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(54) IMPROVEMENTS IN AND RELATING TO ELECTRICAL RESISTORS

(71) We, MATSUSHITA ELECTRICAL INDUSTRIAL CO. LTD., a Japanese company, of 1006 Kadoma, Osaka, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to non-linear resistors of the type in which the resistance varies with the applied voltage due to the bulk properties of resistance material. Such non-linear resistors, or varistors, can be used for surge suppression in electrical equipment and for voltage stabilisation.

The invention includes from one aspect a sintered material consisting of zinc oxide (ZnO) and, as an additive, 0.01 to 10.0 mol percent bismuth oxide (Bi₂O₃), 0.01 to 10.0 mol percent cobalt oxide (Co₂O₃), 0.01 to 5.0 mol percent boron trioxide (B₂O₃) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).

The invention includes from another aspect a sintered material consisting of zinc oxide (ZnO) and, as an additive 0.01 to 3.0 mol percent bismuth oxide (Bi₂O₃), 0.1 to 3.0 mol percent cobalt oxide (Co₂O₃), 0.01 to 5.0 mol percent boron trioxide (B₂O₃) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO), together with a further additive. Said additive can be 0.01 to 3.0 mol percent of manganese oxide (MnO). Said additive can be 0.01 to 3.0 mol percent of manganese oxide (MnO) with 0.05 to 3.0 mol percent of antimony oxide (Sb₂O₃) or 0.1 to 3.0 mol percent titanium oxide (TiO₂). Said additive can be 0.1 to 3.0 mol

percent of manganese oxide (MnO) together with 0.1 to 3.0 mol percent of titanium oxide (TiO₂) and 0.01 to 3.0 mol percent of chromium oxide (Cr₂O₃) or 0.1 to 3.0 mol percent of nickel oxide (NiO).

The electrical characteristics of a varistor can be expressed by the relation:—

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

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 the exponent n has a numerical value greater than 1. The value of n is calculated from the equation:—

$$N = \frac{\log_{10}(I_2/I_1)}{\log_{10}(V_2/V_1)} \quad (2)$$

where V₁ and V₂ are the voltages across the varistor at specified currents I₁ and I₂, respectively. The suitable value of C depends upon the nature 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 varistors depart from a linear, or ohmic, characteristic.

In embodiments of the invention to be described, varistors are provided which have high n-values, high power dissipation when subjected to surges, and good direct current (d.c.) stability even when used for current densities of less than 0.1mA/cm².

Features and advantages of the invention will appear from the following description of embodiments thereof given by way of example, and from the accompanying drawing,

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which is a diagrammatic, part cross-sectional view through a varistor.

The Figure shows diagrammatically the basic arrangement of a varistor comprising, as its active element, a sintered body 1 having electrodes 2 and 3 making ohmic contact to its opposite major surfaces. The sintered body, which is prepared in a manner to be described, can be of any suitable shape, such as circular, rectangular or square plate form. Wire leads 4 and 5 for connecting the varistor to external circuits are attached conductively to the electrodes 2 and 3, respectively, by connection means 6 and 7, which can be solder or the like conductive material.

The sintered body of the varistor has a composition comprising zinc oxide (ZnO) as the main constituent, and as an additive, 0.01 to 10.0 mol percent bismuth oxide (Bi_2O_3), 0.01 to 10 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO), and strontium oxide (SrO). Such a sintered material exhibits non-linear resistance properties due to the bulk properties of the material; accordingly, a desired C-value for a varistor can be obtained by selecting an appropriate dimension between the electroded surfaces of the varistor, without effecting the n -value. Varistors so made can be given a high n -value, and exhibit good stability in d.c. load conditions.

Improved results, as to d.c. and surge stability can be obtained by using additives consisting of 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.1 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).

Higher n -values and further improved stability can be obtained by using additives consisting of 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3), 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO), and 0.1 to 3.0 mol percent of manganese oxide (MnO).

Still further improvements in n -value and stability can be obtained and C-value controlled by using additives consisting of 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO), 0.1 to 3.0 mol percent of manganese oxide (MnO) and one of 0.05 to 3.0

mol percent of antimony oxide (Sb_2O_3) and 0.1 to 3.0 mol percent of titanium oxide (TiO_2). The addition of antimony oxide increases the C-value of the resultant varistor; the addition of titanium oxide lowers the C-value.

Still further improvement in d.c. and surge stability is obtained by using for the varistor a sintered body comprising zinc oxide (ZnO) as the main constituent and, as additives, 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.1 to 3.0 mol percent manganese oxide (MnO), 0.01 to 5.0 mol percent boron trioxide (B_2O_3), 0.1 to 3.0 mol percent titanium oxide (TiO_2), at least one of 0.01 to 3.0 mol percent chromium oxide (Cr_2O_3) and 0.1 to 3.0 mol percent nickel oxide (NiO), and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).

The sintered body can be prepared by a known ceramic technique. The starting materials, of appropriate composition and proportions are mixed in a wet mill to produce a homogeneous mixture. The mixture is dried and moulded under pressure into a suitable shape, using a pressure from 50 to 500 Kg/cm². The pressed body is sintered in air at 1000° to 1450°C for 1 to 20 hours, and then furnace-cooled to room temperature, that is, to about 15°C to 30°C. The mixtures can be first calcined at 700° to 1000°C and then crushed to facilitate the subsequent pressing step. The mixture to be pressed can be mixed with a suitable binder such as water or polyvinyl alcohol. The sintered body can be lapped on its opposed major surfaces, using an abrasive powder such as silicon carbide of a mean particle size of 50 μ to 10 μ diameter. Electrodes are provided on the opposed surfaces by any suitable method, such as silver painting, vacuum evaporation, or flame spraying of metal such as Al, Zn or Sn.

The nonlinear properties of the body are not significantly affected by the type of electrodes used, but can be varied by varying the dimension of the sintered body between the electroded surfaces: the C-value of the resistor varies in proportion to the thickness of the sintered bodies, but the n -value is substantially independent of thickness. This indicates that the voltage-nonlinear property is due to the bulk characteristic of the material, and it is not due to the nature of the electrode contact.

Lead wires can be attached to the electrodes in any manner, for example by ordinary solder, but it is convenient to use for this purpose a conductive adhesive comprising silver powder and resin in an organic solvent. Varistors can be made in the manner de-

scribed which have good temperature stability, and perform satisfactorily in a d.c. load test, which is carried out by subjecting the varistor to the nominal rated load of 1 watt at 70°C ambient temperature for a period of 500 hours. The varistors also perform well in a surge test carried out by applying surge currents of $8 \times 20 \mu$ sec. duration, at a current density of 500A/cm². The n -values of the varistors are found not to change to any marked extent after heating cycles, load tests, humidity tests, and surge tests. In particular, the C -values and n -values do not change significantly after the d.c. load test, even for currents of less than 0.1mA. To improve resistance to humidity and other effects the resistors can be protected by a resin coating or by encapsulation, using a resin such as epoxy of phenol resin in known manner.

The following are given as examples of the invention.

Example 1.

Starting material comprising 97.0 mol percent zinc oxide, 1.0 mol percent bismuth oxide, 1.0 mol percent cobalt oxide, 0.5 mol percent boron trioxide and 0.5 mol percent magnesium oxide were mixed in a wet mill for 24 hours. The mixture was dried and moulded under pressure into discs 17.5 mm in diameter and 7 mm thick, using a pressure of 250 Kg/cm².

The pressed bodies were sintered in air in conditions set out in Table 1, and then furnace-cooled to room temperature. The sintered body was lapped on its opposed major surfaces using silicon carbide abrasive having a mean particle size of 30μ in diameter, until the body was reduced in thickness to that given in Table 1. The lapped surfaces of the sintered body were then provided with electrodes by spray metalising an aluminium film in known manner.

The electric characteristics of resultant sintered bodies were measured and are shown in Table 1; the results show that the C -value varies approximately in proportion to the thickness of the sintered body while the n -value is essentially independent of the thickness. From this it can be inferred that the voltage nonlinear property of the sintered body is attributable to the bulk characteristics of the material.

Example 2.

Zinc oxide, together with the additives as given in Table 2, was fabricated into varistors by the process described in Example 1. The thickness of the sintered body was 1.0 mm. The electrical characteristics of the sintered bodies were measured and are given in Table 2; the conditions at currents of 0.1mA and 1mA were taken in determining the n -values. The d.c. load test was carried out by apply-

ing the nominal rated load of 1 watt at 70°C ambient temperature for 500 hours. The results indicate that the addition of bismuth oxide, cobalt oxide, boron trioxide and one member selected from the group consisting of magnesium oxide, calcium oxide, barium oxide and strontium oxide, gives high n -values and low percentage changes due to the tests.

Example 3.

Zinc oxide with additives as given in Table 3 were made into varistors by the process described in Example 2. The electrical characteristics of the varistors produced were measured and are given in Table 3. The percentage changes of C and n -values following load and surge tests are also given in Table 3. The surge tests consisted in applying 2 impulses of $8 \times 20\mu$ sec, 500A, and the d.c. load test was as described in Example 2. Table 3 shows that the further addition of manganese oxide results in the higher n -values and smaller percentage changes of characteristics, compared with the materials of Example 2.

Example 4.

Zinc oxide, with additives as in Table 4, was made into varistors as in Example 2. The electrical characteristics were measured and are given in Table 4, and these show that the further addition of one member selected from the group consisting of antimony oxide and titanium oxide results in higher n -values and smaller percentage changes compared with Example 3. The percentage changes of C and n -values after d.c. load and surge tests, carried out as in Example 3, are also given in Table 4.

Example 5.

Zinc oxide, with additives as in Table 5, was made into varistors as in Example 2. The electrical characteristics of the varistors were measured and are given in Table 5, which shows the further addition of nickel oxide and chromium oxide results in the higher values of n and smaller percentage changes than the varistors of Example 4. The percentage changes of C and n -values after d.c. and surge tests as in Example 3 are also given in Table 5.

Example 6.

The varistors made in Examples 2, 3, 4, and 5 were tested in temperature cycle and humidity tests of a kind suitable for electronic components. The temperature cycle test consisted of 5 cycles in which the varistors were held at 85°C ambient temperature for 30 minutes, cooled rapidly to -20°C and then kept at the latter temperature for 30 minutes. The humidity test was carried out at 40°C and 95% relative humidity for 1000 hours.

Table 6 shows the percentage changes of C and n -values after the temperature and humidity tests. Table 6 shows that the percentage changes were small.

TABLE 1.

A.

Thickness (mm)	C (at 1 mA)	n	Sintering Condition	
			Temp.	Time (Hrs)
Initial (5)	680	24	1200°C.	5
2	275	24	"	"
1	135	23	"	"
0.5	68	23	"	"
Initial (5)	600	24	1350°C.	1
2	240	24	"	"
1	120	23	"	"
0.5	60	23	"	"
Initial (5)	850	23	1000°C.	20
2	330	23	"	"
1	170	23	"	"
0.5	85	23	"	"

TABLE 2

Additives (mol %)				Electrical Properties of Resultant Resistor		Change Percentage after Test	
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	MgO	c (at 1 mA)	n	Δc at 0.01 mA	Δn
0.01	3.0	0.5	0.5	57	20	-4.3	-4.3
0.1	3.0	0.5	0.5	79	20	-2.6	-2.1
1.0	3.0	0.5	0.5	133	23	-2.4	-2.3
3.0	3.0	0.5	0.5	141	22	-2.5	-2.4
10.0	3.0	0.5	0.5	149	22	-4.9	-4.4
3.0	0.01	0.5	0.5	69	18	-4.8	-4.5
3.0	0.1	0.5	0.5	125	20	-2.4	-2.2
3.0	1.0	0.5	0.5	129	22	-2.1	-2.3
3.0	3.0	0.5	0.5	137	20	-2.7	-2.6
3.0	10.0	0.5	0.5	158	19	-4.9	-5.0
3.0	3.0	0.01	0.5	117	25	-2.9	-2.5
3.0	3.0	0.1	6.5	125	23	-2.7	-2.4
3.0	3.0	1.0	0.5	123	26	-2.3	-2.4
3.0	3.0	5.0	0.5	142	27	-2.6	-2.5
3.0	3.0	0.5	0.01	137	25	-2.8	-2.9
3.0	3.0	0.5	0.1	126	23	-2.7	-2.2
3.0	3.0	0.5	1.0	122	23	-2.6	-2.4
3.0	3.0	0.5	5.0	106	25	-2.7	-2.4

TABLE 2 (Continued)

Additives (mol %)				Electrical Properties of Resultant Resistor		Change Percentage after Test	
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	CaO	c (at 1 mA)	n	Δc at 0.01 mA	Δn
0.01	3.0	0.5	0.5	58	19	-4.2	-4.2
0.1	3.0	0.5	0.5	78	21	-2.5	-2.2
1.0	3.0	0.5	0.5	134	22	-2.3	-2.2
3.0	3.0	0.5	0.5	142	22	-2.4	-2.5
10.0	3.0	0.5	0.5	148	23	-4.1	-4.5
3.0	0.01	0.5	0.5	70	17	-4.7	-4.4
3.0	0.1	0.5	0.5	124	21	-2.3	-2.3
3.0	1.0	0.5	0.5	130	21	-2.0	-2.2
3.0	3.0	0.5	0.5	140	20	-2.5	-2.4
3.0	10.0	0.5	0.5	157	20	-3.8	-4.1
3.0	3.0	0.01	0.5	118	24	-2.9	-2.4
3.0	3.0	0.1	0.5	124	24	-2.6	-2.5
3.0	3.0	1.0	0.5	124	25	-2.2	-2.3
3.0	3.0	5.0	0.5	141	28	-2.5	-2.6
3.0	3.0	0.5	0.01	138	24	-2.9	-2.8
3.0	3.0	0.5	0.1	125	24	-2.6	-2.3
3.0	3.0	0.5	1.0	123	22	-2.5	-2.3
3.0	3.0	0.5	5.0	105	26	-2.6	-2.5

TABLE 2 (Continued)

Additives (mol %)				Electrical Properties of Resultant Resistor		Change Rate after Test (%)	
				c (at 1 mA)	n	Δc (at 0.01 mA)	Δn
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	BaO				
0.01	3.0	0.5	0.5	56	18	-4.8	-4.5
0.1	3.0	0.5	0.5	77	19	-2.5	-2.4
1.0	3.0	0.5	0.5	132	21	-2.3	-2.5
3.0	3.0	0.5	0.5	141	21	-2.7	-2.9
10.0	3.0	0.5	0.5	147	21	-4.0	-4.7
3.0	0.01	0.5	0.5	68	16	-4.0	-4.2
3.0	0.1	0.5	0.5	123	19	-2.5	-2.5
3.0	1.0	0.5	0.5	128	20	-2.4	-2.5
3.0	3.0	0.5	0.5	139	20	-2.7	-2.9
3.0	10.0	0.5	0.5	156	18	-4.6	-4.3
3.0	3.0	0.01	0.5	116	23	-2.9	-2.9
3.0	3.0	0.1	0.5	123	22	-2.5	-2.7
3.0	3.0	1.0	0.5	122	24	-2.1	-2.6
3.0	3.0	5.0	0.5	140	26	-2.0	-2.8
3.0	3.0	3.0	0.01	136	23	-2.8	-2.8
3.0	3.0	3.0	0.1	124	22	-2.4	-2.5
3.0	3.0	3.0	1.0	121	21	-2.0	-2.6
3.0	3.0	3.0	5.0	104	24	-2.2	-2.7

TABLE 2 (Continued)

Additives (mol %)				Electrical Properties of Resultant Resistor		Change Percentage after Test	
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	SrO	c (at 1 mA)	n	Δc (at 0.01 mA)	Δn
0.01	3.0	0.5	0.5	57	19	-4.3	-4.5
0.1	3.0	0.5	0.5	77	19	-2.4	-2.3
1.0	3.0	0.5	0.5	133	22	-2.4	-2.3
3.0	3.0	0.5	0.5	139	21	-2.5	-2.9
10.0	3.0	0.5	0.5	147	21	-4.7	-4.0
3.0	0.01	0.5	0.5	69	17	-4.8	-4.8
3.0	0.1	0.5	0.5	123	19	-2.2	-2.4
3.0	1.0	0.5	0.5	129	21	-2.1	-2.3
3.0	3.0	0.5	0.5	141	20	-2.5	-2.7
3.0	10.0	0.5	0.5	156	18	-4.7	-4.9
3.0	3.0	0.01	0.5	117	24	-2.6	-2.9
3.0	3.0	0.1	0.5	123	22	-2.5	-2.6
3.0	3.0	1.0	0.5	123	25	-2.3	-2.4
3.0	3.0	5.0	0.5	140	26	-2.4	-2.7
3.0	3.0	0.5	0.01	137	24	-2.8	-2.9
3.0	3.0	0.5	0.1	124	22	-2.5	-2.4
3.0	3.0	0.5	1.0	122	22	-2.6	-2.4
3.0	3.0	0.5	5.0	104	24	-2.5	-2.6

TABLE 3

Additives (mol %)					Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Further additives	(at c 1 mA)	n	Δc (at 0.005 mA)	Δn	Δc	Δn
0.1	0.1	0.1	0.1	MgO 0.01	92	28	-2.0	-2.2	-8.8	-12.5
0.1	0.1	0.1	0.5	MgO 0.01	106	31	-1.8	-2.2	-8.5	-11.6
0.1	0.1	0.1	3.0	MgO 0.01	122	35	-1.9	-2.0	-8.1	-11.5
0.5	0.5	1.0	0.1	MgO 1.0	66	27	-2.0	-2.4	-8.8	-12.7
0.5	0.5	1.0	0.5	MgO 1.0	92	29	-1.8	-2.2	-8.4	-11.7
0.5	0.5	1.0	3.0	MgO 1.0	113	34	-1.6	-2.5	-8.7	-11.1
3.0	3.0	5.0	0.1	MgO 5.0	77	26	-1.8	-2.4	-8.6	-11.3
3.0	3.0	5.0	0.5	MgO 5.0	103	32	-1.5	-2.3	-8.0	-11.6
3.0	3.0	5.0	3.0	MgO 5.0	137	36	-1.6	-2.1	-8.9	-11.1
0.1	0.1	0.1	0.1	CaO 0.01	91	29	-1.9	-2.3	-8.8	-12.7
0.1	0.1	0.1	0.5	CaO 0.01	107	30	-1.7	-2.1	-8.7	-11.6
0.1	0.1	0.1	3.0	CaO 0.01	121	36	-1.8	-2.1	-8.1	-11.5
0.5	0.5	1.0	0.1	CaO 1.0	67	26	-1.9	-2.3	-9.0	-12.7
0.5	0.5	1.0	0.5	CaO 1.0	91	30	-1.7	-2.3	-8.4	-11.9
0.5	0.5	1.0	3.0	CaO 1.0	114	33	-1.5	-2.4	-8.9	-11.4

TABLE 3 (Continued)

Additives (mol %)					Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Further additives	(at c 1 mA)	n	Δc (at 0.005 mA)	Δn	Δc	Δn
3.0	3.0	5.0	0.1	CaO 5.0	76	27	-1.7	-2.5	-8.6	-11.5
3.0	3.0	5.0	0.5	CaO 5.0	104	31	-1.4	-2.2	-8.2	-15.6
3.0	3.0	5.0	3.0	CaO 5.0	136	37	-1.5	-2.2	-8.9	-11.3
0.1	0.1	0.1	0.1	BaO 0.01	90	27	-2.1	-2.5	-10.2	-14.9
0.1	0.1	0.1	0.5	BaO 0.01	105	29	-2.0	-2.4	-9.0	-14.0
0.1	0.1	0.1	3.0	BaO 0.01	120	34	-2.0	-2.3	-8.5	-13.8
0.5	0.5	1.0	0.1	BaO 1.0	65	25	-2.2	-2.6	-10.3	-15.1
0.5	0.5	1.0	0.5	BaO 1.0	90	28	-1.9	-2.5	-9.8	-14.2
0.5	0.5	1.0	3.0	BaO 1.0	112	32	-1.8	-2.7	-9.2	-13.5
3.0	3.0	5.0	0.1	BaO 5.0	75	25	-1.9	-2.7	-10.0	-14.8
3.0	3.0	5.0	0.5	BaO 5.0	102	30	-1.7	-2.5	-9.5	-14.0
3.0	3.0	5.0	3.0	BaO 5.0	135	35	-1.7	-2.4	-9.3	-13.6
0.1	0.1	0.1	0.1	SrO 0.01	90	27	-1.8	-2.4	-9.7	-14.3
0.1	0.1	0.1	0.5	SrO 0.01	106	30	-1.8	-2.2	-8.4	-13.2
0.1	0.1	0.1	3.0	SrO 0.01	120	34	-1.7	-2.2	-8.0	-13.1

TABLE 3 (Continued)

Additives (mol %)					Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Further additives	(at c 1 mA)	n	Δc (at 0.005 mA)	Δn	Δc	Δn
0.5	0.5	1.0	0.1	SrO 1.0	66	26	-2.0	-2.4	-9.7	-14.3
0.5	0.5	1.0	0.5	SrO 1.0	90	28	-1.6	-2.4	-9.3	-13.5
0.5	0.5	1.0	3.0	SrO 1.0	113	33	-1.6	-2.5	-8.6	-12.7
3.0	3.0	5.0	0.1	SrO 5.0	75	25	-1.6	-2.6	-9.5	-14.1
3.0	3.0	5.0	0.5	SrO 5.0	103	31	-1.5	-2.3	-8.9	-13.2
3.0	3.0	5.0	3.0	SrO 5.0	135	35	-1.4	-2.3	-8.8	-12.9

TABLE 4

Additives (mol %)							Electrical Properties of Resultant Varistor		Changes Percentage after Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Sb_2O_3	TiO_2	Further Additives	c (at 1 mA)	n	Δc (at 0.002 mA)	Δn	Δc	Δn
0.1	0.1	0.1	0.1	0.05	—	MgO 0.01	50	50	-1.8	-1.9	-6.3	-7.2
0.1	0.1	0.1	0.1	1.0	—	MgO 0.01	56	52	-1.6	-2.2	-6.9	-7.1
0.1	0.1	0.1	0.1	3.0	—	MgO 0.01	82	53	-1.7	-1.8	-6.1	-7.1
0.5	0.5	1.0	0.5	0.05	—	MgO 1.0	51	52	-1.8	-2.0	-6.9	-7.8
0.5	0.5	1.0	0.5	1.0	—	MgO 1.0	67	53	-1.8	-1.9	-6.2	-7.1
0.5	0.5	1.0	0.5	3.0	—	MgO 1.0	86	56	-1.8	-1.8	-6.9	-7.9
3.0	3.0	5.0	3.0	0.05	—	MgO 3.0	72	50	-2.0	-1.8	-6.3	-7.3
3.0	3.0	5.0	3.0	1.0	—	MgO 3.0	88	53	-1.5	-2.3	-6.9	-7.4
3.0	3.0	5.0	3.0	3.0	—	MgO 3.0	109	54	-1.8	-1.8	-6.9	-7.2
0.1	0.1	0.1	0.1	0.05	—	CaO 0.01	49	51	-1.7	-2.0	-6.2	-7.1
0.1	0.1	0.1	0.1	1.0	—	CaO 0.01	57	51	-1.5	-2.1	-6.0	-7.2
0.1	0.1	0.1	0.1	3.0	—	CaO 0.01	81	54	-1.6	-1.9	-6.0	-7.9
0.5	0.5	1.0	0.5	0.05	—	CaO 1.0	52	51	-1.7	-1.9	-6.0	-7.9
0.5	0.5	1.0	0.5	1.0	—	CaO 1.0	66	54	-1.7	-2.0	-6.1	-7.1
0.5	0.5	1.0	0.5	3.0	—	CaO 1.0	87	55	-1.7	-1.7	-6.0	-7.2

TABLE 4 (Continued)

Additives (mol %)							Electrical Properties of Resultant Varistor		Changes Percentage after Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Sb_2O_3	TiO_2	Further Additives	c (at 1 mA)	n	Δc (at 0.002 mA)	Δn	Δc	Δn
3.0	3.0	3.0	3.0	0.05	—	CaO 3.0	71	51	-1.9	-1.9	-6.1	-7.2
3.0	3.0	3.0	3.0	1.0	—	CaO 3.0	89	52	-1.4	-2.2	-6.0	-7.5
3.0	3.0	3.0	3.0	3.5	—	CaO 3.0	108	55	-1.7	-1.9	-6.8	-7.1
0.1	0.1	0.1	0.1	0.05	—	BaO 0.01	48	49	-1.9	-2.2	-6.3	-7.2
0.1	0.1	0.1	0.1	1.0	—	BaO 0.01	55	50	-1.8	-2.4	-6.0	-7.2
0.1	0.1	0.1	0.1	3.0	—	BaO 0.01	80	52	-1.8	-2.1	-6.1	-7.1
0.5	0.5	1.0	0.5	0.05	—	BaO 1.0	50	50	-2.0	-2.2	-7.0	-7.9
0.5	0.5	1.0	0.5	1.0	—	BaO 1.0	65	52	-1.9	-2.2	-7.2	-7.1
0.5	0.5	1.0	0.5	3.0	—	BaO 1.0	85	54	-2.0	-2.0	-7.0	-7.2
3.0	3.0	3.0	3.0	0.05	—	BaO 3.0	70	49	-2.1	-2.1	-7.3	-7.3
3.0	3.0	3.0	3.0	1.0	—	BaO 3.0	87	51	-1.7	-2.5	-7.0	-7.5
3.0	3.0	3.0	3.0	3.0	—	BaO 3.0	107	53	-1.9	-2.1	-7.9	-7.2
0.1	0.1	0.1	0.1	-0.05	—	SrO 0.01	48	49	-1.6	-2.1	-7.2	-7.1
0.1	0.1	0.1	0.1	1.0	—	SrO 0.01	56	51	-1.6	-2.2	-7.8	-7.2
0.1	0.1	0.1	0.1	3.0	—	SrO 0.01	80	52	-1.5	-2.0	-7.0	-7.9

TABLE 4 (Continued)

Additives (mol %)							Electrical Properties of Resultant Varistor		Changes Percentage after Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	B_2O_3	MnO	Sb_2O_3	TiO_2	Further Additives	c (at 1 mA)	n	Δc (at 0.002 mA)	Δn	Δc	Δn
0.5	0.5	1.0	0.5	0.05	—	SrO	51	51	-1.8	-2.0	-7.8	-7.7
0.5	0.5	1.0	0.5	1.0	—	SrO	65	52	-1.6	-2.1	-7.1	-7.2
0.5	0.5	1.0	0.5	3.0	—	SrO	86	55	-1.8	-1.8	-7.8	-7.8
3.0	3.0	3.0	3.0	0.05	—	SrO	70	49	-1.8	-2.0	-7.2	-7.2
3.0	3.0	3.0	3.0	1.0	—	SrO	88	52	-1.5	-2.3	-7.8	-7.3
3.0	3.0	3.0	3.0	3.0	—	SrO	107	53	-1.6	-2.0	-7.8	-7.1
0.1	0.1	0.1	0.1	—	0.1	MgO	22	31	-2.2	-1.9	-7.4	-8.7
0.1	0.1	0.1	0.1	—	1.0	MgO	8	32	-1.8	-2.0	-6.8	-8.3
0.1	0.1	0.1	0.1	—	3.0	MgO	7	30	-1.8	-2.1	-6.9	-8.4
0.5	0.5	1.0	0.5	—	0.1	MgO	26	32	-1.8	-1.9	-6.8	-9.3
0.5	0.5	1.0	0.5	—	1.0	MgO	10	32	-1.6	-1.8	-6.7	-8.4
0.5	0.5	1.0	0.5	—	3.0	MgO	8	32	-1.6	-2.0	-6.3	-8.6
3.0	3.0	3.0	3.0	—	0.1	MgO	50	32	-2.0	-1.7	-6.6	-9.0
3.0	3.0	3.0	3.0	—	1.0	MgO	31	32	-1.6	-1.8	-6.3	-8.6
3.0	3.0	3.0	3.0	—	3.0	MgO	29	31	-1.8	-2.0	-5.9	-8.8

TABLE 4 (Continued)

Additives (mol %)							Electrical Properties of Resultant Varistor		Change Percentage after Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	MnO	Sb ₂ O ₃	TiO ₂	Further Additives	c (at 1 mA)	n	Δc (at 0.002 mA)	Δn	Δc	Δn
0.1	0.1	0.1	0.1	—	0.1	CaO 0.01	21	32	-2.1	-2.0	-7.3	-8.8
0.1	0.1	0.1	0.1	—	1.0	CaO 0.01	9	31	-1.7	-1.9	-6.7	-8.2
0.1	0.1	0.1	0.1	—	3.0	CaO 0.01	6	31	-1.7	-2.2	-6.8	-8.5
0.5	0.5	1.0	0.5	—	0.1	CaO 1.0	27	32	-1.7	-1.8	-6.7	-8.4
0.5	0.5	1.0	0.5	—	1.0	CaO 1.0	9	32	-1.5	-1.9	-6.6	-8.6
0.5	0.5	1.0	0.5	—	3.0	CaO 1.0	9	31	-1.5	-1.9	-6.2	-8.5
3.0	3.0	3.0	3.0	—	0.1	CaO 3.0	49	33	-1.9	-1.8	-6.5	-9.1
3.0	3.0	3.0	3.0	—	1.0	CaO 3.0	32	31	-1.5	-1.7	-6.2	-8.5
3.0	3.0	3.0	3.0	—	3.0	CaO 3.0	28	32	-1.7	-2.1	-5.8	-8.9
0.1	0.1	0.1	0.1	—	0.1	BaO 0.01	20	30	-2.3	-2.2	-7.5	-11.0
0.1	0.1	0.1	0.1	—	1.0	BaO 0.01	7	30	-2.0	-2.2	-7.0	-10.5
0.1	0.1	0.1	0.1	—	3.0	BaO 0.01	5	29	-1.9	-2.4	-7.0	-10.7
0.5	0.5	1.0	0.5	—	0.1	BaO 1.0	25	30	-2.0	-2.1	-7.0	-11.0
0.5	0.5	1.0	0.5	—	1.0	BaO 1.0	8	31	-1.7	-2.1	-6.8	-10.7
0.5	0.5	1.0	0.5	—	3.0	BaO 1.0	7	30	-1.8	-2.2	-6.5	-10.8

TABLE 4 (Continued)

Additives (mol %)							Electrical Properties of Resultant Varistor		Change Percentage after Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	B ₂ O ₃	MnO	Sb ₂ O ₃	TiO ₂	Further Additives	c (at 1 mA)	n	Δc (at 0.002 mA)	Δn	Δc	Δn
3.0	3.0	3.0	3.0	—	0.1	BaO 3.0	48	31	-2.1	-2.0	-6.7	-11.3
3.0	3.0	3.0	3.0	—	1.0	BaO 3.0	30	30	-1.8	-2.0	-6.5	-10.8
3.0	3.0	3.0	3.0	—	3.0	BaO 3.0	27	30	-1.9	-2.3	-6.0	-11.1
0.1	0.1	0.1	0.1	—	0.1	SrO 0.01	20	30	-2.0	-2.1	-7.2	-10.9
0.1	0.1	0.1	0.1	—	1.0	SrO 0.01	8	31	-1.8	-2.0	-6.8	-10.3
0.1	0.1	0.1	0.1	—	3.0	SrO 0.01	5	29	-1.6	-2.3	-6.7	-10.6
0.5	0.5	1.0	0.5	—	0.1	SrO 1.0	26	31	-1.8	-1.9	-6.8	-11.0
0.5	0.5	1.0	0.5	—	1.0	SrO 1.0	8	30	-1.4	-2.0	-6.5	-10.6
0.5	0.5	1.0	0.5	—	3.0	SrO 1.0	84	31	-1.6	-2.0	-6.3	-10.6
3.0	3.0	3.0	3.0	—	0.1	SrO 3.0	48	32	-1.9	-1.9	-6.4	-11.0
3.0	3.0	3.0	3.0	—	1.0	SrO 3.0	31	31	-1.6	-1.8	-6.3	-10.6
3.0	3.0	3.0	3.0	—	3.0	SrO 3.0	27	30	-1.6	-2.2	-5.8	-11.0

TABLE 5

Additives (mol %) --										Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	MnO	TiO ₂	B ₂ O ₃	NiO	Cr ₂ O ₃	Further additives	c (at 1 mA)	n	Δc (at 0.001 mA)	Δn	Δc	Δn		
0.1	0.1	0.1	0.1	0.1	0.1	—	MgO 0.01	9	29	-2.4	-1.7	-3.6	-5.2		
0.1	0.1	0.1	0.1	0.1	0.5	—	MgO 0.01	15	31	-2.0	-1.8	-3.3	-5.1		
0.1	0.1	0.1	0.1	0.1	3.0	—	MgO 0.01	30	32	-1.9	-1.9	-3.2	-5.8		
0.5	0.5	0.5	1.0	1.0	0.1	—	MgO 1.0	12	31	-2.2	-1.7	-3.4	-5.2		
0.5	0.5	0.5	1.0	1.0	0.5	—	MgO 1.0	19	33	-2.0	-1.6	-3.2	-4.9		
0.5	0.5	0.5	1.0	1.0	3.0	—	MgO 1.0	32	32	-1.8	-1.8	-3.8	-5.8		
3.0	3.0	3.0	3.0	3.0	0.1	—	MgO 3.0	27	31	-2.2	-1.6	-3.7	-5.4		
3.0	3.0	3.0	3.0	3.0	0.5	—	MgO 3.0	33	33	-2.0	-1.7	-3.5	-5.3		
3.0	3.0	3.0	3.0	3.0	3.0	—	MgO 3.0	42	34	-2.0	-1.9	-2.9	-4.7		
0.1	0.1	0.1	0.1	0.1	0.1	—	CaO 0.01	8	30	-2.3	-1.8	-3.5	-5.3		
0.1	0.1	0.1	0.1	0.1	0.5	—	CaO 0.01	16	30	-1.8	-1.7	-3.2	-5.0		
0.1	0.1	0.1	0.1	0.1	3.0	—	CaO 0.01	29	33	-1.8	-2.0	-3.1	-4.9		
0.5	0.5	0.5	1.0	1.0	1.0	—	CaO 1.0	13	30	-2.1	-1.6	-3.3	-5.1		
0.5	0.5	0.5	1.0	1.0	0.5	—	CaO 1.0	18	33	-1.9	-1.7	-3.1	-5.0		
0.5	0.5	0.5	1.0	1.0	3.0	—	CaO 1.0	33	31	-1.7	-1.7	-3.7	-6.7		

TABLE 5 (Continued)

Additives (mol %)								Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	MnO	TiO ₂	B ₂ O ₃	NiO	Cr ₂ O ₃	Further additives	c (at 1 mA)	n	Δc (at 0.001 mA)	Δn	Δc	Δn
3.0	3.0	3.0	3.0	3.0	0.1	—	CaO 3.0	26	32	-2.1	-1.7	-3.6	-6.5
3.0	3.0	3.0	3.0	3.0	0.5	—	CaO 3.0	34	32	-1.9	-1.6	-3.4	-5.2
3.0	3.0	3.0	3.0	3.0	3.0	—	CaO 3.0	41	35	-1.9	-1.9	-2.8	-4.8
0.1	0.1	0.1	0.1	0.1	0.1	—	CaO 0.01	7	28	-2.5	-2.0	-4.7	-6.5
0.1	0.1	0.1	0.1	0.1	0.5	—	CaO 0.01	14	29	-2.2	-2.0	-4.5	-6.3
0.1	0.1	0.1	0.1	0.1	3.0	—	CaO 0.01	28	31	-2.0	-2.2	-4.3	-6.1
0.5	0.5	0.5	1.0	1.0	0.1	—	BaO 1.0	11	29	-2.4	-1.9	-4.6	-6.4
0.5	0.5	0.5	1.0	1.0	0.5	—	BaO 1.0	17	32	-2.1	-1.9	-4.3	-6.2
0.5	0.5	0.5	1.0	1.0	3.0	—	BaO 1.0	31	30	-2.0	-2.0	-5.0	-7.0
3.0	3.0	3.0	3.0	3.0	0.1	—	BaO 3.0	25	30	-2.3	-1.9	-4.8	-6.7
3.0	3.0	3.0	3.0	3.0	0.5	—	BaO 3.0	32	31	-2.2	-1.9	-4.7	-6.5
3.0	3.0	3.0	3.0	3.0	3.0	—	BaO 3.0	40	33	-2.1	-2.1	-4.0	-6.0
0.1	0.1	0.1	0.1	0.1	0.1	—	SrO 0.01	7	28	-2.2	-1.9	-4.4	-6.4
0.1	0.1	0.1	0.1	0.1	0.5	—	SrO 0.01	15	30	-2.0	-1.8	-4.3	-6.1
0.1	0.1	0.1	0.1	0.1	3.0	—	SrO 0.01	28	31	-1.7	-2.1	-4.0	-6.0

TABLE 5 (Continued)

Additives (mol %)										Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	MnO	TiO ₂	B ₂ O ₃	NiO	Cr ₂ O ₃	Further additives	c (at 1 mA)	n						
										Δc (at 0.001 mA)	Δn	Δc	Δn	Δc	Δn
0.5	0.5	0.5	1.0	1.0	0.1	—	SrO	12	30	-2.2	-1.7	-4.4	-6.2	-4.4	-6.2
0.5	0.5	0.5	1.0	1.0	0.5	—	SrO	17	32	-1.8	-1.8	-4.0	-6.1	-4.0	-6.1
0.5	0.5	0.5	1.0	1.0	3.0	—	SrO	32	31	-1.8	-1.8	-4.8	-6.8	-4.8	-6.8
3.0	3.0	3.0	3.0	3.0	0.1	—	SrO	25	30	-2.0	-1.9	-4.5	-6.6	-4.5	-6.6
3.1	3.0	3.0	3.0	3.0	0.5	—	SrO	33	32	-2.0	-1.7	-4.5	-6.3	-4.5	-6.3
3.1	3.0	3.0	3.0	3.0	3.0	—	SrO	40	33	-1.8	-1.9	-3.7	-5.9	-3.7	-5.9
0.1	0.1	0.1	0.1	0.1	—	0.01	MgO	9	30	-2.7	-2.0	-2.4	-4.2	-2.4	-4.2
0.1	0.1	0.1	0.1	0.1	—	0.5	MgO	10	31	-2.4	-2.1	-2.2	-4.2	-2.2	-4.2
0.1	0.1	0.1	0.1	0.1	—	3.0	MgO	22	31	-2.4	-1.9	-2.3	-4.0	-2.3	-4.0
0.5	0.5	0.5	1.0	1.0	—	0.01	MgO	11	31	-2.4	-1.9	-2.3	-4.2	-2.3	-4.2
0.5	0.5	0.5	1.0	1.0	—	0.5	MgO	14	31	-2.7	-1.8	-2.2	-3.9	-2.2	-3.9
0.5	0.5	0.5	1.0	1.0	—	3.0	MgO	26	33	-2.5	-2.0	-2.6	-4.0	-2.6	-4.0
3.0	3.0	3.0	3.0	3.0	—	0.01	MgO	32	31	-2.6	-1.7	-2.6	-4.4	-2.6	-4.4
3.0	3.0	3.0	3.0	3.0	—	0.5	MgO	33	35	-2.4	-1.8	-2.5	-4.5	-2.5	-4.5
3.0	3.0	3.0	3.0	3.0	—	3.0	MgO	49	36	-2.4	-1.9	-2.4	-4.0	-2.4	-4.0

TABLE 5 (Continued)

Additives (mol %)										Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	MnO	TiO_2	B_2O_3	NiO	Cr_2O_3	Further additives	c (at 1 mA)	n	Δc (at 0.001 mA)	Δn	Δc	Δn		
0.1	0.1	0.1	0.1	0.1	—	0.01	CaO 0.01	8	31	-2.6	-2.1	-2.3	-4.3		
0.1	0.1	0.1	0.1	0.1	—	0.5	CaO 0.01	11	30	-2.3	-2.0	-2.1	-4.1		
0.1	0.1	0.1	0.1	0.1	—	3.0	CaO 0.01	21	32	-2.3	-2.0	-2.2	-4.1		
0.5	0.5	0.5	1.0	1.0	—	0.01	CaO 1.0	12	30	-2.3	-1.8	-2.2	-4.1		
0.5	0.5	0.5	1.0	1.0	—	0.5	CaO 1.0	13	32	-2.6	-1.9	-2.1	-4.0		
0.5	0.5	0.5	0.5	1.0	—	3.0	CaO 1.0	27	34	-2.4	-1.9	-2.5	-4.9		
3.0	3.0	3.0	3.0	3.0	—	0.01	CaO 3.0	31	32	-2.5	-1.8	-2.5	-4.5		
3.0	3.0	3.0	3.0	3.0	—	0.5	CaO 3.0	34	35	-2.3	-1.7	-2.4	-4.4		
3.0	3.0	3.0	3.0	3.0	—	3.0	CaO 3.0	48	36	-2.3	-2.0	-2.3	-4.1		
0.1	0.1	0.1	0.1	0.1	—	0.01	BaO 0.01	7	29	-2.8	-2.3	-3.5	-4.5		
0.1	0.1	1.0	0.1	0.1	—	0.5	BaO 0.01	9	29	-2.6	-2.3	-3.4	-4.4		
0.1	0.1	1.0	0.1	0.1	—	3.0	BaO 0.01	20	30	-2.5	-2.2	-3.4	-4.3		
0.5	0.5	0.5	1.0	1.0	—	0.01	BaO 1.0	10	29	-2.6	-2.1	-3.5	-4.4		
0.5	0.5	0.5	1.0	1.0	—	0.5	BaO 1.0	12	30	-2.8	-2.1	-3.3	-4.2		
0.5	0.5	0.5	1.0	1.0	—	3.0	BaO 1.0	25	33	-2.7	-2.2	-3.8	-5.2		

TABLE 5 (Continued)

Additives (mol %)										Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi_2O_3	Co_2O_3	MnO	TiO_2	B_2O_3	NiO	Cr_2O_3	Further additives	c (at 1 mA)	n						
										Δc (at 0.001 mA)	Δn	Δc	Δn		
3.0	3.0	3.0	3.0	3.0	—	0.01	BaO 3.0	30	30	-2.7	-2.0	-3.7	-4.7		
3.0	3.0	3.0	3.0	3.0	—	0.5	BaO 3.0	32	34	-2.6	-2.0	-3.7	-4.7		
3.0	3.0	3.0	3.0	3.0	—	3.0	BaO 3.0	47	34	-2.5	-2.2	-3.5	-4.3		
0.1	0.1	0.1	0.1	0.1	—	0.01	SrO 0.01	7	29	-2.5	-2.2	-3.2	-4.4		
0.1	0.1	0.1	0.1	0.1	—	0.5	SrO 0.01	10	30	-2.4	-2.1	-3.2	-4.2		
0.1	0.1	0.1	0.1	0.1	—	3.0	SrO 0.01	20	30	-2.2	-2.1	-3.1	-4.2		
0.5	0.5	0.5	1.0	1.0	—	0.01	SrO 1.0	11	30	-2.4	-1.9	-3.3	-4.2		
0.5	0.5	0.5	1.0	1.0	—	0.5	SrO 1.0	12	30	-2.5	-2.0	-3.0	-4.1		
0.5	0.5	0.5	1.0	1.0	—	3.0	SrO 1.0	26	34	-2.5	-2.0	-3.6	-5.0		
3.0	3.0	3.0	3.0	3.0	—	0.01	SrO 3.0	30	30	-2.4	-1.9	-3.4	-4.6		
3.0	3.0	3.0	3.0	3.0	—	0.5	SrO 3.0	33	35	-2.4	-1.8	-3.5	-4.5		
3.0	3.0	3.0	3.0	3.0	—	3.0	SrO 3.0	47	34	-2.2	-2.1	-3.2	-4.2		
0.1	0.1	0.1	0.1	0.1	0.1	0.01	MgO 0.01	12	35	-1.9	-2.0	-1.2	-1.0		
0.1	0.1	0.1	0.1	0.1	0.1	0.5	MgO 0.01	18	37	-1.8	-2.0	-1.1	-1.9		
0.1	0.1	0.1	0.1	0.1	0.1	3.0	MgO 0.01	32	38	-1.8	-1.9	-1.0	-1.9		

TABLE 5 (Continued)

Additives (mol %)								Electrical Properties of Resultant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	MnO	TiO ₂	B ₂ O ₃	NiO	Cr ₂ O ₃	Further additives	c (at 1 mA)	n	Δc (at 0.001 mA)	Δn	Δc	Δn
0.5	0.5	0.5	1.0	1.0	0.5	0.01	MgO 1.0	14	34	-1.8	-1.9	-1.2	-1.8
0.5	0.5	0.5	1.0	1.0	0.5	0.5	MgO 1.0	19	36	-1.7	-1.9	-0.6	-0.8
0.5	0.5	0.5	1.0	1.0	0.5	3.0	MgO 1.0	35	37	-1.5	-1.8	-1.1	-1.7
3.0	3.0	3.0	3.0	3.0	3.0	3.0	MgO 3.0	28	36	-1.9	-1.9	-1.3	-1.6
3.0	3.0	3.0	3.0	3.0	3.0	3.0	MgO 3.0	35	37	-1.8	-1.8	-1.1	-1.5
3.0	3.0	3.0	3.0	3.0	3.0	3.0	MgO 3.0	49	38	-1.6	-1.8	-1.0	-1.5
0.5	0.5	0.5	1.0	1.0	0.5	0.01	CaO 1.0	15	34	-1.9	-2.0	-1.4	-1.9
0.5	0.5	0.5	1.0	1.0	0.5	0.5	CaO 1.0	20	35	-1.9	-2.1	-1.0	-0.5
0.5	0.5	0.5	1.0	1.0	0.5	3.0	CaO 1.0	37	35	-1.7	-1.8	-1.2	-1.3
0.5	0.5	0.5	1.0	1.0	0.5	0.5	BaO 1.0	21	36	-1.9	-2.2	-0.7	-1.2
0.5	0.5	0.5	1.0	1.0	0.5	0.5	SrO 1.0	23	37	-2.1	-2.3	-0.8	-0.7
0.5	0.5	0.5	1.0	1.0	0.5	0.5	BaO 1.0 SrO 1.0	25	35	-1.7	-1.8	-0.7	-0.9
0.5	0.5	0.5	1.0	1.0	0.5	0.5	CaO 1.0 MgO 1.0	27	37	-1.5	-1.7	-0.6	-0.8

TABLE 5 (Continued)

Additives (mol %)								Electrical Properties of Resulant Varistor		Change Percentage after DC Load Test		Change Percentage after Surge Test	
Bi ₂ O ₃	Co ₂ O ₃	MnO	TiO ₂	B ₂ O ₃	NiO	Cr ₂ O ₃	Further additives	c (at 1 mA)	n	Δc (at 0.001 mA)	Δn	Δc	Δn
0.5	0.5	0.5	1.0	1.0	0.5	0.5	SrO 1.0 MgO 1.0	25	36	-1.4	-1.5	-0.6	-0.9
0.5	0.5	0.5	1.0	1.0	0.5	0.5	CaO 1.0 BaO 1.0	27	36	-1.4	-1.5	-0.5	-0.9
0.5	0.5	0.5	1.0	1.0	0.5	0.5	BaO 1.0 MgO 1.0	29	37	-1.3	-1.4	-0.5	-0.8
0.5	0.5	0.5	1.0	1.0	0.5	0.5	SrO 1.0 CaO 1.0	30	37	-1.2	-1.4	-0.5	-0.8
0.5	0.5	0.5	1.0	1.0	0.5	0.5	BaO 0.5 CaO 0.5 SrO 0.5 MgO 0.5	33	40	-0.5	-0.7	-0.5	-0.6

TABLE 6

Sample No.	Percentage Change			
	Heating Cycle Test		Humidity Test	
	Δc	Δn	Δc	Δn
Example 2	-4.9	-6.5	-5.2	-6.8
Example 3	-2.8	-5.7	-3.7	-5.4
Example 4	-1.8	-3.9	-1.1	-3.7
Example 5	-1.0	-2.5	-0.8	-2.2

WHAT WE CLAIM IS:—

1. A sintered material consisting of zinc oxide (ZnO) and, as an additive 0.01 to 10.0 mol percent bismuth oxide (Bi_2O_3), 0.01 to 10.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).
2. A material according to claim 1, wherein said additive consists of 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).
3. A material according to claim 2, but modified by the inclusion of 0.1 to 3.0 mol percent of manganese oxide (MnO).
4. A material according to claim 3, but modified by the inclusion of 0.05 to 3.0 mol

percent of antimony oxide (Sb_2O_3) or 0.1 to 3.0 mol percent titanium oxide (TiO_2).

5. A material according to claim 3, but modified by the inclusion of 0.01 to 3.0 mol percent of titanium oxide (TiO_2) and 0.01 to 3.0 mol percent of chromium oxide (Cr_2O_3) or 0.1 to 3.0 mol percent of nickel oxide (NiO).

6. A sintered material of a composition in accordance with any of the examples herein.

7. A sintered material substantially as described herein.

8. A varistor comprising a body of sintered material in accordance with any of the preceding claims and electrodes on said body.

9. A varistor substantially as described with reference to the accompanying drawings.

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TABLE 6

Sample No.	Percentage Change			
	Heating Cycle Test		Humidity Test	
	Δc	Δn	Δc	Δn
Example 2	-4.9	-6.5	-5.2	-6.8
Example 3	-2.8	-5.7	-3.7	-5.4
Example 4	-1.8	-3.9	-1.1	-3.7
Example 5	-1.0	-2.5	-0.8	-2.2

WHAT WE CLAIM IS:—

1. A sintered material consisting of zinc oxide (ZnO) and, as an additive 0.01 to 10.0 mol percent bismuth oxide (Bi_2O_3), 0.01 to 10.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).

2. A material according to claim 1, wherein said additive consists of 0.1 to 3.0 mol percent bismuth oxide (Bi_2O_3), 0.1 to 3.0 mol percent cobalt oxide (Co_2O_3), 0.01 to 5.0 mol percent boron trioxide (B_2O_3) and 0.01 to 5.0 mol percent of at least one of magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO) and strontium oxide (SrO).

3. A material according to claim 2, but modified by the inclusion of 0.1 to 3.0 mol percent of manganese oxide (MnO).

4. A material according to claim 3, but modified by the inclusion of 0.05 to 3.0 mol

percent of antimony oxide (Sb_2O_3) or 0.1 to 3.0 mol percent titanium oxide (TiO_2).

5. A material according to claim 3, but modified by the inclusion of 0.01 to 3.0 mol percent of titanium oxide (TiO_2) and 0.01 to 3.0 mol percent of chromium oxide (Cr_2O_3) or 0.1 to 3.0 mol percent of nickel oxide (NiO).

6. A sintered material of a composition in accordance with any of the examples herein.

7. A sintered material substantially as described herein.

8. A varistor comprising a body of sintered material in accordance with any of the preceding claims and electrodes on said body.

9. A varistor substantially as described with reference to the accompanying drawings.

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