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[54] **VOLTAGE NONLINEAR RESISTORS**

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[51] **Int. Cl.** **H01c 7/12**

[58] **Field of Search** 338/21; 252/518, 252/520

[56] **References Cited**

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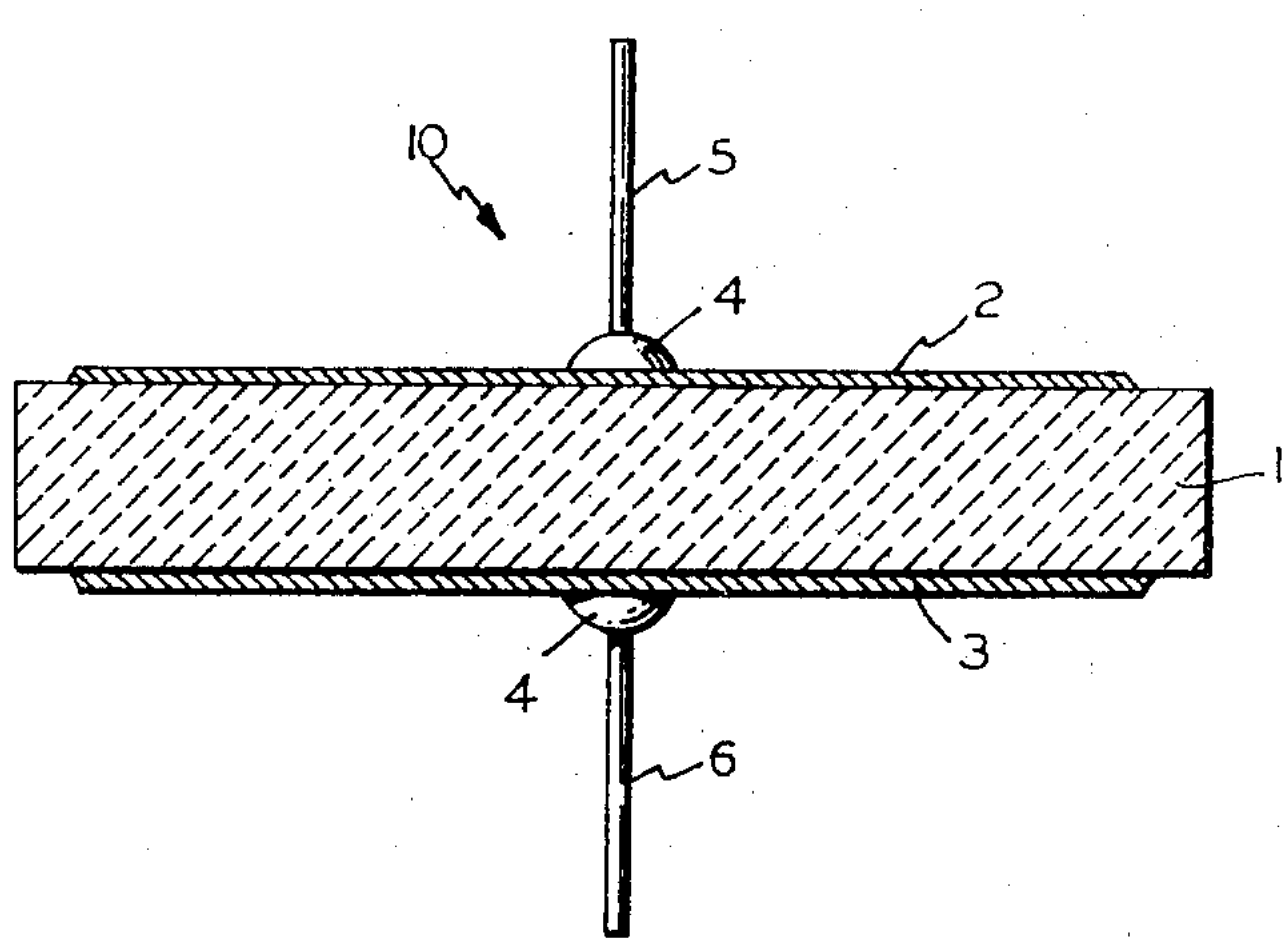
[57] **ABSTRACT**

A voltage dependent resistor in a bulk type comprising a sintered body consisting essentially of, as a major part, zinc oxide (ZnO) and as an additive, 0.05 to 20.0 mole percent of silicon dioxide (SiO_2) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi_2O_3), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO), and lead oxide (PbO), and electrodes in contact with the body.

6 Claims, 1 Drawing Figure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VOLTAGE NONLINEAR RESISTORS

This invention relates to voltage dependent resistors having non-ohmic resistance due to the bulk thereof and more particularly to varistors comprising zinc oxide and silicon dioxide.

Various voltage dependent resistors such as silicon carbide varistors, selenium rectifiers and germanium or silicon p-n junction diodes have been widely used for stabilization of voltage or current of electrical circuits. The electrical characteristics of such a voltage dependent resistor are expressed by the relation:

$$I = (V/C)^n$$

where V is the voltage across the resistor, I is the current flowing through the resistor, C is a constant corresponding to the voltage at a given current and exponent n is a numerical value greater than 1. The value of n is calculated by the following equation:

$$n = [\log_{10}(I_2/I_1)]/[\log_{10}(V_2/V_1)]$$

where V_1 and V_2 are the voltages at given currents I_1 and I_2, respectively. The given currents of I_1 and I_2 are conveniently set up to 0.1mA and 1mA, respectively. The desired value of C depends upon the kind of application to which the resistor is to be put. It is ordinarily desirable that the value of n be as large as possible since this exponent determines the extent to which the resistors depart from ohmic characteristics.

Voltage dependent resistors comprising sintered bodies of zinc oxide with or without additives and silver paint electrodes applied thereto, have previously been disclosed. The non-linearity of such varistors is attributed to the interface between the sintered body of zinc oxide with or without additives and the silver paint electrode and is controlled mainly by changing the compositions of said sintered body and silver paint electrode. Therefore, it is not easy to control the C-value over a wide range after the sintered body is prepared. Similarly, in varistors comprising germanium or silicon p-n junction diodes, it is difficult to control the C-value over a wide range because the non-linearity of these varistors is not attributed to the bulk but to the p-n junction. On the other hand, thd silicon carbide varistors have non-linearity due to the contacts among the individual grains of silicon carbide bonded together by a ceramic binding material, i.e. to the bulk, and the C-value is controlled by changing a dimension in the direction in which the current flows through the varistors. The silicon carbide varistors, however, have a relatively low n-value ranging from 3 to 6.

An object of the present invention is to provide a voltage dependent resistor having non-linearity due to the bulk thereof and being characterized by a high C-value, high n-value and high stability with respect to temperature, humidity and electric load.

A further object of the present invention is to provide a voltage dependent resistor characterized by a high resistance to surge current.

The other objects of the invention will become apparent upon consideration of the following description taken together with the accompanying drawing in which the single FIGURE is a partly cross-sectional view through a voltage dependent resistor in accordance with the invention.

Before proceeding with a detailed description of the voltage dependent resistors contemplated by the invention, their construction will be described with reference to the aforesaid figure of drawing wherein reference character **10** designates, as a whole, a voltage dependent resistor comprising, as its active element, a sintered body having a pair of electrodes **2** and **3** applied to opposite surfaces thereof. Said sintered body **1** is prepared in a manner hereinafter set forth and is in any form such as circular, square or rectangular plate form. Wire leads **5** and **6** are attached conductively to the electrodes **2** and **3**, respectively, by a connection means **4** such as solder or the like.

A voltage dependent resistor according to the invention comprises a sintered body of a composition consisting essentially of, as a major part, zinc oxide (ZnO) and, as an additive, 0.05 to 20.0 mole percent of silicon dioxide (SiO_2) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi_2O_3), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO) and electrodes in contact with said body.

The higher n-value can be obtained when said additive consists essentially of 0.1 to 10 mole percent of silicon dioxide (SiO_2) and 0.1 to 3.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi_2O_3), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).

Table 1 shows the optimal compositions of said additive for producing a voltage dependent resistor having high n-value, high C-value, high stability with respect to temperature, humidity, electric load and high resistance to surge current. The voltage dependent resistor according to the present invention is particularly characterized by a high resistance to surge current as shown in the Table.

The sintered body **1** can be prepared by a per se well known ceramic technique. The starting materials in the compositions described in the foregoing description are mixed in a wet mill so as to produce a homogeneous mixture. The mixtures are dried and pressed in a mold into the desired shape at a pressure from 100 kg/cm² to 1,000kg/cm². The pressed bodies are sintered in air at 1,000°C to 1,450°C for 1 to 10 hours, and then furnace-cooled to room temperature (about 15° to about 30°C).

The mixture can be preliminarily calcined at 700° to 1,000°C and pulverized for easy fabrication in the subsequent pressing step. The mixture to be pressed can be admixed with a suitable binder such as water, polyvinyl alcohol, etc.

It is advantageous that the sintered body be lapped at the opposite surfaces by abrasive powder such as silicon carbide having a particle size of 300 meshe to 1,500 meshe.

The sintered bodies are provided, at the opposite surfaces thereof, with suitable electrodes by any available and suitable method, for example, with a spray metallized film of aluminum and/or copper.

TABLE 1

[Optimal Composition of Additives (mole percent)]

SiO_2	Bi_2O_3	CoO	MnO	Sb_2O_3	Cr_2O_3	NiO
0.1~10	0.1~3.0			0.1~3.0		
0.1~10	0.1~3.0				0.1~3.0	
0.1~10	0.1~3.0					0.1~3.0
0.1~10	0.1~3.0			0.1~3.0	0.1~3.0	
0.1~10	0.1~3.0			0.1~3.0		0.1~3.0
0.1~10	0.1~3.0				0.1~3.0	0.1~3.0
0.1~10	0.1~3.0			0.1~3.0	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0		0.1~3.0		
0.1~10	0.1~3.0	0.1~3.0			0.1~3.0	
0.1~10	0.1~3.C	0.1~3.0				0.1~3.0

TABLE 1—Continued

[Optimal Composition of Additives (mole percent)]

SiO_2	Bi_2O_3	CoO	MnO	Sb_2O_3	Cr_2O_3	NiO
0.1~10	0.1~3.0	0.1~3.0	----------	0.1~3.0	0.1~3.0	----------
0.1~10	0.1~3.0	0.1~3.0	----------	0.1~3.0	----------	0 1~3.0
0.1~10	0.1~3.0	0.1~3.0	----------	----------	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0	----------	0.1~3.0	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	----------	0.1~3.0	0.1~3.0	----------	----------
0.1~10	0.1~3.0	----------	0.1~3.0	----------	0.1~3.0	----------
0.1~10	0.1~3.0	----------	0.1~3.0	----------	----------	0.1~3.0
0.1~10	0.1~3.0	----------	0.1~3.0	0.1~3.0	0.1~3.0	----------
0.1~10	0.1~3.0	----------	0.1~3.0	0.1~3.0	----------	0.1~3.0
0.1~10	0.1~3.0	----------	0.1~3.0	----------	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	----------	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	----------	----------
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	----------	0.1~3.0	----------
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	----------	----------	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	----------
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	----------	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	----------	0.1~3.0	0.1~3.0
0.1~10	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0	0.1~3.0

Lead wires can be attached to the electrodes in a per se conventional manner by using conventional solder having a low melting point. It is convenient to employ a conductive adhesive comprising silver powder and resin in an organic solvent in order to connect the lead wires to the electrodes.

Voltage dependent resistors according to this invention have a high stability with respect to temperature and in the load life test, which is carried out at 70°C at a rating power for 1,000 hours. The n-value and C-value do not change remarkably after heating cycles and load life test. Similarly, voltage dependent resistors according to this invention show a high surge resistance. It is advantageous for achievement of a high stability with respect to humidity that the resultant voltage dependent resistors be embedded in a humidity proof resin such as epoxy resin and phenol resin in a per se well known manner. The n-value is independent of the thickness of the sintered body, while the C-value varies in proportion to the thickness of the sintered body. The variation in the C-value with thickness of the sintered body indicates that the nonlinearity of voltage dependent resistor according to this invention is attributable to the bulk of the sintered body itself, not to the barrier between the electrodes and the sintered body.

Presently preferred illustrative embodiments of the invention are as follows:

Example 1

Starting materials listed in Table 2 are mixed in a wet mill for 5 hours. Each mixture is dried and pressed in a mold into a disc 13mm in diameter and 2.5mm thick at a pressure of 340 kg/cm^2.

The pressed bodies are sintered in air for 1 hour at the temperatures listed in Table 2, and then furnace-cooled to room temperature (about 15°C to about 30°C). The sintered discs are lapped to the thicknesses listed in Table 2 by lapping opposite surfaces thereof with silicon carbide abrasive having a particle size of 600 meshes. The opposite surfaces of the sintered discs are provided with a spray metallized film of aluminum by a per se well known technique. Lead wires are attached to the aluminum electrodes by means of conductive silver paint. The electric characteristics of the resultant resistors are shown in Table 2. It will be readily understood that the C-value changes in proportion to the thickness of the sintered body.

TABLE 2

Composition of sintered body (mol. percent)			Sintering temp. (° C.)	Thickness (mm.)	Electrical characteristics	
ZnO	SiO_2	Further additives			C (at 1 ma.)	n
94.5	5	Bi_2O_3 (0.5)	1,200	2.0	170	6.2
				1.5	126	6.3
				1.0	85	6.1
94.5	5	CoO (0.5)	1,250	2.0	205	7.4
				1.5	153	7.4
				1.0	102	7.3
94.5	5	MnO (0.5)	1,250	2.0	224	8.0
				1.5	167	8.1
				1.0	111	8.1
94.5	5	BaO (0.5)	1,300	2.0	340	7.5
				1.5	253	7.4
				1.0	170	7.4
94.5	5	SrO (0.5)	1,250	2.0	300	5.4
				1.5	225	5.3
				1.0	151	5.4
94.5	5	PbO (0.5)	1,200	2.0	720	5.9
				1.5	540	5.9
				1.0	355	5.8

Example 2

Starting materials according to Table 3 are mixed and pressed in the same manner as that described in Example 1.

Each pressed body is sintered in air at 1,250°C for 1 hour and then furnace-cooled to room temperature (about 15° to about 30°C). The sintered disc is lapped by lapping the opposite surfaces thereof with silicon carbide abrasive having a particle size of 600 mesh. The resulting sintered disc is 10mm in diameter; and 1.5mm in thick. The opposite surfaces of the sintered disc are provided with a spray metallized film of aluminum by a per se well known technique. Lead wires are attached to the aluminum electrodes by means of conductive silver paint. The resultant resistors are tested in accordance with a method widely used in testing electronic components parts. The load life test is carried out at 70°C ambient temperature at 1.5 watt rating power for 1,000 hours. The heating cycle test is carried out by repeating 5 times a cycle in which said resistors are kept at 85°C ambient temperature for 30 minutes, cooled rapidly to −20°C and then kept at such temperature for 30 minutes. Further, the impulse test is carried out by applying 100 times 8 × 20μs impulses of 1,500Ap. The electric characteristics of the resultant resistor are shown in Table 3. It will be readily understood that the high n-value, the high C-value at a given current of 1 mA and the high stability are obtained by the addition of silicon dioxide.

Example 3

Starting materials according to Table 4 are pressed, fired, lapped, electrodes are attached and then the resistor tested in the same manner as described in Example 2. The electric characteristics of the resultant resistors are shown in Table 4. It can be easily understood that the resistors having the compositions of Table 4 have higher n-value, high C-value and more excellent stability, particularly with respect to the impulse test.

TABLE 3

Composition of sintered body (mol percent)			Electric characteristics		Change rate (percent)					
					Load life test		Heating cycle test		Impulse test	
ZnO	SiO_2	Further additives	C (at 1 ma.)	n	ΔC	Δn	ΔC	Δn	ΔC	Δn
99.90	0.05	Bi_2O_3 (0.05)	85	4.4	−9.3	−9.3	−8.8	−9.2	−4.9	−4.9
89.95	0.05	Bi_2O_3 (10)	100	4.2	−9.7	−9.4	−9.1	−9.4	−4.7	−4.8
79.95	20	Bi_2O_3 (0.05)	200	4.1	−9.6	−8.8	−9.4	−9.6	−4.6	−4.8
70.0	20	Bi_2O_3 (10)	350	4.3	−9.9	−9.0	−9.1	−8.9	−4.9	−4.7
99.8	0.1	Bi_2O_3 (0.1)	115	5.8	−7.3	−5.8	−7.7	−7.7	−3.7	−4.0
96.9	0.1	Bi_2O_3 (3)	150	5.6	−7.2	−7.3	−7.4	−7.6	−3.7	−4.0
89.9	10	Bi_2O_3 (0.1)	225	5.4	−5.9	−7.4	−7.3	−7.2	−3.6	−4.0
87.0	10	Bi_2O_3 (3)	270	5.4	−5.7	−7.0	−7.8	−8.0	−3.9	−3.7
94.5	5	Bi_2O_3 (0.5)	100	6.0	−5.2	−5.0	−4.6	−4.8	−3.5	−3.3
99.90	0.05	CoO (0.05)	130	4.7	−9.0	−8.9	−9.0	−8.9	−4.7	−4.5
89.95	0.05	CoO (10)	160	4.9	−9.1	−8.9	−9.1	−9.0	−4.9	−4.7
79.95	20	CoO (0.05)	390	5.0	−8.9	−9.0	−8.7	−9.5	−4.7	−4.5
70.0	20	CoO (10)	500	4.7	−9.1	−9.2	−9.0	−8.7	−4.8	−4.9
99.8	0.1	CoO (0.1)	140	6.5	−7.2	−6.3	−7.1	−7.2	−4.0	−3.8
96.9	0.1	CoO (3)	185	6.7	−7.7	−7.1	−7.2	−6.4	−3.9	−3.4
89.9	10	CoO (0.1)	220	5.9	−7.0	−6.9	−6.8	−6.5	−3.7	−3.7
87.0	10	CoO (3)	270	6.3	−7.0	−7.5	−7.1	−6.8	−3.5	−3.5
94.5	5	CoO (0.5)	153	7.4	−5.0	−4.9	−5.1	−5.2	−3.3	−3.1
99.90	0.05	MnO (0.05)	190	5.2	−9.1	−8.9	−9.0	−8.8	−4.8	−4.9
89.95	0.05	MnO (10)	220	5.0	−9.6	−8.7	−8.7	−8.8	−4.7	−4.8
79.95	20	MnO (0.05)	540	4.7	−9.7	−9.2	−8.8	−9.0	−4.7	−4.9
70.0	20	MnO (10)	650	4.9	−8.9	−9.0	−9.4	−9.5	−4.9	−4.7
99.8	0.1	MnO (0.1)	220	6.5	−7.2	−3.7	−6.3	−7.1	−3.8	−4.0
96.9	0.1	MnO (3)	250	6.6	−7.3	−4.0	−7.0	−7.0	−3.7	−4.0
89.9	10	MnO (0.1)	380	6.5	−6.5	−3.6	−6.9	−6.7	−3.9	−3.7
87.0	10	MnO (3)	395	6.7	−7.0	−4.0	−7.1	−6.7	−3.9	−3.7
94.5	5	MnO (0.5)	167	8.1	−5.2	−5.4	−5.3	−5.4	−3.4	−3.3
99.90	0.05	BaO (0.05)	200	4.4	−8.7	−9.0	−9.2	−9.3	−4.8	−4.5
89.95	0.05	BaO (10)	240	4.5	−9.5	−8.8	−9.2	−9.2	−4.7	−4.9
79.95	20	BaO (0.05)	670	4.5	−8.8	−8.8	−9.4	−8.7	−4.5	−4.7
70.0	20	BaO (10)	800	4.3	−8.9	−9.2	−8.9	−9.2	−4.2	−4.2
99.8	0.1	BaO (0.1)	310	5.9	−7.4	−7.4	−7.0	−7.1	−3.7	−4.0
96.9	0.1	BaO (3)	335	5.8	−7.0	−7.0	−7.1	−7.1	−3.5	−3.9
89.9	10	BaO (0.1)	415	5.7	−7.0	−6.7	−6.4	−6.4	−3.3	−4.0
87.0	10	BaO (3)	470	5.9	−6.8	−6.6	−6.8	−7.0	−3.7	−3.7
94.5	5	BaO (0.5)	270	7.3	−4.4	−4.6	−5.0	−4.8	−3.1	−3.5
99.90	0.05	SrO (0.05)	175	4.2	−8.7	−9.4	−8.4	−9.0	−4.7	−4.5
89.95	0.05	SrO (10)	180	4.3	−8.6	−9.5	−9.0	−9.1	−4.9	−4.7
79.95	20	SrO (0.05)	580	4.1	−8.9	−8.9	−8.7	−8.7	−4.9	−4.9
70.0	20	SrO (10)	700	4.2	−8.2	−7.7	−8.2	−8.4	−4.5	−4.7
99.8	0.1	SrO (0.1)	290	4.7	−6.9	−7.0	−6.9	−6.3	−4.0	−3.8
96.9	0.1	SrO (3)	300	4.8	−7.1	−6.2	−7.1	−6.5	−3.7	−3.7
89.9	10	SrO (0.1)	415	4.8	−6.3	−6.3	−6.2	−6.0	−3.5	−3.7
87.0	10	SrO (3)	450	4.6	−6.7	−6.5	−6.2	−6.7	−3.8	−3.6
94.5	5	SrO (0.5)	225	5.3	−4.5	−4.9	−4.2	−4.2	−3.3	−3.3
99.90	0.05	PbO (0.05)	[illegible]	4.2	−9.0	−9.1	−8.6	−8.7	−4.6	−4.1
89.95	0.05	PbO (10)	420	4.1	−8.2	−9.3	−8.7	−8.8	−4.7	−4.0
79.95	20	PbO (0.05)	1,050	4.1	−9.0	−9.1	−8.5	−9.4	−4.9	−4.3
70.0	20	PbO (10)	1,200	4.3	−9.3	−8.9	−9.1	−9.1	−4.6	−4.5
99.8	0.1	PbO (0.1)	400	5.0	−6.4	−7.0	−6.6	−6.3	−4.1	−4.0
96.9	0.1	PbO (3)	580	4.8	−6.4	−6.7	−6.5	−6.3	−3.9	−3.7
89.9	10	PbO (0.1)	690	4.9	−5.9	−6.0	−7.1	−6.6	−3.8	−3.6
87.0	10	PbO (3)	750	5.0	−6.4	−6.7	−6.4	−5.8	−3.9	−3.5
94.5	5	PbO (0.5)	490	5.7	−4.4	−4.2	−4.2	−4.4	−3.7	−3.2
94.0	5	Bi_2O_3 (0.5), CoO (0.5)	150	16	−3.9	−4.0	−3.8	−4.1	−3.4	−3.2
94.0	5	Bi_2O_3 (0.5), MnO (0.5)	190	18	−3.4	−3.9	−4.2	−3.6	−3.5	−3.3
94.0	5	Bi_2O_3 (0.5), BaO (0.5)	350	17	−3.4	−4.3	−3.5	−3.9	−3.7	−3.7
94.0	5	Bi_2O_3 (0.5), SrO (0.5)	290	16	−4.0	−4.7	−3.7	−4.0	−3.7	−3.3
94.0	5	Bi_2O_3 (0.5), PbO (0.5)	400	15	−4.1	−4.7	−3.6	−3.9	−3.5	−3.6
94.0	5	CoO (0.5), MnO (0.5)	200	16	−3.7	−4.2	−4.4	−3.5	−3.3	−3.4
94.0	5	CoO (0.5), BaO (0.5)	370	19	−4.4	−3.9	−3.8	−3.7	−3.9	−3.9
94.0	5	CoO (0.5), SrO (0.5)	450	18	−3.3	−4.4	−4.0	−3.8	−3.4	−3.4
94.0	5	CoO (0.5), PbO (0.5)	400	18	−4.0	−4.0	−3.6	−3.5	−3.5	−3.3
94.0	5	MnO (0.5), BaO (0.5)	300	17	−4.4	−5.0	−3.8	−4.5	−3.8	−3.6
94.0	5	MnO (0.5), SrO (0.5)	270	19	−3.8	−4.5	−4.0	−4.5	−3.9	−3.8
94.0	5	MnO (0.5), PbO (0.5)	420	15	−4.0	−4.4	−4.1	−3.9	−3.1	−3.6
94.0	5	BaO (0.5), SrO (0.5)	320	16	−4.2	−3.4	−2.7	−3.1	−3.2	−3.9
94.0	5	BaO (0.5), PbO (0.5)	480	16	−4.1	−3.8	−3.8	−3.5	−3.4	−3.7
94.0	5	SrO (0.5), PbO (0.5)	430	15	−4.4	−3.9	−3.9	−4.2	−3.9	−3.9

TABLE 4

Composition of sintered body (mol. percent)								Electrical characteristics		Change rate (percent)					
										Load life test		Heating cycle test		Impulse test	
ZnO	SiO2	Bi2O3	CoO	MnO	Sb2O3	Cr2O3	NiO	C (at 1 ma.)	n	ΔC	Δn	ΔC	Δn	ΔC	Δn
99.7	0.1	0.1			0.1			160	23	−4.5	−4.5	−4.7	−4.9	−4.8	−4.7
99.7	0.1	0.1				0.1		140	23	−4.7	−4.5	−4.6	−4.7	−4.8	−4.8
99.7	0.1	0.1					0.1	135	23	−4.7	−4.4	−4.7	−4.2	−4.4	−4.2
99.6	0.1	0.1			0.1	0.1		175	24	−4.7	−4.5	−4.4	−4.3	−4.2	−4.3
99.6	0.1	0.1			0.1		0.1	170	24	−4.7	−4.6	−4.4	−4.4	−4.3	−4.2
99.6	0.1	0.1				0.1	0.1	175	23	−4.3	−4.6	−4.5	−4.4	−4.7	−4.3
99.5	0.1	0.1			0.1	0.1	0.1	190	25	−4.1	−4.2	−4.0	−4.2	−4.1	−4.0
84.0	10	3			3			300	23	−4.0	−4.0	−4.0	−3.9	−3.9	−3.9
84.0	10	3				3		290	23	−3.9	−3.9	−4.2	−3.8	−3.9	−3.8
84.0	10	3					3	275	23	−4.1	−4.0	−4.1	−3.8	−3.7	−3.8
81.0	10	3			3	3		325	25	−3.8	−4.0	−4.0	−3.8	−3.7	−3.5
81.0	10	3			3		3	310	25	−3.9	−4.1	−3.9	−3.7	−3.9	−3.7
81.0	10	3				3	3	300	24	−4.2	−3.9	−3.8	−3.6	−3.8	−3.6
78.0	10	3			3	3	3	380	27	−3.9	−3.9	−3.7	−3.9	−3.5	−3.1
94.0	5	0.5			0.5			200	27	−3.7	−3.2	−4.0	−3.9	−3.0	−2.9
94.0	5	0.5				0.5		190	26	−3.6	−3.3	−3.2	−3.5	−3.1	−2.8
94.0	5	0.5					0.5	180	24	−3.5	−3.4	−3.4	−3.8	−3.1	−3.2
93.5	5	0.5			0.5	0.5		240	32	−3.5	−3.7	−3.7	−3.7	−3.4	−3.3
93.5	5	0.5			0.5		0.5	230	33	−3.6	−3.3	−3.6	−3.7	−3.0	−3.1
93.5	5	0.5				0.5	0.5	215	30	−3.7	−3.3	−3.5	−3.8	−3.3	−3.2
93.0	5	0.5			0.5	0.5	0.5	270	35	−2.3	−2.2	−2.4	−2.3	−2.4	−2.2
99.6	0.1	0.1	0.1		0.1			210	27	−4.0	−3.9	−3.9	−4.0	−3.5	−4.0
99.6	0.1	0.1	0.1			0.1		200	27	−3.7	−4.0	−3.8	−3.7	−4.0	−3.7
99.6	0.1	0.1	0.1				0.1	195	25	−3.7	−4.0	−3.6	−3.5	−4.0	−4.0
99.5	0.1	0.1	0.1		0.1	0.1		240	29	−4.0	−3.3	−3.9	−3.7	−3.7	−4.0
99.5	0.1	0.1	0.1		0.1		0.1	240	28	−3.5	−3.7	−4.0	−3.7	−3.9	−3.7
99.5	0.1	0.1	0.1			0.1	0.1	235	28	−3.8	−4.0	−3.7	−3.9	−3.8	−3.5
99.4	0.1	0.1	0.1		0.1	0.1	0.1	300	30	−3.5	−3.5	−3.7	−3.7	−3.8	−3.8
81.0	10	3	3		3			270	29	−3.7	−3.6	−3.3	−3.8	−3.5	−3.4
81.0	10	3	3			3		360	27	−3.6	−3.4	−3.5	−3.8	−3.1	−3.2
81.0	10	3	3				3	350	26	−3.7	−3.6	−3.6	−3.8	−3.4	−3.5
78.0	10	3	3		3	3		400	33	−3.5	−3.3	−3.7	−3.7	−3.7	−3.7
78.0	10	3	3		3		3	400	30	−3.5	−3.5	−3.3	−3.4	−3.7	−3.6
78.0	10	3	3			3	3	370	31	−3.4	−3.6	−3.0	−3.1	−3.3	−3.4
75.0	10	3	3		3	3	3	460	37	−3.0	−2.9	−3.0	−2.9	−3.0	−2.9
93.5	5	0.5	0.5		0.5			260	37	−2.3	−3.1	−3.3	−2.9	−2.9	−3.0
93.5	5	0.5	0.5			0.5		250	36	−2.2	−3.2	−2.9	−2.7	−2.2	−2.2
93.5	5	0.5	0.5				0.5	250	37	−2.4	−3.1	−2.8	−2.4	−2.3	−2.3
93.0	5	0.5	0.5		0.5	0.5		330	40	−2.4	−3.0	−2.7	−2.4	−2.5	−2.4
93.0	5	0.5	0.5		0.5		0.5	330	41	−2.2	−2.9	−2.5	−2.3	−2.5	−2.5
93.0	5	0.5	0.5			0.5	0.5	310	41	−2.4	−2.4	−2.6	−2.7	−2.3	−2.3
92.5	5	0.5	0.5		0.5	0.5	0.5	390	45	−1.9	−1.9	−1.7	−1.9	−2.1	−2.0
99.6	0.1	0.1		0.1	0.1			300	36	−4.0	−3.9	−4.0	−3.7	−3.9	−3.8
99.6	0.1	0.1		0.1		0.1		290	36	−3.7	−4.0	−3.7	−4.0	−3.8	−3.7
99.6	0.1	0.1		0.1			0.1	285	34	−3.9	−4.0	−4.0	−4.0	−3.9	−3.9
99.5	0.1	0.1		0.1	0.1	0.1		360	38	−3.7	−3.7	−3.9	−3.7	−3.7	−3.6
99.5	0.1	0.1		0.1	0.1		0.1	350	38	−3.7	−3.9	−3.9	−3.9	−3.7	−3.8
99.5	0.1	0.1		0.1		0.1	0.1	330	37	−3.6	−3.6	−3.5	−3.8	−3.9	−3.6
99.4	0.1	0.1		0.1	0.1	0.1	0.1	380	40	−3.1	−4.0	−3.6	−3.2	−2.9	−2.8
81.0	10	3		3	3			520	42	−2.9	−3.8	−3.4	−3.8	−3.0	−3.0
81.0	10	3		3		3		570	42	−3.8	−3.7	−3.4	−3.7	−3.1	−3.2
81.0	10	3		3			3	500	42	−3.7	−3.0	−3.9	−3.4	−3.2	−3.4
78.0	10	3		3	3	3		550	44	−2.7	−3.3	−3.7	−3.3	−3.3	−3.1
78.0	10	3		3	3		3	540	43	−3.9	−3.7	−3.5	−3.6	−3.1	−3.1
78.0	10	3		3		3	3	540	43	−3.7	−3.8	−3.6	−3.6	−3.3	−3.2
75.0	10	3		3	3	3	3	600	47	−3.1	−3.9	−3.8	−3.7	−3.0	−3.1
93.5	5	0.5		0.5	0.5			415	48	−3.0	−3.0	−2.9	−2.4	−2.5	−2.4
93.5	5	0.5		0.5		0.5		410	48	−3.7	−2.9	−3.0	−2.5	−2.5	−2.5
93.5	5	0.5		0.5			0.5	405	46	−3.0	−3.0	−2.7	−2.8	−2.3	−2.4
93.0	5	0.5		0.5	0.5	0.5		460	51	−3.0	−2.9	−2.7	−2.3	−2.6	−2.5
93.0	5	0.5		0.5	0.5		0.5	460	50	−2.9	−2.8	−2.8	−2.4	−2.6	−2.5
93.0	5	0.5		0.5		0.5	0.5	440	49	−2.9	−2.8	−2.9	−2.7	−2.7	−2.7
92.5	5	0.5		0.5	0.5	0.5	0.5	500	55	−2.0	−1.9	−2.1	−1.8	−1.7	−1.8
99.5	0.1	0.1	0.1	0.1	0.1			440	35	−2.9	−3.0	−2.7	−2.9	−3.0	−3.0
99.5	0.1	0.1	0.1	0.1		0.1		430	35	−2.6	−2.9	−2.8	−2.7	−2.8	−2.7
99.5	0.1	0.1	0.1	0.1			0.1	425	33	−2.7	−2.9	−2.9	−2.6	−2.7	−2.8
99.4	0.1	0.1	0.1	0.1	0.1	0.1		470	37	−2.8	−2.8	−2.7	−2.7	−2.7	−2.8
99.4	0.1	0.1	0.1	0.1	0.1		0.1	470	38	−2.5	−2.8	−2.8	−2.9	−2.9	−2.7
99.4	0.1	0.1	0.1	0.1		0.1	0.1	465	37	−2.7	−2.8	−2.7	−2.8	−2.9	−2.7
99.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	500	43	−2.7	−2.4	−2.5	−2.3	−2.4	−2.3
78.0	10	3	3	3	3			730	44	−3.0	−2.9	−2.9	−2.7	−3.0	−2.8
78.0	10	3	3	3		3		720	42	−2.7	−2.7	−2.9	−2.8	−2.9	−2.7
78.0	10	3	3	3			3	715	42	−2.9	−2.8	−2.9	−2.9	−2.7	−2.7
75.0	10	3	3	3	3	3		780	49	−2.7	−2.8	−2.6	−2.6	−2.7	−2.7
75.0	10	3	3	3	3		3	750	48	−2.5	−2.7	−2.8	−2.7	−2.7	−2.6
75.0	10	3	3	3		3	3	740	47	−2.4	−2.3	−2.2	−2.5	−2.3	−2.4
72.0	10	3	3	3	3	3	3	850	52	−2.0	−2.1	−2.2	−2.4	−2.0	−2.0
93.0	5	0.5	0.5	0.5	0.5			590	54	−1.5	−1.9	−1.4	−1.2	−1.7	−1.1
93.0	5	0.5	0.5	0.5		0.5		570	54	−1.2	−1.4	−1.1	−1.1	−1.0	−1.7
93.0	5	0.5	0.5	0.5			0.5	565	53	−1.3	−1.2	−1.1	−1.3	−1.3	−1.2
92.5	5	0.5	0.5	0.5	0.5	0.5		620	60	−1.3	−1.3	−1.4	−1.5	−1.2	−1.1
92.5	5	0.5	0.5	0.5	0.5		0.5	600	59	−1.3	−1.9	−1.1	−1.1	−1.0	−1.2
92.5	5	0.5	0.5	0.5		0.5	0.5	600	57	−1.2	−1.9	−1.8	−1.2	−1.1	−1.1
92.0	5	0.5	0.5	0.5	0.5	0.5	0.5	660	65	−0.5	−0.5	−0.4	−0.5	−0.8	−0.9

What we claim is:

1. A voltage dependent resistor of the bulk type comprising a sintered body consisting essentially of, as a major part, zinc oxide (ZnO) and as an additive, 0.05 to 20.0 mole percent of silicon dioxide (SiO_2) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi_2O_3), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO), and lead oxide (PbO), and electrodes in contact with said body.

2. A voltage dependent resistor according to claim **1**, wherein said additive consists essentially of 0.1 to 10.0 mole percent of silicon dioxide (SiO_2) and 0.1 to 3.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi_2O_3), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).

3. A voltage dependent resistor according to claim **1** wherein said additive consists essentially of 0.1 to 10.0 mole percent of silicon dioxide (SiO_2), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), and further contains 0.1 to 3.0 mole percent of at least one member selected from the group consisting of antimony oxide (Sb_2O_3), chromium oxide (Cr_2O_3) and nickel oxide (NiO).

4. A voltage dependent resistor according to claim **1**, wherein said additive consists essentially of 0.1 to 10.0 mole percent of silicon dioxide (SiO_2), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), and 0.1 to 3.0 mole percent of cobalt oxide (CoO) and further contains 0.1 to 3.0 mole percent of at least one member selected from the group consisting of antimony oxide (Sb_2O_3), chromium oxide (cr_2O_3) and nickel oxide (NiO).

5. A voltage dependent resistor according to claim **1** wherein said additive consists essentially of 0.1 to 10.0 mole percent of silicon dioxide (SiO_2), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3) and 0.1 to 3.0 mole percent of manganese oxide (MnO), and further contains 0.1 to 3.0 mole percent of at least one member selected from the group consisting of antimony oxide (Sb_2O_3), chromium oxide (Cr_2O_3) and nickel oxide (NiO).

6. A voltage dependent resistor according to claim **1** wherein said additive consists essentially of 0.1 to 10.0 mole percent of silicon dioxide (SiO_2), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.1 to 3.0 mole percent of cobalt oxide (CoO) and 0.1 to 3.0 mole percent of manganese oxide (MnO), and further contains 0.1 to 3.0 mole percent of at least one member selected from the group consisiting of antimony oxide (Sb_2O_3), chromium oxide (Cr_2O_3) and nickel oxide (NiO).

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