

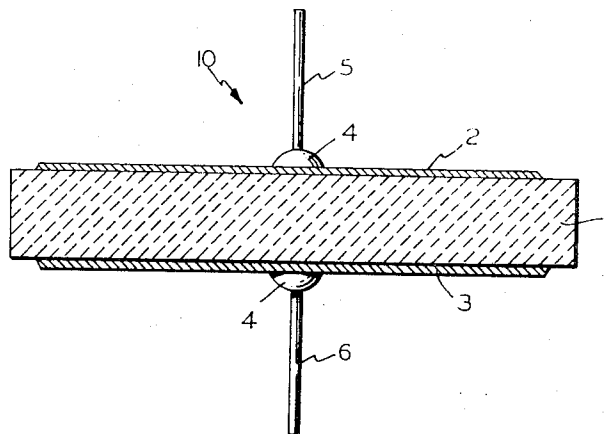
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VOLTAGE DEPENDENT RESISTORS IN A BULK TYPE

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INVENTORS

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ATTORNEYS

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3,682,841 VOLTAGE DEPENDENT RESISTORS IN A BULK TYPE

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5 Claims

ABSTRACT OF THE DISCLOSURE

A voltage dependent resistor of the bulk type. The resistor has a sintered body consisting essentially of, as a major part, zinc oxide (ZnO) and, as an additive, 0.05 to 10.0 mole percent of beryllium oxide (BeO) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO). Electrodes are provided which are in contact with said body.

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 beryllium oxide.

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:

$$I = \left(\frac{V}{C} \right)^n$$

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:

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

where V₁ and V₂ are the voltages at given currents I₁ and I₂, 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, the 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 and are prepared by firing in non-oxidizing atmosphere, especially for the purpose of obtaining a lower C-value.

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 low C-value and high n-value.

Another object of the present invention is to provide a method for making a voltage dependent resistor having the non-linearity due to the bulk thereof and being characterized by a high n-value, without using non-oxidizing atmosphere.

These objects are achieved by providing 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 10.0 mole percent of beryllium oxide (BeO) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO), and electrodes in contact with said body.

These and 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 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.

The sintered body 1 of the voltage dependent resistor according to the invention comprises a composition consisting essentially of, as a major part, zinc oxide (ZnO) and, as an additive, 0.05 to 10.0 mole percent of beryllium oxide (BeO) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO) and has the electrodes 2 and 3 in contact with said body.

A higher n-value can be obtained when said additive consists essentially of 1.0 to 8.0 mole percent of beryllium oxide (BeO) and 0.1 to 3.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), cobalt oxide (CoO), manganese oxide (MnO), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).

Table 1 shows the optimal compositions of said additives for producing a voltage dependent resistor having high n-value, low C-value and high stability with respect to temperature, humidity and electric load.

The sintered body 1 can be prepared by a per se well known ceramic technique. The starting materials having the compositions described in the foregoing description are mixed in a wet mill so as to produce homogeneous mixtures. The mixtures are dried and pressed in a mold into the desired shape at a pressure of from 100 kg./cm.² to 1000 kg./cm.². The pressed bodies are sintered

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in air at 1000° C. to 1450° C. for 1 to 3 hours, and then furnace-cooled to room temperature (about 15 to about 30° C.).

The mixture can be preliminarily calcined at 700° to 1000° 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 have the opposite surfaces thereof lapped by abrasive powder such as silicon carbide having a particle size of 300 mesh to 1500 mesh.

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

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 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 a load life test, which is carried out at 70° C. at a rating power for 500 hours. The n-value and C-value do not change greatly after the heating cycles and the load life test. 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 the voltage dependent resistor according to this invention is attributed to the bulk of the sintered body itself, not to any barrier between the electrodes and the sintered body.

Presently preferred illustrative embodiments of the invention are as follows:

EXAMPLE 1

Respective starting materials listed in Table 2 are mixed in a wet mill for 5 hours. The mixture is dried and pressed in a mold into discs 13 mm. in diameter and 2.5 mm. in thickness at a pressure of 340 kg./cm.²

The pressed bodies are sintered in air for 1 hour at the temperature listed in Table 2, and then furnace-cooled to room temperature (about 15° C. to about 30° C.). The sintered discs have the opposite surfaces lapped to the thickness listed in Table 2 by silicon carbide abrasive having a particle size of 600 mesh. The opposite surfaces of the sintered disc are provided with a spray metallized film of aluminum in 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.

EXAMPLE 2

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

The pressed bodies are sintered in air at 1350° C. for 1 hour and then furnace-cooled to room temperature (about 15° to about 30° C.). The sintered discs have the opposite surfaces thereof lapped by silicon carbide abrasive having a particle size of 600 mesh. The resulting sintered discs have a size of 10 mm. diameter and 1.5 mm. thickness. 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

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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 watt rating power for 500 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. The electric characteristics of the resultant resistors are shown in Table 3. It will be readily understood that the n-value can be elevated and the C-value at a given current of 10 ma. can be lowered remarkably by the addition of beryllium oxide.

EXAMPLE 3

Respective starting materials according to Table 4 are pressed, fired, lapped, electrodes-attached and then tested in the same manner as that 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 shown in Table 4 have higher n-value, lower C-value and more excellent stability.

TABLE 1
[Optimal composition of additive (mole percent)]

BeO	NiO	B ₂ O ₃	Other additive
1.0~8.0	0.1~3.0	-----	Bi ₂ O ₃ , 0.1~3.0.
1.0~8.0	0.1~3.0	-----	CoO, 0.1~3.0.
1.0~8.0	0.1~3.0	-----	MnO, 0.1~3.0.
1.0~8.0	0.1~3.0	-----	BaO, 0.1~3.0.
1.0~8.0	0.1~3.0	-----	SrO, 0.1~3.0.
1.0~8.0	0.1~3.0	-----	PbO, 0.1~3.0.
1.0~8.0	-----	0.02~1.0	Bi ₂ O ₃ , 0.1~3.0.
1.0~8.0	-----	0.02~1.0	CoO, 0.1~3.0.
1.0~8.0	-----	0.02~1.0	MnO, 0.1~3.0.
1.0~8.0	-----	0.02~1.0	BaO, 0.1~3.0.
1.0~8.0	-----	0.02~1.0	SrO, 0.1~3.0.
1.0~8.0	-----	0.02~1.0	PbO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	Bi ₂ O ₃ , 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	CoO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	MnO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	BaO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	SrO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	PbO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	Bi ₂ O ₃ , 0.1~3.0; MnO, 0.1~3.0;
			CoO, 0.1~3.0.
1.0~8.0	0.1~3.0	0.02~1.0	Bi ₂ O ₃ , 0.1~3.0; MnO, 0.1~3.0;
			CoO, 0.1~3.0; TiO ₂ , 0.1~3.0.

TABLE 2

Composition of sintered body (mol. percent)			Sintering temp. (° C.)	Thickness (mm.)	Electric characteristics	
ZnO	BeO	Further additives			C (at 10 ma.)	n
95.5	4	Bi ₂ O ₃ , 0.5	1,150	3.0	15	4.4
				2.0	10	4.4
				1.5	7.5	4.3
				1.0	5.1	4.3
				3.0	148	4.3
95.5	4	CoO, 0.5	1,150	2.0	99	4.2
				1.5	75	4.4
				0.5	50	4.3
				3.0	119	4.0
				2.0	80	4.0
95.5	4	MnO, 0.5	1,150	1.5	59	4.0
				1.0	40	3.9
				3.0	51	7.1
				2.0	33	7.0
				1.5	25	7.0
95.5	4	BaO, 0.5	1,350	1.0	16	6.9
				3.0	41	5.1
				2.0	27	5.0
				1.5	21	5.0
				1.0	14	5.0
95.5	4	SrO, 0.5	1,350	3.0	200	5.1
				2.0	140	5.1
				1.5	105	5.0
				1.0	70	5.0

TABLE 3

Composition of sintered body (mol. percent)					Electric characteristics		Change rate (percent)			
ZnO	BeO	NiO	B ₂ O ₃	Further additives	C (at 10 ma.)	η	Load life test		Heating cycle test	
							ΔC	$\Delta \eta$	ΔC	$\Delta \eta$
99.90	0.05			Bi ₂ O ₃ , 0.05	32	4.3	-9.3	-8.4	-9.0	-8.2
89.95	0.05			Bi ₂ O ₃ , 10	30	4.2	-8.4	-8.4	-8.1	-8.5
89.95	10			Bi ₂ O ₃ , 0.05	31	4.1	-8.6	-9.0	-8.5	-8.6
80.0	10			Bi ₂ O ₃ , 10	28	4.3	-9.0	-9.1	-9.1	-8.7
98.9	1			Bi ₂ O ₃ , 0.1	14	4.9	-5.3	-6.0	-5.5	-5.7
96.0	1			Bi ₂ O ₃ , 3	15	4.9	-5.4	-5.3	-5.4	-5.8
91.9	8			Bi ₂ O ₃ , 0.1	14	4.7	-6.0	-5.3	-6.2	-6.2
89.0	8			Bi ₂ O ₃ , 3	15	4.8	-6.8	-6.0	-5.8	-6.1
95.5	4			Bi ₂ O ₃ , 0.5	6.5	4.9	-3.2	-4.0	-3.5	-3.8
99.90	0.05			CoO, 0.05	100	4.2	-8.0	-7.8	-8.0	-9.0
89.95	0.05			CoO, 10	98	4.2	-8.3	-7.9	-8.1	-9.2
89.95	10			CoO, 0.05	98	4.0	-7.8	-8.0	-7.9	-8.5
80.0	10			CoO, 10	99	4.1	-8.1	-8.1	-8.0	-8.8
98.9	1			CoO, 0.1	72	4.5	-4.2	-4.3	-4.1	-4.2
96.0	1			CoO, 3	70	4.6	-4.8	-5.1	-4.2	-4.5
91.9	8			CoO, 0.1	68	4.5	-5.1	-5.0	-4.8	-4.5
89.0	8			CoO, 3	70	4.4	-4.0	-4.5	-4.1	-3.8
95.5	4			CoO, 0.5	45	4.7	-2.0	-1.9	-2.1	-2.0
99.90	0.05			MnO, 0.05	105	4.2	-9.1	-8.8	-9.2	-8.8
89.95	0.05			MnO, 10	102	4.1	-8.5	-8.7	-8.8	-9.0
89.95	10			MnO, 0.05	104	4.2	-8.0	-8.0	-8.8	-9.0
80.0	10			MnO, 10	105	4.0	-8.8	-8.0	-8.2	-8.5
98.9	1			MnO, 0.1	75	4.5	-4.2	-3.9	-4.3	-5.0
96.0	1			NnO, 3	72	4.6	-4.0	-4.0	-5.0	-5.0
91.9	8			MnO, 0.1	70	4.5	-4.5	-3.8	-4.7	-4.8
89.0	8			MnO, 3	73	4.7	-5.0	-4.0	-5.1	-4.7
95.5	4			MnO, 9.5	48	5.0	-2.0	-2.1	-2.4	-2.4
99.90	0.05			BaO, 0.05	62	4.2	-8.8	-9.0	-8.0	-9.1
89.95	0.05			BaO, 10	60	4.3	-8.7	-9.0	-8.2	-9.2
89.95	10			BaO, 0.05	60	4.5	-8.6	-8.8	-8.4	-8.9
80.0	10			BaO, 10	61	4.2	-9.0	-8.7	-7.9	-9.2
98.9	1			BaO, 0.1	38	5.7	-4.4	-5.1	-4.0	-5.0
96.0	1			BaO, 3	37	5.6	-3.9	-5.0	-4.1	-5.1
91.9	8			BaO, 0.1	39	5.6	-5.0	-4.8	-3.9	-5.1
89.0	8			BaO, 3	40	5.5	-4.8	-4.6	-3.8	-5.0
95.5	4			BaO, 0.5	25	7.0	-3.4	-2.8	-3.0	-2.7
99.90	0.05			SrO, 0.05	43	4.2	-8.8	-7.8	-9.1	-9.0
89.95	0.05			SrO, 10	42	4.3	-8.8	-7.9	-8.0	-9.0
89.95	10			SrO, 0.05	45	4.1	-7.9	-6.8	-8.5	-8.7
80.0	10			SrO, 10	4.6	4.2	-8.0	-7.0	-8.2	-8.5
98.9	1			SrO, 0.1	3.1	4.5	-4.9	-5.0	-3.8	-4.3
96.0	1			SrO, 3	29	4.4	-5.0	-4.2	-5.1	-4.2
91.9	8			SrO, 0.1	30	4.4	-5.3	-4.3	-4.0	-5.0
89.0	8			SrO, 3	27	4.5	-4.7	-4.5	-4.2	-4.9
95.5	4			SrO, 0.5	21	5.0	-2.4	-3.0	-2.1	-2.3
99.90	0.05			PbO, 0.05	200	4.2	-8.0	-9.1	-8.8	-9.0
89.95	0.05			PbO, 10	202	4.2	-8.3	-9.2	-8.7	-9.0
89.95	10			PbO, 0.05	198	4.1	-9.1	-9.5	-9.0	-8.8
80.0	10			PbO, 10	200	4.2	-9.3	-8.9	-9.1	-9.1
98.9	1			PbO, 0.1	150	5.0	-5.7	-6.0	-4.6	-5.3
96.0	1			PbO, 3	147	4.8	-5.4	-5.8	-5.3	-5.4
91.9	8			PbO, 0.1	147	4.9	-6.0	-6.0	-5.1	-5.6
89.0	8			PbO, 3	150	5.0	-5.4	-5.7	-4.6	-5.8
95.5	4			PbO, 0.5	105	5.0	-3.8	-3.9	-3.2	-3.0
95.0	4			Bi ₂ O ₃ , 0.5						
				CoO, 0.5	20	13	-2.8	-3.1	-3.6	-4.1
95.0	4			Bi ₂ O ₃ , 0.5						
				MnO, 0.5	30	18	-1.9	-2.0	-3.1	-3.7
95.0	4			Bi ₂ O ₃ , 0.5						
				BaO, 0.5	21	14	-2.4	-3.4	-3.5	-4.0
95.0	4			Bi ₂ O ₃ , 0.5						
				SrO, 0.5	18	12	-5.0	-4.8	-3.9	-4.0
95.0	4			Bi ₂ O ₃ , 0.5						
				PbO, 0.5	65	10	-4.1	-5.0	-4.0	-3.9
95.0	4			CoO, 0.5						
				MnO, 0.5	70	10	-3.8	-4.2	-5.4	-4.0
95.0	4			CoO, 0.5						
				BaO, 0.5	95	17	-2.1	-3.0	-2.8	-2.9
95.0	4			CoO, 0.5						
				SrO, 0.5	80	18	-2.4	-2.4	-3.0	-2.8
95.0	4			CoO, 0.5						
				PbO, 0.5	130	10	-3.0	-4.1	-3.3	-3.5
95.0	4			MnO, 0.5						
				BaO, 0.5	75	18	-5.4	-5.0	-4.8	-4.9
95.0	4			MnO, 0.5						
				SrO, 0.5	120	12	-4.8	-4.4	-4.0	-4.8
95.0	4			MnO, 0.5						
				PbO, 0.5	100	11	-5.0	-5.0	-4.1	-3.9
95.0	4			BaO, 0.5						
				SrO, 0.5	50	10	-3.0	-2.4	-2.7	-3.1
95.0	4			BaO, 0.5						
				PbO, 0.5	110	11	-3.1	-2.9	-2.2	-2.5
95.0	4			SrO, 0.5						
				PbO, 0.5	100	10	-4.4	-3.8	-3.9	-4.1
95.4	4	0.1		Bi ₂ O ₃ , 0.5	6.0	5.2	-2.5	-3.0	-3.4	-2.8
95.0	4	0.5		Bi ₂ O ₃ , 0.5	5.5	5.1	-1.0	-1.2	-1.4	-1.2
92.5	4	3		Bi ₂ O ₃ , 0.5	6.8	5.3	-2.7	-1.9	-2.0	-2.1
95.48	4		0.02	Bi ₂ O ₃ , 0.5	7.5	5.5	-2.0	-3.4	-3.8	-3.1
95.0	4		0.5	Bi ₂ O ₃ , 0.5	7.0	5.6	-1.4	-1.6	-1.8	-1.4
94.5	4		1	Bi ₂ O ₃ , 0.5	7.4	5.5	-3.0	-3.0	-2.8	-3.0
95.38	4	0.1	0.02	Bi ₂ O ₃ , 0.5	6.3	6.0	-2.5	-2.4	-3.3	-3.0
94.5	4	0.5	0.5	Bi ₂ O ₃ , 0.5	5.2	6.3	-1.0	-1.0	-1.1	-1.2
91.5	4	3	1	Bi ₂ O ₃ , 0.5	6.8	6.1	-3.0	-2.2	-2.4	-2.1
95.0	4	0.5		CoO, 0.5	40	5.0	-2.4	-3.1	-3.3	-3.5
95.0	4	0.5		MnO, 0.5	60	5.0	-2.0	-3.4	-3.0	-2.9
95.0	4	0.5		BaO, 0.5	22	8.1	-1.9	-1.8	-3.1	-2.8
95.0	4	0.5		SrO, 0.5	12	6.0	-1.8	-2.9	-2.7	-3.0
95.0	4	0.5		PbO, 0.5	100	6.5	-2.2	-3.1	-2.4	-2.5
95.0	4		0.5	CoO, 0.5	40	5.0	-2.4	-3.3	-4.0	-2.8
95.0	4		0.5	MnO, 0.5	55	4.9	-3.0	-3.0	-3.0	-3.0
95.0	4		0.5	BaO, 0.5	19	8.0	-2.8	-2.9	-2.8	-4.5

TABLE 3—Continued

Composition of sintered body (mol. percent)					Electric characteristics		Change rate (percent)			
ZnO	BeO	NiO	B ₂ O ₃	Further additives	C (at 10 ma.)	n	Load life test		Heating cycle test	
							ΔC	Δn	ΔC	Δn
95.0	4	-----	0.5	SrO, 0.5	10	6.0	-2.1	-2.5	-2.9	-3.2
95.0	4	-----	0.5	PbO, 0.5	90	6.2	-3.0	-3.1	-2.5	-3.8
94.5	4	0.5	0.5	CoO, 0.5	35	5.1	-4.0	-3.0	-3.9	-3.8
94.5	4	0.5	0.5	MnO, 0.5	50	5.0	-3.5	-3.6	-3.0	-2.9
94.5	4	0.5	0.5	BaO, 0.5	17	8.2	-3.8	-2.9	-3.3	-3.4
94.5	4	0.5	0.5	SrO, 0.5	8	6.2	-2.9	-2.5	-2.9	-3.0
94.5	4	0.5	0.5	PbO, 0.5	90	6.5	-2.5	-3.8	-2.8	-3.4
94.88	4	0.1	0.02	{Bi ₂ O ₃ , 0.5 CoO, 0.5}	15	14	-1.5	-1.8	-2.0	-1.9
94.0	4	0.5	0.5	{Bi ₂ O ₃ , 0.5 CoO, 0.5}	12	15	-0.5	-0.7	-1.0	-0.9
91.0	4	3	1	{Bi ₂ O ₃ , 0.5 CoO, 0.5}	16	13	-1.8	-2.0	-2.1	-1.7

TABLE 4

Composition of sintered body (mol percent)						Electric characteristics	Change rate (percent)				
ZnO	BeO	Bi ₂ O ₃	CoO	MnO	Further additives	C (at 10 ma.)	Load life test			Heating cycle test	
							n	ΔC	Δn	ΔC	Δn
98.58	1	0.1	0.1	0.1	{NiO, 0.1 B ₂ O ₃ , 0.02	40	16	-3.8	-3.5	-4.0	-3.9
96.5	1	0.5	0.5	0.5	{NiO, 0.5 B ₂ O ₃ , 0.5	30	20	-1.9	-2.0	-1.8	-2.1
86.0	1	3	3	3	{NiO, 3 B ₂ O ₃ , 1	42	16	-3.5	-3.4	-3.4	-3.3
95.58	4	0.1	0.1	0.1	{NiO, 0.1 B ₂ O ₃ , 0.02	38	20	-1.5	-2.0	-1.5	-2.0
93.5	4	0.5	0.5	0.5	{NiO, 0.5 B ₂ O ₃ , 0.5	25	25	-0.5	-1.0	-1.2	-0.9
83.0	4	3	3	3	{NiO, 3 B ₂ O ₃ , 1	40	19	-2.0	-2.1	-1.6	-2.1
91.58	8	0.1	0.1	0.1	{NiO, 0.1 B ₂ O ₃ , 0.02	50	13	-3.8	-3.2	-2.9	-3.0
89.5	8	0.5	0.5	0.5	{NiO, 0.5 B ₂ O ₃ , 0.5	32	18	-2.0	-1.8	-1.9	-2.1
79.0	8	3	3	3	{NiO, 3 B ₂ O ₃ , 1	55	14	-4.0	-3.9	-3.3	-3.2
98.48	1	0.1	0.1	0.1	{NiO, 0.1 TiO ₂ , 0.1 B ₂ O ₃ , 0.02	30	12	-3.7	-3.3	-4.0	-3.7
96.0	1	0.5	0.5	0.5	{NiO, 0.5 TiO ₂ , 0.5 B ₂ O ₃ , 0.5	18	18	-2.5	-2.1	-3.0	-1.9
83.0	1	3	3	3	{NiO, 3 TiO ₂ , 3 B ₂ O ₃ , 1	27	11	-4.1	-3.5	-3.3	-3.8
95.48	4	0.1	0.1	0.1	{NiO, 0.1 TiO ₂ , 0.1 B ₂ O ₃ , 0.02	17	14	-2.0	-2.4	-2.1	-3.0
93.0	4	0.5	0.5	0.5	{NiO, 0.5 TiO ₂ , 0.5 B ₂ O ₃ , 0.5	12	20	-0.5	-0.5	-1.0	-1.0
80.0	4	3	3	3	{NiO, 3 TiO ₂ , 3 B ₂ O ₃ , 1	16	15	-1.9	-2.2	-2.3	-1.9
91.48	8	0.1	0.1	0.1	{NiO, 0.1 TiO ₂ , 0.1 B ₂ O ₃ , 0.02	27	11	-4.0	-2.9	-3.7	-3.9
89.0	8	0.5	0.5	0.5	{NiO, 0.5 TiO ₂ , 0.5 B ₂ O ₃ , 0.5	18	17	-2.0	-2.4	-1.9	-2.1
76.0	8	3	3	3	{NiO, 3 TiO ₂ , 3 B ₂ O ₃ , 1	26	12	-3.8	-4.0	-3.5	-3.8

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 10.0 mole percent of beryllium oxide (BeO) and 0.05 to 10.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), 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 of the bulk type according to claim 1, wherein said additive consists essentially of 1.0 to 8.0 mole percent of beryllium oxide (BeO) and 0.1 to 3.0 mole percent, in total, of at least one member selected from the group consisting of bismuth oxide (Bi₂O₃), cobalt oxide (CoO), manganese oxide (MnO),

60 barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).

3. A voltage dependent resistor of the bulk type according to claim 2, wherein said additive further includes at least one member selected from the group consisting of 65 0.1 to 3.0 mole percent of nickel oxide (NiO) and 0.02 to 1.0 mole percent of boron trioxide (B₂O₃).

4. A voltage dependent resistor according to claim 1, wherein said additive consists essentially of 1.0 to 8.0 mole percent of beryllium oxide (BeO), 0.1 to 3.0 mole percent of bismuth oxide (Bi₂O₃), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO), 0.1 to 3.0 mole percent of nickel oxide (NiO), 0.1 to 3.0 mole percent of titanium oxide (TiO₂) 70 and 0.02 to 1.0 mole percent of boric oxide (B₂O₃).

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5. A voltage dependent resistor according to claim 1, wherein said additive consists essentially of 1.0 to 8.0 mole percent of beryllium oxide (BeO), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.1 to 3.0 mole percent of manganese oxide (MnO), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of nickel oxide (NiO) and 0.02 to 1.0 mole percent of boric oxide (B_2O_3).

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