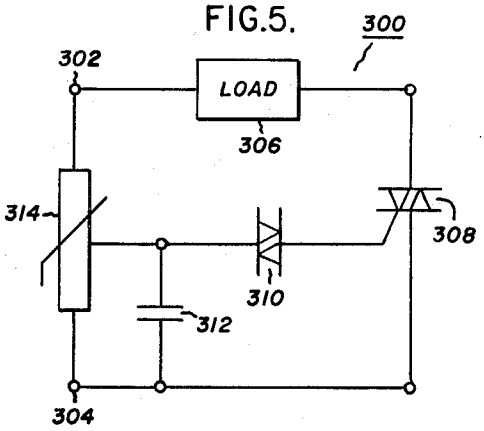


FIG. 6.

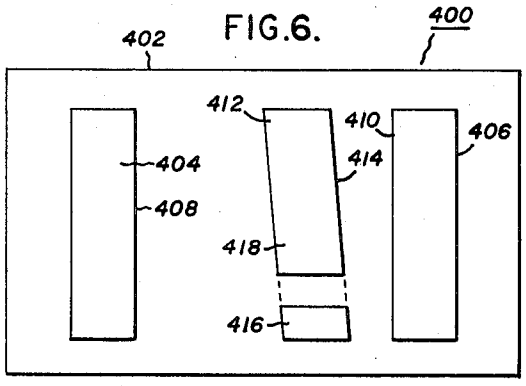
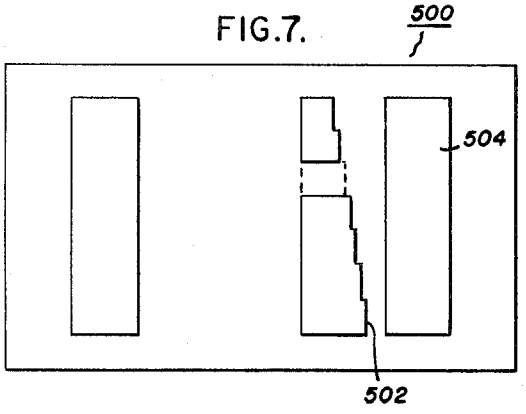


FIG. 7.



METAL OXIDE VARISTOR WITH SELECTIVELY POSITIONABLE INTERMEDIATE ELECTRODE

This is a division of application Ser. No. 188,984, filed Oct. 13, 1971, now U.S. Pat. No. 3,754,200, titled "Metal Oxide Varistor with Selectively Positionable Intermediate Electrode."

My invention is directed to a metal oxide varistor having at least three electrodes with the third electrode being located to allow selection of a desired potential as compared to the first electrode.

It can be generally stated that the current which flows between two spaced points is directly related to the potential difference between the points. For most known substances current conduction therethrough is equal to the applied potential difference divided by a constant, which has been defined by Ohm's law to be its resistance. There are, however, a few known substances which have been observed to exhibit non-linear resistances and which require resort to the following equation (1) to relate quantitatively current and voltage:

$$I = (V/C)^{alpha} \quad (1)$$

where V is the voltage between two points separated by a body of the substance under consideration, I is the current flowing between the two points, C is a constant, and alpha is an exponent greater than **1.** There are many known electrical circuits in which it is quite desirable to incorporate one or more functional elements having non-linear or exponential resistance characteristics. For example, the non-linear resistance properties of silicon carbide have been widely utilized in commercial silicon carbide varistors. Typically silicon carbide varistors exhibit an alpha of no more than **6.**

It has been recently appreciated that varistors having alphas in excess of **10** within the current density range of 10^{-3} to 10^{2} amperes per square centimeter may be made from bodies comprised of metal oxides. The metal oxide body may be formed predominantly of zinc oxide with small quantities of one or more other metal oxides also being present. Metal oxide varistors having alphas in excess of **10** are disclosed in Canadian Patent No. 831,691, issued Jan. 6, 1970, for example. While the alphas of these metal oxide varistors is identified by the current density range of 10^{-3} to 10^{2} amperes per square centimeter, which characteristically exhibits substantially constant alphas, it is appreciated that the alphas remain high also at higher and lower current densities, although some decline from maximum alpha values have been observed.

Certain improved forms of metal oxide varistors are disclosed in my co-pending applications Ser. No. 165,001, now U.S. Pat. No. 3,768,058 METAL OXIDE VARISTOR WITH LATERALLY SPACED ELECTRODES, filed July 22, 1971, and Ser. No. 169,200, now U.S. Pat. No. 3,743,897 HYBRID CIRCUIT ARRANGEMENT WITH METAL OXIDE VARISTOR SHUNT, filed Aug. 5, 1971.

It is one object of my present invention to provide a metal oxide varistor having a third electrode which is capable of selectably dividing the potential difference between two remaining electrodes. It is another object to provide a three electrode metal oxide varistor in which the third electrode may be selectively located with respect to a remaining electrode. It is still another object to provide a three electrode metal oxide varistor

in which the third electrode is in the form of discrete elements differentially spaced from one electrode so that a desired potential relationship between the one electrode and one of the elements of the third electrode can be established.

In one aspect, my invention is directed to the combination comprising a metal oxide varistor body means having an alpha in excess of **10** in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter. A first electrode adapted to be biased to a first potential lies in ohmic contact with the metal oxide varistor body means at a first location. A second electrode adapted to be biased to a second potential lies in ohmic contact with the metal oxide varistor body means at a second location spaced from the first location. Third electrode means lies in ohmic contact with the metal oxide varistor body means for permitting selectable potentials intermediate the first and second potentials to be picked from the metal oxide varistor body means at any one of a plurality of selectable locations spaced from and mediate the first and second locations.

My invention may be better understood by reference to the following detailed description considered in conjunction with the drawings, in which

FIG. **1** is an elevation of one metal oxide varistor formed according to my invention;

FIG. **2** is a sectional view taken along section line **2—2** in FIG. **1**;

FIG. **3** is a plan view of second embodiment of my invention;

FIG. **4** is a sectional view taken along section line **4—4** in FIG. **3**;

FIG. **5** is a schematic circuit diagram;

FIG. **6** is a plan view of a third embodiment of my invention; and

FIG. **7** is a plan view of a fourth embodiment of my invention.

In FIGS. **1** and **2** a varistor **100** is shown formed according to my invention including a metal oxide varistor body **102,** which has an alpha as defined in equation (1) in excess of **10.** The metal oxide varistor body may be formed according to the teaching of the Canadian patent cited above or in any other known manner. As shown, the body is in the geometrical configuration of a cylindrical rod. First and second electrodes **103** and **104** are located at opposite ends of the cylindrical rod. The electrodes may be ohmically conductively associated with the varistor body in any convenient conventional manner.

Surrounding the rod is a third electrode **106.** In the specific form shown the third electrode is in the form of a resilient band. The opposite ends of the band are separated by a gap **108.** The band is normally resiliently biased so that it compressively engages the surface of the rod. In this way the band is fixedly positioned between the electrodes **103** and **104** in predetermined spaced relation thereto. In order to reposition the band it is merely necessary to apply a spreading force to the opposite ends thereof so as to enlarge the gap **108.** This increases the diameter of the band and allows it to be slidably repositioned along the rod to any desired spacing with respect to the first and second electrodes.

In FIGS. **3** and **4** a varistor **200** is shown, which is an alternative embodiment of my invention. A metal oxide varistor body **202** is supported on a dielectric substrate **204.** First and second electrodes **206** and **208** are ohmically conductively attached to the metal oxide varistor

body at its opposite ends along a first major surface **210** thereof. A third electrode means is formed by a plurality of discrete electrode elements **212***a*, **212***b*, **212***d*, **212***e*, **212***f*, and **212***g* positioned along the first major surface in ohmic contact with the metal oxide varistor body. Each third electrode element is spaced both from the first and second electrodes and from each remaining element of the third electrode means. The third electrode elements are positioned so that in order of progressive displacement from the first electrode every other (meaning every second or alternate) element is also laterally offset. In this way a larger number of elements may be located within a given lateral displacement along the major surface of the metal oxide varistor body than could be achieved if the elements were all aligned. In the specific embodiment shown the edge of the element **212***a* most remote from the electrode **208** is aligned with the edge of the next successive element **212***b*, which (in terms of displacement distance from the electrode **208**) is closest to the element **212***a*. In like manner each of the successive elements is provided with an edge surface nearest the electrode **208** that is aligned with the edge surface most remote from the electrode **208** of the next nearest element to the electrode **208.** In this way any lack of selectivity in spacing the elements with respect to the electrode **208** attributable to the requirement of laterally spacing the elements from each other is entirely avoided. In other words, it is apparent that spacing of adjacent elements is achieved through the use of lateral offsets rather than by preventing elements from lying at certain distances from one of the first and second electrodes.

The metal oxide varistors **100** and **200** may be utilized in like or similar manner. In utilizing the metal oxide varistor **100** the first and second electrodes **103** and **104** may be electrically biased to lie at differing potentials, so that a potential difference is established between the electrodes. The current flowing between the electrodes through the metal oxide varistor body **102** for a given potential difference between the electrodes will be a function of the conductivity of the metal oxide varistor body when subjected to that particular level of electrical stress. The conductivity is a function both of the composition of the metal oxide forming the body and of the distance between the first and second electrodes. Hence, referring to equation (1), it can be seen that with a large spacing between the first and second electrodes the current density will be small, since the value of C will be comparatively large. In this way a relatively large potential difference may be present across the first and second electrodes with only a small current flowing therebetween. However, it should be borne in mind that the current and voltage relationship is still controlled by equation (1); hence any further increase in the potential will be accompanied by a disproportionate increase in the current, attributable to the high alpha of the metal oxide varistor body.

I have recognized that even though current and voltage are not linearly related by reason of the large alpha of the metal oxide varistor body, there will be a linear voltage drop across the length of the body. In order to place the third electrode at any desired potential intermediate the potentials of the first and second electrodes it is merely necessary to position the third electrode at an intermediate location which is readily ascertainable by reason of the linear potential drop. As a specific example, if it is assumed that the first and second electrodes lie at **100** and 200 volts, respectively, the third electrode may readily be adjusted to a potential of 140 volts merely by locating the edge of the third electrode nearest the first electrode so that 40 percent of the length of the metal oxide varistor body lying between the first and second electrodes lies between the first and third electrodes.

From the foregoing it is apparent that the third electrode **106** of the varistor **100** may be positioned at a selected potential intermediate the potentials of the electrodes **103** and **104** merely by expanding the band and sliding the electrode along the rod forming the metal oxide varistor body. When the expanding forces are removed from the band, its resilience will firmly locate the band in the desired position on the rod.

In using the varistor **200** it is apparent that when the first and second electrodes **206** and **208** are biased to different potential levels, the third electrode means will assume a potential intermediate the applied potentials. While the third electrode means is comprised of elements **212***a*-**212***g* each of which are fixedly positioned with respect to the first and second electrodes, it is apparent that by reason of their differing spacings with respect to the first and second electrodes each of the elements of the third electrode will lie at a different potential level. Accordingly, an intermediate potential may be selected merely by selecting one of the third electrode elements that lies at this potential. Whereas in the varistor **100** a continuous spectrum of intermediate potentials may be selected, in the varistor **200** the selectable intermediate potentials are in the form of a plurality of stepped increments. The difference in value of the increments is noted to be a function merely of the width of the elements. If only one row of elements were employed, rather than two laterally offset rows as shown, the stepped increments of potential would be a function both of the width of the elements and of their spacing.

It is apparent that the varistors formed according to my invention are readily applicable to a variety of uses by reason of their capability for selective electrode spacings. In a very simple application only the first and third electrodes may be utilized. The spacing between the first and third electrodes may be selectively chosen to give the desired current and voltage characteristics for the device, and the device may be substituted for any conventional two terminal varistor. In a more preferred application the first electrode may be biased to a potential differing from that of the second electrode, and an intermediate potential of a selectable value may be picked from the varistor body by the ohmic connection provided by the third electrode. In still other applications the third electrode may be biased to a potential either higher or lower than that of either the first and second electrodes.

To provide a specific example of an application for a varistor according to my invention, in FIG. **5** an electrical circuit **300** is schematically shown comprised of input terminals **302** and **304** which may be attached to an alternating current or direct current potential source, not shown. An electrical load **306** and a triac **308** are connected in series across the input terminals. Connected to the gate lead of the triac is a diac **310.** A capacitor **312** is connected between the input terminal **304** and the diac.

A varistor **314,** which may be either varistor **100** or varistor **200,** is connected across the input terminals of

the circuit. The varistor is preferably connected across the input terminals by what correspond to the first and second electrodes in the varistors **100** and **200.** The varistor provides a selectably referenced third electrode which is connected to the diac and capacitor.

When the input terminals **302** and **304** of the circuit are connected to an A-C or pulsating D-C potential source, proper spatial location of the third electrode with respect to the first and second electrodes can control the phase angle at which the triac is fired. As is well understood in the art, firing of the triac is achieved by firing the diac **310.** The diac switches from an initially high impedance to a comparatively low impedance state when a predetermined potential difference thereacross is exceeded. The relationship of diac firing to application of a potential difference across the input terminals of the circuit is a function of the rate at which the capacitor **312** is charged. The potential difference between electrode of the varistor **314** connected to the input terminal **302** and the third electrode controls the rate at which the capacitor can be charged. Referring to equation (1), it can be seen that at the beginning of a voltage half-cycle only a low charging current may be permitted to flow by the varistor. However, since the current increases as a function of the voltage raised to at least the tenth power, the minimum contemplated value of alpha, it can be seen an increasing potential difference between the third electrode and input terminal **302** greatly increases the charging rate of the capacitor. Hence a much more selective charging of the capacitor is obtainable than is possible merely using a linear resistor as a current limiter. A second function that is provided by the varistor **314** is to selectively shunt the load and triac when a large potential is placed across the input terminals. Thus, the varistor functions very effectively not only to allow selective phase control of triac firing, but also to protect the circuit against voltage transients.

The varistor **314** is unique in that it performs a circuit function never before performable with a single electronic component. Consider, for example, the result of substituting a conventional resistive potentiometer for the varistor **314.** An increase in voltage applied across the terminals **302** and **304** would result in a proportionate acceleration of the rate at which the capacitor **312** is charged with a corresponding decrease in the phase angle of firing. With the varistor **314** the third electrode is for all practical purposes clamped at a fixed maximum potential difference with respect to the input terminal **302,** since the input terminals **302** and **304** are also effectively clamped at a fixed maximum potential difference thereacross. Hence, the potential applied across the input terminals of the circuit may vary above a predetermined potential in an unpredicted manner without having any appreciable effect on the phase angle of firing. In fact, the varistor **314** performs in a manner that could only be approximated with a resistive potentiometer which is connected across the input terminals of the circuit in parallel with a pair of back-to-back Zener diodes. It is, of course, recognized that the relative invariancy with which the input potential can be clamped improves as the alpha of the varistor increases. Since the varistor **314** exhibits an alpha in excess of **10,** it is capable of clamping the input potential to the circuit with a degree of effectiveness.

In FIG. **6** a varistor **400** is formed according to my invention comprised of a metal oxide varistor body **402.** On the major surface of the body exposed to view are located a first electrode **404** and a second electrode **406.** The electrodes may be identical to electrodes **206** and **208.** The first electrode presents an edge surface **408** that is spaced from and parallel with an edge surface **410** of the second electrode. Thus, when the first and second electrodes are biased to differing potentials, a potential drop is present within the metal oxide varistor body that is uniform across the width of the varistor. A third electrode **412** is located in ohmic conductive relation with the exposed surface of the metal oxide varistor body between the first and second electrodes. The third electrode is located so that it presents an edge **414** that diverges across the width of varistor from the edge **410** of the second electrode.

Initially the varistor **400** is formed so that the third electrode is a unitary element lying closer to the second electrode at its nearest approach than is deemed desirable in any contemplated application for the varistor. Also, the unitary third electrode at the greatest divergence of its edge **414** from the edge **410** of the second electrode lies at a greater distance than is deemed desirable for any contemplated application. The varistor may then be precisely adjusted to yield a specific voltage and current relationship between the second and third electrodes merely by dividing the third electrode into two segments **416** and **418.** the nearest approach of the segment **418** to the edge **410** is precisely chosen to yield the desired voltage and current characteristics when a potential difference is established between the first and second electrodes and a lead attachment is made to the segment **418.** The third electrode may be conveniently segmented using techniques conventionally employed for trimming resistors in thick film integrated circuits.

In FIG. **7** a varistor **500** is illustrated which may be identical to varistor **400,** except that in place of the continuously diverging edge **414** associated with the third electrode a stepped edge **502** is provided. Each step along the edge is preferably substantially parallel to the edge of the adjacent electrode **504.** The advantage of using a stepped edge is that a sharper current-voltage knee or switching characteristic is obtained than is obtainable using a diverging edge.

In the foregoing description I have set forth certain aspects of my invention by reference to certain specific embodiments. It is appreciated that it may be desired to modify or add to the specific embodiments shown to serve specific end applications. For example, none of the varistors above shown are packaged in any way. My varistors may be utilized without packages in protected environments. For example, in a controlled inert gas atmosphere there would be no reason to package my varistors. In many applications it will be desirable to hermetically encase at least the metal oxide varistor body portion of my varistors. This may be accomplished by encapsulating the varistors in a dielectric such as glass or plastic, for example. Alternatively, the varistors may be fitted into hermetically sealed housings in generally similar manner as semiconductive elements are so housed. When the varistor **200** is encapsulated, it is preferred that all of the third electrode elements protrude beyond the encapsulant to allow selection of one element after packaging.

I have shown the metal oxide varistor body in the form or a rod and in the form of a supported element. The exact geometrical configuration of the metal oxide

varistor body is not deemed critical to my invention. For example, the use of a slidable electrode is possible even with flat plate metal oxide varistor bodies. Generally flat plate metal oxide varistor bodies are preferred where the varistor is to be used with or form a part of an integrated circuit. No particular means have been shown for attaching electrical connectors to the electrodes, since this is considered to be well within the ordinary skill of the art. It is noted that a number of mechanical arrangements are known to the art for slidably mounting electrodes that could be utilized in the practice of my invention without the exercise of invention. For example, instead of forming the entire band **106** of metal only one specific point on the band may be allowed to make conductive contact with the metal oxide varistor body. For many applications this may allow more accurate choice of the exact potential to be picked off by the third electrode. Instead of having the slidable third electrode make contact directly to the metal oxide varistor body directly it may make contact to metallized surface areas of the metal oxide varistor body. For example, in the varistor **100** there may be provided a plurality of metal rings extending around the rod and spaced laterally along the rod between the first and second electrodes. The rings may be fixedly attached to the metal oxide varistor body in ohmic conductive relation therewith. The resilient band **106** would then slide over the rings and make electrical connection to whichever ring or rings it happened to overlie.

In the discussion of my invention I have made reference to only one electrode lying between the first and second electrodes. It is recognized that in various applications it may be desired to make electrical connection to more than one location along the metal oxide varistor body between the first and second electrodes. For example, it may be desired to pick-off from the metal oxide varistor body two or more potential levels which are intermediate the potentials of the first and second electrodes. In the varistor **100** this may be accomplished merely by adding one or more additional resilient bands. In the varistor **200** this may be accomplished merely providing electrical connections to more than one of the third electrode elements. In the varistors **400** and **500** this may be accomplished by forming plural discrete third electrode segments that each will lie at the desired intermediate potentials.

Inasmuch as numerous modifications of my invention will readily occur to those skilled in the art, it is intended that the scope of my invention be determined by reference to the following claims:

What I claim and desire to be secured by letters Patent of the United States is:

1. The combination comprising

metal oxide varistor body means having an alpha in excess of **10** in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter,

a first electrode adapted to be biased to a first potential lying in ohmic contact with said metal oxide varistor body means at a first location,

a second electrode adapted to be biased to a second potential lying in ohmic contact with said metal oxide varistor body means at a second location spaced from said first location, and

third electrode means lying in ohmic contact with said metal oxide varistor body means for permitting selectable potentials intermediate said first and second potentials to be picked from said metal oxide varistor body means, said third electrode means being comprised of a plurality of spaced elements located on said metal oxide varistor body means each at a different spacing from said first electrode.

2. The combination according to claim **1** in which said metal oxide varistor body means is provided with a first major surface and said first electrode, said second electrode and said third electrode means are all associated with said first major surface.

3. The combination according to claim **1** in which said metal oxide varistor body means is in the form of a layer supported by a dielectric substrate and is provided with a first major surface and said first electrode, said second electrode and said third electrode means are all associated with said first major surface.

4. The combination comprising

metal oxide varistor body means having an alpha in excess of 10 in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter,

a first electrode lying in ohmic contact with said metal oxide varistor body means at a first location,

a second electrode lying in ohmic contact with said metal oxide varistor body means at a second location spaced from said first location, and

a plurality of discrete electrode elements lying in ohmic contact with said metal oxide varistor body spaced from each other and spaced by differing amounts from said first electrode.

5. The combination comprising

metal oxide varistor body means having an alpha in excess of **10** in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter,

a first electrode lying in ohmic contact with said metal oxide varistor body means at a first location and presenting a first edge,

a second electrode lying in ohmic contact with said metal oxide varistor body means at a second location spaced from said first edge, and

third electrode means located between and spaced from said first and second electrodes lying in ohmic contact with said metal oxide varistor body means,

said third electrode means presenting a second edge adjacent to said first edge, but spaced therefrom and diverging from said first edge, and

said third electrode being divided into two laterally spaced elements, the second edge of one of said elements being spaced from said first edge of said first electrode by a distance chosen to provide the desired potential difference when a selected current density is being conducted by said metal oxide varistor body means therebetween.

6. The combination according to claim **5** in which said second edge continuously diverges from said first edge.

7. The combination according to claim **5** in which said second edge diverges from said first edge in stepped increments.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,818,411 Dated June 18, 1974

Inventor(s) John D. Harnden, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Page 1, Related U. S. Application Data, Item 62, for the Patent Number of the parent application change "3,768,058" to -- 3,754,200 --.

Signed and sealed this 8th day of April 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
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