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[54] POTTED METAL OXIDE VARISTOR

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 185,723, Oct. 1, 1971, abandoned.

[52] U.S. Cl. .... **338/20**, 29/613, 317/235 Q
[51] Int. Cl. **H01c 7/10**
[58] Field of Search .... 338/13, 20, 21; 317/235 Q; 29/610, 613

[56] **References Cited**

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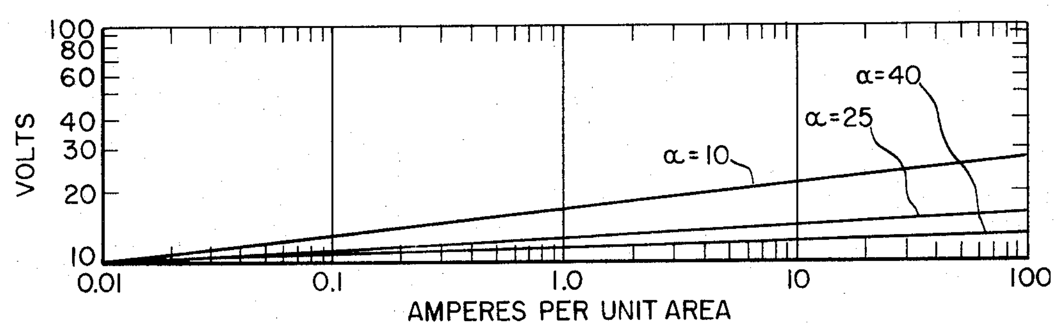
[57] **ABSTRACT**

A metal oxide varistor has a high thermal conductivity potting material encapsulating completely the metal oxide varistor and a portion of the leads therefrom, a pair of metal plates spaced in a generally parallel reslationship to the opposite major surfaces of the varistor and bonded thereto by the potting material, and one of the plates having at least a pair of mounting holes therein or other suitable means.

10 Claims, 4 Drawing Figures



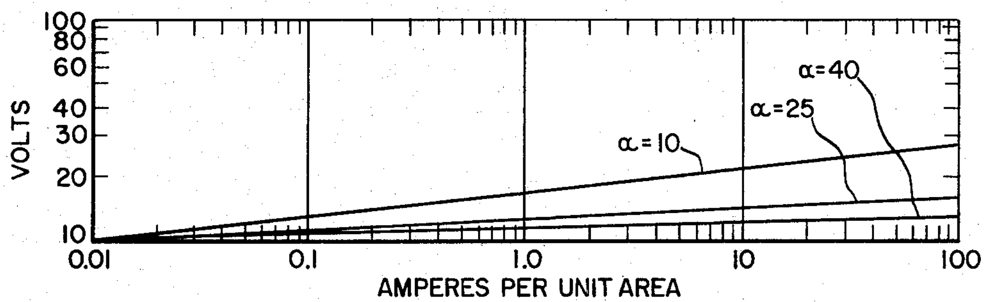


Fig.1

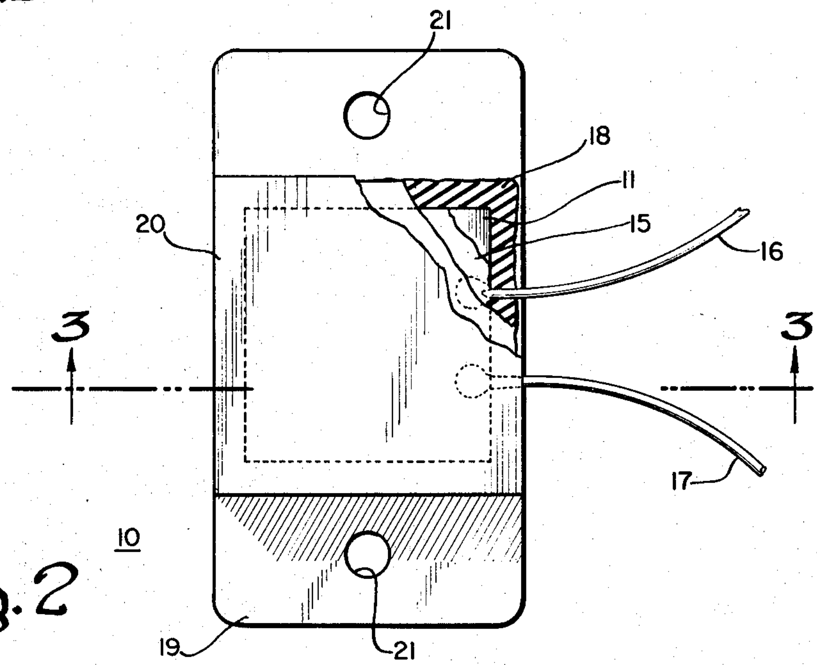


Fig. 2

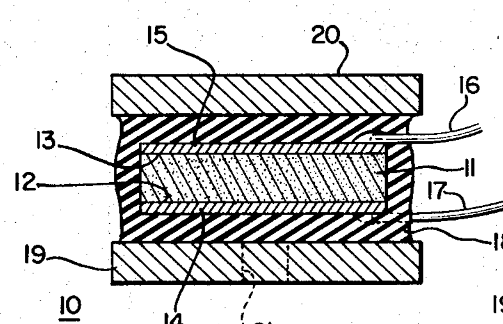


Fig.3

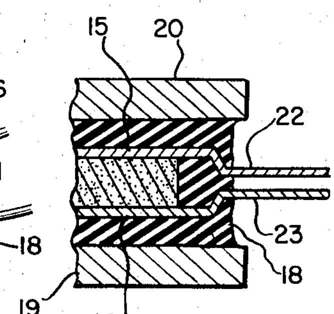


Fig.4

POTTED METAL OXIDE VARISTOR

This application relates to metal oxide varistors, and more particularly, to such varistors which are encapsulated with high thermal conductivity potting material. This application is a continuation-in-part of my copending application, Ser. No. 185,723, filed Oct. 1, 1971, now abandoned, and assigned as herein.

There are a few known materials which exhibit nonlinear resistance characteristics and which require resort to the following equation to relate quantitatively current and voltage:

$$I = (V/C)$$

where V is the voltage between two points separated by a body of the material under consideration, I is the current flowing between the two points, C is a constant and α is an exponent greater than 1. Both C and α are functions of the geometry of the body formed from the material and the composition thereof, and C is primarily a function of the material grain size whereas α is primarily a function of the grain boundary. Materials such as silicon carbide exhibit nonlinear or exponential resistance characteristics and have been utilized in commercial silicon carbide varistors, however, such varistors typically exhibit an alpha (α) exponent of no more than 6.

Metal oxide varistor materials, also referred to herein as MOV, a trademark of the General Electric Company, having alphas in excess of **10** within the current density range of 10^{-3} to 10^2 amperes per square centimeter are described, for example, in Canadian Pat. No. 831,691, issued Jan. 6, 1970. Although the alpha of the MOV materials in which range the alpha remains substantially constant, are identified by the current density range of 10^{-3} to 10^2 amperes per square centimeter, it is appreciated that the alphas remain high also at higher and lower currents although some deviation from maximum alpha values may occur. The MOV material is a polycrystalline ceramic material formed of a particular metal oxide with small quantities of one or more other metal oxides being added. As one example, the predominant metal oxide is zinc oxide with small quantities of bismuth oxide being added. Other additives may be aluminum oxide, iron oxide, magnesium oxide, and calcium oxide as other examples. The predominant metal oxide is sintered with the additive oxide or oxides to form a sintered ceramic metal oxide body. Since the MOV is fabricated as a ceramic powder, the MOV material can be pressed into a variety of shapes of various sizes. Being polycrystalline, the characteristics of the MOV are determined by the grain or crystal size, grain composition, grain boundary composition, and grain boundary thickness, all of which can be controlled in the ceramic fabrication process.

The nonlinear resistance relationship of the MOV is such that the resistance is very high (up to approximately 10,000 megohms) at very low current levels in the microampere range and progresses in a nonlinear manner to an extremely low value (tenths of an ohm) at high current levels. The resistance is also more nonlinear with increasing values of alpha. These nonlinear resistance characteristics result in voltage versus current characteristics wherein the voltage is effectively limited, the voltage limiting or clamping action being more enhanced at the higher values of the alpha exponent. Thus, the voltage versus current characteristics of the MOV is similar to that of the Zener diode with the added characteristic of being symmetrically bidirectional and over more decades of current. The breakdown mechanism of the MOV is not yet clearly understood but is completely unlike the avalanche mechanism associated with Zener diodes, a possible theoretical explanation of its operation being that of space charge limited current. The "breakdown" voltage of an MOV device is determined by the particular composition of the MOV material and the thickness to which it is pressed in the fabrication process. The MOV involves conduction changes at grain boundaries resulting in the advantage of bulk phenomenon allowing great flexibility in the design for specific applications simply by changing the dimensions of the body of MOV material. That is, the current conduction in the absence of closely spaced electrodes along one surface of the MOV body is through the bulk thereof. The bulk property of the MOV permits a much higher energy handling capability as compared to junction devices. Thus, since an MOV device can be built up to any desired thickness, it is operable at much higher voltages than the Zener diode junction device and can be used in a range from a few volts to several kilovolts. The voltage changes across a silicon carbide varistor device are much greater than across an MOV device for a given current change and thus the silicon carbide varistor has a much smaller voltage operating range thereby limiting its applications. The thermal conductivity of MOV material is fairly high (approximately ½ that of alumina) whereby it has a much higher power handling capability than silicon carbide, and it exhibits a negligible switching time in that its response time is in the subnanosecond domain. Finally, the MOV material and devices made thereof can be accurately machined and can be soldered, capabilities not possible for the larger grained silicon carbide.

It is known in the art that the encapsulation or "potting" of semiconductor devices, such as silicon carbide varistors, silicon transistors, and germanium devices, in plastic potting materials such as, for example, epoxy materials, frequently results in undesirable degradation in the performance characteristics of the semiconductor devices. The degradation in performance characteristics has two origins. The first of these is a chemical reaction occurring between the plastic encapsulant and the semiconductor device. The second is a mechanical stress upon the semiconductor device resulting from the substantially different coefficients of expansion of the semiconductor material and the plastic encapsulating material.

Subsequently, the chemical reaction causing performance degradation was determined to be in fact an electrochemical reaction. Several choices of materials are now known in the art to be available, which will permit the plastic encapsulation of low voltage semiconductor devices wherein the voltage stresses are on the order of a few volts and in any event do not exceed ten volts, and the performance degrading electrochemical reaction does not take place. However, heretofore, it has not been possible to successfully encapsulate a high voltage semiconductor device in a plastic potting material directly.

My present invention is directed to providing an improved potted metal oxide varistor.

The primary object of my invention is to provide a metal oxide varistor with increased power capacity and improved thermal capability, especially at high operating voltages and at the same time providing the very desirable electrical isolation between the heat cooling members and the electrical connections.

In accordance with one aspect of my invention, a metal oxide varistor has a high thermal conductivity potting material encapsulating completely the metal oxide varistor and a portion of the leads therefrom, a pair of metal plates spaced in a generally parallel relationship to the opposite major surfaces of the varistor and bonded thereto by the potting material, and one of the plates having at least a pair of mounting holes therein or other suitable means.

These and various other objects, features and advantages of the invention will be better understood from the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a graphical representation of the nonlinear resistance and resultant voltage limiting characteristics of the MOV material for different values of the exponent alpha plotted in terms of volts vs. amperes on a log-log scale;

FIG. 2 is a top elevation view partially in section of a metal oxide varistor made in accordance with my invention;

FIG. 3 is a sectional view of the metal oxide varistor shown in FIG. 2 which is taken along line 3—3 in FIG. 2; and

FIG. 4 is a sectional view of a portion of a modified metal oxide varistor.

The volts versus amperes characteristics plotted in FIG. 1 of the drawing illustrate the nonlinear or exponential resistance characteristics exhibited by MOV material, and in particular, indicate the increasing nonlinearity and enhanced voltage limiting obtained with increased values of the exponent alpha (α). The volts abscissa is in terms of voltage and the amperes ordinate is in terms of current density. Although the use of linear scales on the graph would show the decreasing slopes (decreasing resistance values) with increasing currents, such curves can be readily manipulated by the choice of scales, and for this reason, log–log scales are chosen to obtain a family of lines each of which remains substantially straight within the indicated current range. It can be seen from the FIG. 1 plots that the resistance exhibited by the MOV material is quite high at low current levels and becomes increasingly smaller in a nonlinear exponential manner with increasing current levels, and such nonlinearity is greater for greater values of the exponent alpha (α). Extension of the plots to lower and higher current levels would obviously indicate correspondingly much higher and lower resistances, respectively, and operation of the subject machines may transiently reach such levels. The "leakage" current through the MOV material is negligible.

In FIGS. 2 and 3 of the drawing, there is shown generally at **10** a metal oxide varistor embodying my invention. Varistor **10** has a metal oxide substrate **11** with first and second opposed major surfaces **12** and **13** and having an alpha in excess of 10 in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter. A pair of electrodes **14** and **15** are in nonrectifying contact with the respective opposite major surfaces **12** and **13** of substrate **11**. A pair of electrical leads **16** and **17** are in electrical contact with electrodes **14** and **15**, respectively. In operation, the varistor of this invention is intended to be connected into an electrical circuit by leads **16** and **17** for protecting the circuit, or components thereof, against voltage transients. Electrodes **14** and **15** have, in operation, typically a steady state voltage stress in excess of 20 volts between them, and are subjected to transient voltage stresses on the order of thousands of volts. A high thermal conductivity potting material **18** encapsulates completely substrate **11**, electrodes **14** and **15**, and a portion of leads **16** and **17**. A pair of high thermal conductivity plates **19** and **20** are spaced in a generally parallel relationship to the opposite major surfaces **12** and **13** of the substrate **11**. Plates **19** and **20** are bonded in position by potting material **18**. Base or bottom plate **19**, which is of larger dimensions than plate **20** has at least a pair of mounting holes **21** therein. Plates **19** and **20** could carry fins to increase further the available surface area resulting in a reduced thermal impedance and thus even greater power capacity.

The metal oxide varistor of my invention has improved power capacity over the conventional lead mounted metal oxide varistor by at least an order of magnitude.

In FIG. **4** of the drawing, there is shown a sectional view of a portion of a modified metal oxide varistor. As opposed to affixing a pair of leads **16** and **17** to the exterior surfaces of electrodes **14** and **15**, respectively, as in FIGS. 2 and 3, a pair of electrical leads or connectors **22** and **23** in FIG. **4** are affixed to and in electrical contact with the respective edges of electrodes **14** and **15**. In this manner, the exterior surface of each lead is initially approximately flush with the exterior surface of the respective electrode thereby reducing the thickness of the potting material **18** between each associated electrode and plate. The respective varistors of FIGS. **1, 2,** and **3** can be further modified by bonding plate **19** directly to electrode **14**, for example, by soldering, without potting material therebetween. The varistor is otherwise similar in construction.

Advantages are obtained from a metal oxide varistor primarily due to the following three exceptional properties of MOV material (1) the resistance characteristics are highly nonlinear ($\alpha > 10$) over a very wide range of current and result in a high degree of voltage limiting, (2) the response time is negligible and relatively nonvarying, (3) the high thermal conductivity permits rapid dissipation of heat developed in operation, and (4) the metal oxide varistor material does not react chemically with epoxy potting components, even when subjected to very high voltage stresses, and it is not subject to mechanical damage resulting from differential expansion coefficients because the MOV material is mechanically very strong. MOV material limits voltage build-up and provides a relatively low resistance path for the current which thence decays at a rate determined primarily by the LR time constant of the associated device or until a current zero is reached, the resistance of the MOV body increasing substantially as the voltage, and primarily the current, are decreasing.

My varistor provides the unique advantage of increased heat dissipation over a conventional varistor thereby producing improved power capacity. Such increased heat dissipation is accomplished by encapsulating the metal oxide substrate, its associated electrodes and a portion of the respective leads with a high thermal conductivity potting material of which I prefer epoxy resin material. Such high thermal conductivity epoxy resins are commercially available. I found that this advantage is increased further by adding a high thermal conductivity ceramic to the epoxy resin prior to encapsulation of the metal oxide substrate. Of various suitable and available ceramics, including beryllium oxide, boron nitride, and aluminum nitride, I prefer to employ boron nitride.

This advantage is increased still further by bonding a pair of high thermal, conductivity plates in spaced relationship to the opposite major surfaces of the metal oxide substrate with the high thermal conductivity potting material, which has preferably added thereto the above discussed ceramic material. Of suitable and available plates for this purpose, metal plates, and particularly copper metal plates, are preferred. One of the plates is provided with at least a pair of mounting holes therein and is preferably of larger dimensions than the other plate.

Thus, while my invention has been particularly shown and described with reference to the above illustrated embodiment thereof, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the scope of the invention as defined by the following claims.

THE INVENTION CLAIMED IS:

1. A metal oxide varistor comprising a metal oxide substrate having first and second opposed major surfaces and having an alpha in excess of 10 in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter, a pair of electrodes having an electrical potential in excess of 20 volts applied therebetween in non-rectifying contact with the respective opposite major surfaces of the substrate, a high thermal conductivity potting material encapsulating one major surface and the edges of the substrate and its associated electrode, and a pair of metal plates spaced in a generally parallel relationship to the opposite major surfaces of the substrate, at least one of said plates being bonded in position by the potting material.

2. A metal oxide varistor as in claim **1**, in which each said electrode has an electrical lead in contact therewith and wherein: the potting material encapsulates additionally the second major surface of the substrate, its associated electrode, and a portion of the associated leads thereby encapsulating completely the substrate, and the second plate is bonded in position by the potting material.

3. A metal oxide varistor as in claim **1**, in which the potting material is a high thermal conductivity epoxy material.

4. A metal oxide varistor as in claim **1**, in which the potting material has a high thermal conductivity ceramic incorporated therein.

5. A metal oxide varistor as in claim **4**, in which the ceramic is boron nitride.

6. A metal oxide varistor as in claim **1**, in which the plates are copper.

7. A metal oxide varistor comprising a metal oxide substrate having first and second opposed major surfaces and having an alpha in excess of 10 in the current density range of from 10^{-3} to 10^{2} amperes per square centimeter, a pair of electrodes in non-rectifying contact with the respective opposite major surfaces of the substrate, a high thermal conductivity epoxy potting material including a ceramic selected from the group consisting of beryllium oxide, boron nitride, and aluminum nitride encapsulating one major surface and the edges of the substrate and its associated electrode, and a pair of metal plates spaced in a generally parallel relationship to the opposite major surfaces of the substrate, at least one of said plates being bonded in position by the potting material.

8. A metal oxide varistor as in claim **7**, in which each of said electrodes has an electrical lead in contact therewith and wherein: the potting material encapsulates additionally the second major surface of the substrate, its associated electrode, and a portion of the associated leads thereby encapsulating completely the substrate, and the second plate is bonded in position by the potting material.

9. A metal oxide varistor as in claim **7**, in which the ceramic is boron nitride.

10. A metal oxide varistor as in claim **7**, in which the plates are copper.

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