

1 387 674

PATENT SPECIFICATION

(11) 1 387 674

- (21) Application No. 39710/72 (22) Filed 25 Aug. 1972
 (31) Convention Application Nos. 66185/71, 66186/71, 66187/71 and 66188/71
 (32) Filed 27 Aug. 1971
 (31) Convention Application Nos. 72797/71 and 72798/71
 (32) Filed 17 Sept. 1971
 (31) Convention Application No. 74351/71 (32) Filed 22 Sept. 1971 in
 (33) Japan (JA)
 (44) Complete Specification published 19 March 1975
 (51) INT CL² H01C 7/10
 (52) Index at acceptance
 H1K 213 236 272 274 276 277 283 284 294 295 297 300
 304 312 313 314 323 325 331 345 34Y 441 455 470
 483 489 493 502 52Y 53Y 578 581 621 627 636
 (72) Inventors TAKESHI MASUYAMA, MIKIO MATSUURA and
 ATSUSHI IGA



(54) IMPROVEMENTS IN AND RELATING TO ELECTRICAL RESISTORS

(71) We, MATSUSHITA ELECTRIC 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 electrical resistors of the voltage dependent type, or varistors. Voltage dependent resistors, such as silicon carbide varistors, selenium rectifiers and germanium or silicon p-n junction diodes are widely used for stabilisation or control of voltage or current in electrical circuits. The electrical characteristics of such a voltage dependent resistor can be expressed by the relation:

$$I = \left(\frac{V}{C} \right)^n \quad (1)$$

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 by the following equation:

$$n = [\log(I_2/I_1)] / [\log(V_2/V_1)] \quad (2)$$

where V₁ and V₂ are voltages at a given current 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 should be as large as possible since this exponent

[Price 33p]

determines the degree to which the resistor departs from an ohmic or linear characteristic.

Varistors, as made by conventional methods, have various disadvantages, and the methods certain limitations; the present invention has for its object to provide an improved method of making varistors, resulting in varistors of improved characteristics, as will appear hereinafter.

The invention includes a method of making an electrical resistor which includes the step of diffusing into a surface of a sintered body including zinc oxide exhibiting inherent non-linear resistance properties, lithium or sodium ions or both.

The invention includes a method of making an electrical resistor which includes the steps of providing a sintered body including zinc oxide having inherent non-linear resistance properties, providing electrodes on spaced surfaces of said body, and diffusing lithium or sodium ions into a further surface of said body.

The invention includes a sintered body including zinc oxide having an inherent non-linear resistance characteristic, and ions of lithium or sodium or both diffused into a surface thereof to a depth of at least 0.01 mm.

The invention includes a sintered body including zinc oxide having an inherent non-linear resistance characteristic, electrodes upon two spaced surfaces of said body, and ions of lithium or sodium or both diffused into a further surface of said body.

Preferred features and advantages of the invention will appear from the following description of embodiments thereof, given by

35

40

45

50

55

60

65

70

way of example, together with the accompanying drawing which is a diagrammatic cross-sectional view of a form of varistor. The varistor shown in the drawing comprises a sintered body 1, which may be of any suitable shape, such as a circular disc or rod or circular, square, or rectangular plate form. The body has a side surface 2 and opposed end surfaces 3 and 4, to which electrodes 5 and 6 are applied respectively. Wire leads 8 and 9 are attached conductively to the electrodes 5 and 6, respectively, by a connection means 7 such as solder.

Such a varistor can be made by first providing a sintered body including zinc oxide which has inherent voltage dependent properties, and diffusing lithium ions and/or sodium ions into the side surface or surfaces of the body and applying electrodes to the end surfaces of the body.

The sintered body can be prepared by using a composition described in one or more of U.K. patent specifications Nos. 1,244,745, 1,285,379, 1,285,362, 1,286,287, 1,285,380 and 1,286,134. From the various compositions possible, good results can be obtained with a composition consisting essentially of, as a major part, 80.0 to 99.9 mol percent of zinc oxide, and, as additives, 0.05 to 10.0 mol percent of bismuth oxide (Bi_2O_3) and a total of 0.05 to 10.00 mol percent, of at least one member selected from cobalt oxide (CoO), manganese oxide (MnO), antimony oxide (Sb_2O_3), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).

The diffusion of the lithium and/or sodium ions can be effected by any suitable method for example by coating the side surface of the body with a powdered lithium or sodium compound which is converted into lithium oxide at a suitable firing temperature. Preferably the surface of the sintered body is coated with a paste including the lithium or sodium compound and then heated at a given temperature for a given time.

A varistor made in this way exhibits good stability of characteristics in conditions of varying or extreme humidity. For good humidity stability the diffusion depth should be not less than 0.01 mm. The diffusion depth can be easily controlled by diffusion time and temperature in a known manner. The higher diffusion temperature or the longer diffusion time results in a greater depth of diffusion. Of lithium and sodium ions, the former give a better humidity stability for the same depth of diffusion.

The direct current (D.C.) stability of resultant resistor in conditions of high humidity is significantly improved when the paste comprises, as a solid ingredient, 0.5 to 10.0 parts by weight of Li_2O and one at least of the further constituents of 0.01 to 10.0 parts of CoO , 0.01 to 10.0 parts of MnO , 0.01 to 10.0 parts of Ag_2O , 0.01 to 10.0 parts of

Cr_2O_3 and 0.01 to 10.0 parts of NiO , all by weight.

Further improved D.C. stability is obtained with a paste comprising, as a solid ingredient, in the following percentages by weight, 0.5 to 10.0% lithium oxide (Li_2O), 3.0 to 35.0% boron trioxide (B_2O_3), 5.0 to 43.0% silicon dioxide (SiO_2) and 12.0 to 91.5% bismuth oxide (Bi_2O_3) or lead oxide (PbO).

Further improved D.C. humidity stability is obtained with a paste comprising, as a solid ingredient, in percentages by weight, 0.8 to 10.0% lithium oxide (Li_2O), 50.0 to 80.0% barium oxide (BaO) and 10.0 to 40.0% boron trioxide (B_2O_3).

The best results have been obtained with a paste comprising, as a solid ingredient, 1.0 to 2.5 parts by weight of Li_2O and 1.0 to 3.0 parts by weight of K_2O .

The sintered body 1 can be prepared by any suitable known ceramic technique. For example, the starting materials comprising zinc oxide powder and the additives such as the oxides of bismuth, cobalt, manganese, antimony, barium, strontium, lead, uranium or tin, are mixed in a wet mill so as to produce a homogeneous mixture. The mixture is dried and pressed in a mould into a suitable shape under a pressure of 100 Kg/cm^2 to 1000 Kg/cm^2 . If a rod-shaped body is required, the mixed slurry can be fabricated into the desired shape by extrusion and drying. The pressed or extruded bodies are sintered in air at a temperature of 1000 to 1450°C for 1 to 5 hours, and then furnace-cooled to room temperature. The sintering temperature is controlled having regard to the desired electrical resistivity, non-linearity and stability. Electrical resistivity can be reduced by air-quenching the sintered material from the sintering temperature to room temperature. The mixture can be given a preliminary calcining at 700 to 1000°C, and then pulverised for easy fabrication in the subsequent pressing step. The mixtures may include a suitable binder such as water or polyvinyl alcohol. The sintered body so made exhibits an inherent non-ohmic resistance in the bulk, so that the C-value of a varistor made from it can be varied, without affecting the n - value by changing the dimension of the body between its end surfaces; a lesser dimension results in the lower value of C.

The side surface or surfaces of the sintered body is or are coated with a paste including lithium oxide or sodium oxide powder and fired at a given temperature in oxidising atmosphere so as to cause diffusion of Li or Na ions into the bulk of said sintered body; the body is then cooled to room temperature. A suitable paste includes, as a solid ingredient, lithium oxide powder with or without further additives or sodium oxide powder and, as a binding material, an organic resin such as epoxy, vinyl or

phenol resin in an organic solvent such as butyl acetate or toluene. The lithium oxide or sodium oxide can be replaced with any lithium or sodium compound, such as an oxalate, carbonate, nitrate, sulphate, iodide, bromide, fluoride, amide, hydroxide, imide or oxychloride, which in the firing operation is converted into lithium oxide or sodium oxide and diffused into the sintered body as lithium or sodium ions. The binding material is removed during firing. The firing temperature and firing time depend on the weight of lithium or sodium component included in the applied paste and should be controlled so that the Li or Na ions diffuse into the sintered body to the desired depth and not less than 0.01 mm; the higher the diffusion temperature used the shorter can be the diffusion time. The surface of the sintered body into which the Li or Na ions are diffused shows a very high electrical resistivity, and ensures good humidity stability. If the firing temperature is higher than 1000°C the diffusion of Li and Na ions is rapid making it difficult to control the diffusion time sufficiently precisely to give a desired depth of diffusion. If the firing temperature is less than 600°C for Li ions or less than 650°C for Na ions, the diffusion time is inconveniently long; accordingly a suitable diffusion temperature is 600 to 1000°C for Li ions and 650 to 1000°C for Na ions.

After the diffusion process, electrodes are applied to the end surfaces of the sintered body. The electrodes can be provided by any available suitable method, for example by heating a paint of noble metal, by electroless or electrolytic plated Ag, Cu, Ni, Sn or other metal, by vacuum evaporation of Al, Zn, Sn or other metal or by flame spraying of Cu, Sn, Al, Zn or other metal. If the electrodes are formed by heating a noble metal paint at a temperature higher than the diffusion temperature, the electrodes are preferably provided first, before the diffusing process.

Lead wires can be attached to the electrodes in any suitable manner by, for example, conventional soldering, but in making connection to silver electrodes it is convenient to use a conductive adhesive comprising silver powder and resin in an organic solvent. Varistors made as described in this specification have shown high stability to temperature and humidity variations and under load life tests carried out at 70°C, 90% relative humidity,

and at nominal rated power for 500 hours. The n-values and C-values have been found not to change significantly after load life tests.

The following Examples are given.

Example 1.

Mixtures were made using starting materials as set out in Table 1, and mixed in a wet mill for 5 hours.

In each case, the mixture was dried and pressed in a mould to the shape of a disc or cylinder 13 mm in diameter, with a thickness as set out in Table 1, using a pressure of 340 Kg/cm². The pressed body was sintered in air at the temperature listed in Table 1 and then furnace-cooled to room temperature (about 15° to about 30°C). The side surface of the sintered body was coated, with a paste containing 50 percent by weight of lithium carbonate or sodium carbonate and 50 percent by weight of an epoxy resin butyl alcohol solution. The amount of paste to be applied per unit area of the surface is determined by the weight of the lithium carbonate or sodium carbonate to be converted into lithium oxide or sodium oxide, as shown in Table 1. The applied paste was fired at a temperature of 800°C for 1 hour in air. Chemical analysis of fired body indicated that lithium oxide or sodium oxide produced from the carbonate diffused into the sintered body of zinc oxide to a depth of greater than 0.01 mm.

The end surfaces of the sintered body were provided with electrodes as a sprayed film of aluminium, applied in known manner. Lead wires are attached to the aluminium electrodes by means of conductive silver paint. The electrical characteristics of the resultant resistor in each case were measured and are given in Table 1, using methods appropriate for electronic components. Load tests were carried out at 70°C ambient temperature, 90% relative humidity at 1 watt nominal power rating for 500 hours. Table 1 gives C-values measured at a current of 1mA, changes of C-values (ΔC) and changes of n-value (Δn) after life test. Compositions for the sintered body having no Li or Na ions diffused into the body have been found to display change rates of -20% in C-value at the current of 1mA and -50% for n value after the life test under load. The improvement due to the diffusing steps, in improving the D.C. stability at high humidity, will be apparent.

TABLE I
Section A

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mol.%)	Additive (mol.%)		Temp- erature (°C)	Time (Hrs.)		C (V)	n	Δ C (%)	Δ n (%)
99.5	Bi ₂ O ₃ 0.5	3	1200	1	1	160	5.5	+16.0	-14.5
99.5	Bi ₂ O ₃ 0.5	10	1200	1	1	530	5.6	+16.5	-14.6
99.5	Bi ₂ O ₃ 0.5	20	1200	1	1	1070	5.5	+16.9	-14.8
99.5	Bi ₂ O ₃ 0.5	20	1200	1	0.1	1065	5.4	+17.0	-14.9
99.5	Bi ₂ O ₃ 0.5	20	1200	1	10	1085	5.7	+16.3	-14.6
97.0	Bi ₂ O ₃ 3.0	3	1200	3	1	180	4.9	+16.1	-14.4
97.0	Bi ₂ O ₃ 3.0	10	1200	3	1	605	4.8	+16.4	-14.7
97.0	Bi ₂ O ₃ 3.0	20	1200	3	1	1195	4.9	+16.7	-14.7
97.0	Bi ₂ O ₃ 3.0	20	1200	3	0.1	1140	4.8	+16.9	-14.9
97.0	Bi ₂ O ₃ 3.0	20	1200	3	10	1250	5.0	+17.0	-14.5
97.0	Bi ₂ O ₃ 3.0	20	1000	3	1	1600	4.5	+16.1	-15.0
99.5	CoO 0.5	3	1000	2	1	330	3.1	+10.5	-9.2
99.5	CoO 0.5	10	1000	2	1	1010	3.1	+10.4	-9.0
99.5	CoO 0.5	20	1000	2	1	2015	3.0	+10.2	-8.9

TABLE 1 (Continued)

Section A

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mol.%)	Additive (mol.%)		Temp- erature (°C)	Time (Hrs.)		C (V)	n	Δ C (%)	Δ n (%)
97.0	CoO 3.0	20	1100	1	10	270	3.1	+10.0	-9.5
97.0	CoO 3.0	20	1100	1	1	260	3.0	+10.1	-8.7
99.5	UO ₂ 0.5	3	1350	1	1	155	4.2	+9.9	-10.0
99.5	UO ₂ 0.5	10	1200	1	1	1720	3.4	+9.7	-10.1
99.5	UO ₂ 0.5	20	1350	1	1	1015	4.1	+9.5	-10.1
95.0	SnO ₂ 5.0	3	1300	1	1	30	1.9	+9.3	-10.3
95.0	SnO ₂ 5.0	10	1300	1	1	110	2.0	+9.7	-10.5
95.0	SnO ₂ 5.0	20	1300	1	1	225	2.0	+10.5	-10.7
99.5	MnO 0.5	3	1200	1	1	450	4.6	+15.2	-17.0
99.5	MnO 0.5	10	1200	1	1	1500	4.7	+15.2	-17.2
99.5	MnO 0.5	20	1200	1	1	3000	4.6	+15.5	-17.2
99.5	MnO 0.5	20	1200	1	0.1	2990	4.7	+15.8	-17.1
99.5	MnO 0.5	20	1200	1	10	3015	4.8	+15.3	-17.1
97.0	MnO 3.0	3	1200	2	1	600	4.4	+15.7	-17.0

Section A.

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mol.%)	Additive (mol.%)		Temperature (°C)	Time (Hrs.)		C (V)	n	Δ C (%)	Δ n (%)
97.0	MnO 3.0	10	1200	2	1	2010	4.4	+15.9	-17.1
97.0	MnO 3.0	20	1200	2	1	4015	4.3	+16.0	-17.1
97.0	MnO 3.0	20	1200	2	0.1	4000	4.5	+16.5	-17.2
97.0	MnO 3.0	20	1200	2	10	4020	4.6	+15.6	-17.1
97.0	MnO 3.0	20	1000	5	1	3900	3.8	+16.6	-17.5
99.5	Sb ₂ O ₃ 0.5	3	1200	1	1	200	2.8	+14.1	-8.5
99.5	Sb ₂ O ₃ 0.5	10	1200	1	1	550	2.9	+14.2	-8.8
99.5	Sb ₂ O ₃ 0.5	20	1200	1	1	1100	2.9	+14.2	-9.0
99.5	Sb ₂ O ₃ 0.5	20	1200	1	0.1	1100	2.8	+14.1	-9.8
99.5	Sb ₂ O ₃ 0.5	20	1200	1	10	1150	2.9	+14.0	-8.2
97.0	Sb ₂ O ₃ 3.0	3	1200	2	1	400	2.1	+14.2	-8.3
97.0	Sb ₂ O ₃ 3.0	10	1200	2	1	1100	2.1	+14.3	-8.4
97.0	Sb ₂ O ₃ 3.0	20	1200	2	1	2250	2.0	+14.5	-8.4
97.0	Sb ₂ O ₃ 3.0	20	1200	2	0.1	2200	2.0	+14.7	-8.9

TABLE 1 (Continued)
Section A

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor	Change Rates after Life Test	
			Temp- erature (°C)	Time (Hrs.)				
ZnO (mol.%)	Additive (mol.%)					C (V)	n	
97.0	Sb ₂ O ₃ 3.0	20	1200	2	10	2300	2.0	+13.9 -8.4
97.0	Sb ₂ O ₃ 3.0	20	1000	3	1	3500	2.0	+14.4 -8.5
99.5	BaO 0.5	3	1300	1	1	120	8.0	+15.4 -15.8
99.5	BaO 0.5	10	1300	1	1	405	7.9	+15.7 -15.7
99.5	BaO 0.5	20	1300	1	1	805	7.9	+15.7 -15.7
99.5	BaO 0.5	20	1300	1	0.1	805	8.1	+15.7 -15.9
99.5	BaO 0.5	20	1300	1	10	810	8.0	+15.6 -15.7
97.0	BaO 3.0	3	1300	2	1	360	5.9	+15.3 -15.8
97.0	BaO 3.0	10	1300	2	1	1190	6.0	+15.2 -15.8
97.0	BaO 3.0	20	1300	2	1	2395	6.2	+15.2 -16.0
97.0	BaO 3.0	20	1300	2	0.1	2390	6.0	+15.3 -16.2
97.0	BaO 3.0	20	1300	2	10	2400	5.9	+15.2 -15.8
97.0	BaO 3.0	20	1100	3	1	3200	5.0	+15.9 -16.2
99.5	SrO 0.5	3	1300	1	1	90	5.5	+17.0 -14.2

TABLE 1 (Continued)

Section A

Starting Materials.		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ³)	Electrical characteristics of Resultant Resistor	Change Rates after Life Test		
			Temp- erature (°C)	Time (Hrs.)			Δ C (%)	Δ n (%)	
ZnO (mol.%)	Additive (mol.%)					C (V)	n		
99.5	SrO 0.5	10	1300	1	1	300	5.6	+17.1	-14.3
99.5	SrO 0.5	20	1300	1	1	590	5.5	+17.1	-14.5
99.5	SrO 0.5	20	1300	1	0.1	590	5.7	+17.2	-14.8
99.5	SrO 0.5	20	1300	1	10	600	5.7	+17.0	-14.0
97.0	SrO 3.0	3	1300	2	1	220	4.5	+17.3	-14.0
97.0	SrO 3.0	10	1300	2	1	710	4.6	+17.3	-14.3
97.0	SrO 3.0	20	1300	2	1	1425	4.6	+17.5	-14.4
97.0	SrO 3.0	20	1300	2	0.1	1420	4.5	+17.6	-14.7
97.0	SrO 3.0	20	1300	2	10	1435	4.7	+17.2	-14.1
97.0	SrO 3.0	20	1100	5	1	2200	4.0	+18.0	-15.0
99.5	PbO 0.5	3	1300	1	1	2405	6.4	+16.5	-14.6
99.5	PbO 0.5	10	1300	1	1	8050	6.5	+16.6	-14.7
99.5	PbO 0.5	20	1300	1	1	16040	6.7	+16.8	-14.7
99.5	PbO 0.5	20	1300	1	0.1	16000	6.5	+16.9	-15.2

TABLE 1 (Continued)

Section A

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Li ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mol.%)	Additive (mol.%)		Temp- erature (°C)	Time (Hrs.)		C (V)	n	Δ C (%)	Δ n (%)
99.5	PbO 0.5	20	1300	1	10	15990	6.5	+16.6	-14.2
97.0	PbO 3.0	3	1300	2	1	2400	5.2	+16.4	-14.8
97.0	PbO 3.0	10	1300	2	1	9200	5.1	+16.7	-14.9
97.0	PbO 3.0	20	1300	2	1	18500	5.3	+16.9	-15.2
97.0	PbO 3.0	20	1300	2	0.1	18400	5.3	+17.2	-15.5
97.0	PbO 3.0	20	1300	2	10	18450	5.2	+16.5	-14.7
97.0	PbO 3.0	20	1100	5	1	20000	4.7	+17.5	-15.8

TABLE 1

Section B

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Na ₂ O (mg/cm ²)	Electrical characteristics of Resulant Resistor		Change Rates after Life Test	
ZnO (mole.%)	Additive (mole.%)		Temp- erature (°C)	Time (Hrs.)		C (V) (at a given current of 1mA)	n	Δ C (%) (at a given current of 1mA)	Δ n (after Life Test)
99.5	Bi ₂ O ₃ 0.5	3	1200	1	1	150	5.6	+18.7	-17.7
99.5	Bi ₂ O ₃ 0.5	10	1200	1	1	521	5.5	+18.2	-17.7
99.5	Bi ₂ O ₃ 0.5	20	1200	1	1	1060	5.6	+18.7	-17.9
99.5	Bi ₂ O ₃ 0.5	20	1200	1	0.1	1060	5.5	+18.8	-18.1
99.5	Bi ₂ O ₃ 0.5	20	1200	1	10	1075	5.7	+18.0	-17.8
97.0	Bi ₂ O ₃ 3.0	3	1200	3	1	180	4.9	+17.8	-17.7
97.0	Bi ₂ O ₃ 3.0	10	1200	3	1	600	4.7	+18.0	-17.9
97.0	Bi ₂ O ₃ 3.0	20	1200	3	1	1190	4.8	+18.5	-17.8
97.0	Bi ₂ O ₃ 3.0	20	1200	3	0.1	1130	4.7	+18.7	-13.0
97.0	Bi ₂ O ₃ 3.0	20	1200	3	10	1240	5.1	+18.7	-19.6
97.0	Bi ₂ O ₃ 3.0	20	1000	3	1	1595	4.6	+17.9	-18.2
99.5	CoO 0.5	3	1000	2	1	320	3.1	+14.4	-14.4
99.5	CoO 0.5	10	1000	2	1	1000	3.1	+14.2	-14.2

TABLE 1 (Continued)
Section B

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Na ₂ O (mg/cm ²)	Electrical characteristics of Resulant Resistor		Change Rates after Life Test	
ZnO (mole.%)	Additive (mole.%)		Temp- erature (°C)	Time (Hrs.)		C (V) (at a given current of 1mA)	n	Δ C (%) (at a given current of 1mA)	Δ n (after Life Test)
99.5	CoO 0.5	20	1000	2	1	2005	3.0	+14.1	-14.9
97.0	CoO 3.0	20	1100	1	10	265	3.1	+14.0	-14.6
97.0	CoO 3.0	20	1100	1	1	255	3.0	+14.1	-14.9
99.5	UO ₂ 0.5	3	1350	1	1	150	4.2	+13.9	-15.1
99.5	UO ₂ 0.5	10	1200	1	1	1710	3.3	+13.7	-15.3
99.5	UO ₂ 0.5	20	1350	1	1	1010	4.0	+13.5	-15.3
95.0	SnO ₂ 5.0	3	1300	1	1	25	1.8	+13.2	-15.5
95.0	SnO ₂ 5.0	10	1300	1	1	105	2.0	+13.5	-14.7
95.0	SnO ₂ 5.0	20	1300	1	1	220	2.0	+13.4	-14.9
99.5	MnO 0.5	3	1200	1	1	480	4.7	+17.9	-11.0
99.5	MnO 0.5	10	1200	1	1	1500	4.9	+18.1	-11.2
99.5	MnO 0.5	20	1200	1	1	2995	4.7	+18.3	-11.3
99.5	MnO 0.5	20	1200	1	0.1	2980	4.8	+18.6	-11.2

TABLE 1 (Continued)
Section B

Starting Materials		Thickness (mm)	Sintering -		Weight of Applied Na ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mole.%)	Additive (mole.%)		Temp- erature (°C)	Time (Hrs.)		C (V) (at a given current of 1mA)	n	Δ C (%) (at a given current of 1mA)	Δ n (after Life Test)
99.5	MnO 0.5	20	1200	1	10	3010	5.0	+18.1	-11.0
97.0	MnO 3.0	3	1200	2	1	595	4.4	+18.5	-11.1
97.0	MnO 3.0	10	1200	2	1	2000	4.5	+18.6	-11.1
97.0	MnO 3.0	20	1200	2	1	4010	4.4	+18.9	-11.2
97.0	MnO 3.0	20	1200	2	0.1	3990	4.4	+19.3	-11.1
97.0	MnO 3.0	20	1200	2	10	4010	4.7	+18.4	-11.0
97.0	MnO 3.0	20	1000	5	1	3890	3.8	+19.4	-11.6
99.5	Sb ₂ O ₃ 0.5	3	1200	1	1	150	2.8	+17.0	-14.4
99.5	Sb ₂ O ₃ 0.5	10	1200	1	1	550	2.8	+17.1	-14.7
99.5	Sb ₂ O ₃ 0.5	20	1200	1	1	1100	2.9	+17.0	-14.8
99.5	Sb ₂ O ₃ 0.5	20	1200	1	0.1	1050	2.9	+16.9	-15.6
99.5	Sb ₂ O ₃ 0.5	20	1200	1	10	1150	2.8	+16.8	-14.0
97.0	Sb ₂ O ₃ 3.0	3	1200	2	1	350	2.0	+17.1	-14.2

TABLE 1 (Continued)
Section B

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Na ₂ O (mg/cm ²)	Electrical characteristics of Resultant Resistor		Change Rates after Life Test	
ZnO (mole.%)	Additive (mole.%)		Temp- erature (°C)	Time (Hrs.)		C (V) (at a given current of 1mA)	n	Δ C (%) (at a given current of 1mA)	Δ n (after Life Test)
97.0	Sb ₂ O ₃ 3.0	10	1200	2	1	1100	2.0	+17.2	-14.2
97.0	Sb ₂ O ₃ 3.0	20	1200	2	1	2250	2.0	+17.4	-14.3
97.0	Sb ₂ O ₃ 3.0	20	1200	2	0.1	2200	2.0	+17.6	-14.9
97.0	Sb ₂ O ₃ 3.0	20	1200	2	10	2300	2.0	+16.8	-14.3
97.0	Sb ₂ O ₃ 3.0	20	1000	3	1	3450	1.9	+17.2	-14.2
99.5	BaO 0.5	3	1300	1	1	110	8.1	+18.2	-19.4
99.5	BaO 0.5	10	1300	1	1	400	8.0	+18.5	-19.3
99.5	BaO 0.5	20	1300	1	1	800	7.9	+18.6	-19.4
99.5	BaO 0.5	20	1300	1	0.1	800	8.0	+18.5	-19.6
99.5	BaO 0.5	20	1300	1	10	805	8.1	+18.4	-19.3
97.0	BaO 3.0	3	1300	2	1	360	5.8	+18.1	-19.4
97.0	BaO 3.0	10	1300	2	1	1185	6.1	+18.0	-19.5
97.0	BaO 3.0	20	1300	2	1	2390	6.2	+18.1	-19.7

TABLE 1 (Continued)
Section B

Starting Materials		Thickness (mm)	Sintering		Weight of Applied Na ₂ O (mg/cm ²)	Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
			Temp- erature (°C)	Time (Hrs.)		C (V) (at a given current of 1mA)	n	ΔC (%) (at a given current of 1mA)	Δn (after Life Test)
97.0	BaO 3.0	20	1300	2	0.1	2390	6.0	+18.1	-19.0
97.0	BaO 3.0	20	1300	2	10	2400	5.8	+18.0	-19.7
97.0	BaO 3.0	20	1100	3	1	3215	5.1	+18.7	-19.0
99.5	SrO 0.5	3	1300	1	1	90	5.6	+19.7	-18.4
99.5	SrO 0.5	10	1300	1	1	295	5.6	+19.8	-18.5
99.5	SrO 0.5	20	1300	1	1	585	5.5	+19.9	-18.6
99.5	SrO 0.5	20	1300	1	0.1	585	5.7	+20.0	-18.9
99.5	SrO 0.5	20	1300	1	10	600	5.8	+19.8	-18.3
97.0	SrO 3.0	3	1300	2	1	215	4.6	+19.0	-18.2
97.0	SrO 3.0	10	1300	2	1	700	4.6	+19.1	-18.6
97.0	SrO 3.0	20	1300	2	1	1420	4.7	+19.2	-18.6
97.0	SrO 3.0	20	1300	2	0.1	1405	4.4	+19.3	-19.0
97.0	SrO 3.0	20	1300	2	10	1430	4.8	+19.0	-18.3

TABLE 1 (Continued)
Section B

Starting Materials			Thickness (mm)	Sintering		Weight of Applied Na ₂ O (mg/cm ²)	Electrical characteristics of Resulant Resistor		Change Rates after Life Test	
				Temp- erature (°C)	Time (Hrs.)					
ZnO (mole.%)	Additive (mole.%)						C (V) (at a given current of 1mA)	n	Δ C (%) (at a given current of 1mA)	Δ n (after Life Test)
97.0	SrO	3.0	20	1100	5	1	2195	4.2	+19.7	-19.2
99.5	PbO	0.5	3	1300	1	1	2400	6.1	+19.2	-18.8
99.5	PbO	0.5	10	1300	1	1	8040	6.5	+19.4	-18.9
99.5	PbO	0.5	20	1300	1	1	16030	6.6	+19.7	-19.0
99.5	PbO	0.5	20	1300	1	0.1	16000	6.5	+19.6	-19.3
99.5	PbO	0.5	20	1300	1	10	15980	6.7	+19.3	-18.4
97.0	PbO	3.0	3	1300	2	1	2390	5.2	+19.2	-19.0
97.0	PbO	3.0	10	1300	2	1	9200	5.0	+19.5	-19.1
97.0	PbO	3.0	20	1300	2	1	15490	5.4	+19.6	-19.3
97.0	PbO	3.0	20	1300	2	0.1	18400	5.3	+19.0	-19.7
97.0	PbO	3.0	20	1300	2	10	18440	5.1	+19.3	-19.0
97.0	PbO	3.0	20	1100	5	1	19990	4.5	+19.3	-19.0

Example 2.

Starting materials as in Table 2 were used as in Example 1 except as to the following:

5 Pressed size: 13 mm diameter and 10 mm thickness.

Sintering conditions. As in Table 2.

Firing temperature and Time: 800°C for 1 hour.

Weight of applied Li_2O or Na_2O : 1 mg/ cm^2 .

The results of the tests made are given in Table 2.

10

TABLE 2

Starting Materials				Sintering		Applied diffusant							
						Li ions				Na ions			
						Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)	
99.9	0.05	CoO 0.05	1300	1	360	6	+3.9	-4.2	350	5	+7.0	-8.4	
99.4	0.1	CoO 0.5	1300	1	500	11	+3.9	-4.0	495	10	+7.1	-8.3	
99.0	0.5	CoO 0.5	1300	1	620	16	+4.1	-4.1	625	14	+6.9	-8.0	
98.5	1.0	CoO 0.5	1300	1	750	13	+4.0	-4.2	740	12	+7.3	-8.3	
89.5	10.0	CoO 0.5	1300	1	1010	9	+4.1	-4.3	1000	8	+7.2	-8.1	
80.0	10.0	CoO 10.0	1300	2	1100	7	+4.1	-4.2	1095	6	+7.4	-7.8	
99.0	0.5	PbO 0.5	1300	1	175	6	+5.4	-5.7	170	7	+7.0	-8.3	
99.45	0.5	MnO 0.05	1300	1	350	4	+3.5	-3.0	340	3	+6.5	-5.1	
99.4	0.5	MnO 0.1	1300	1	1410	9	+3.6	-2.9	1400	7	+6.6	-4.9	
99.0	0.5	MnO 0.5	1300	1	920	15	+3.4	-2.9	915	14	+7.0	-5.0	
97.0	0.5	MnO 2.5	1300	1	1500	5	+3.8	-3.0	1495	4	+6.8	-5.5	
89.5	0.5	MnO 10	1300	1	1850	4	+3.7	-3.1	1840	3	+6.9	-5.3	

TABLE 2 (Continued)

Sintering Materials				Sintering		Applied diffusant							
						Li ions				Na ions			
						Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)	
99.45	0.5	Sb ₂ O ₃ 0.05	1350	1	740	14	+8.1	-6.9	735	13	+11.6	-11.6	
99.9	0.05	Sb ₂ O ₃ 0.05	1350	1	530	12	+8.2	-6.7	525	10	+11.9	-11.3	
98.9	0.1	Sb ₂ O ₃ 1.0	1350	1	800	17	+8.3	-7.0	790	15	+11.9	-11.5	
98.5	0.5	Sb ₂ O ₃ 1.0	1350	1	830	18	+8.4	-6.8	820	16	+12.0	-11.3	
98.0	1.0	Sb ₂ O ₃ 1.0	1350	1	940	19	+8.2	-6.9	935	18	+12.0	-11.4	
89.0	10.0	Sb ₂ O ₃ 1.0	1350	1	1250	21	+8.4	-7.1	1245	20	+11.9	-11.7	
80.0	10.0	Sb ₂ O ₃ 10.0	1350	2	1130	23	+8.3	-7.0	1125	21	+12.0	-11.5	
99.45	0.5	BaO 0.05	1350	1	570	11	+7.2	-7.4	560	10	+10.9	-11.9	
99.4	0.5	BaO 0.1	1350	1	650	12	+7.4	-7.3	640	11	+11.0	-11.1	
99.0	0.5	BaO 0.5	1350	1	805	14	+7.6	-7.4	800	13	+11.1	-11.1	
97.5	0.5	BaO 2	1350	1	840	16	+7.3	-7.6	830	14	+11.1	-12.4	
89.5	0.5	BaO 10	1350	1	990	18	+7.2	-7.8	985	16	+10.8	-12.3	

TABLE 2 (Continued)

Sintering Materials				Sintering		Applied diffusant						
						Li ions			Na ions			
						Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
99.9	0.05	SrO 0.05	1350	1	210	5	+7.7	-7.7	200	4	+11.5	-12.4
99.4	0.1	SrO 0.5	1350	1	330	5	+7.9	-7.8	325	4	+11.7	-12.5
99.0	0.5	SrO 0.5	1350	1	75	6	+7.6	-7.9	70	5	+11.4	-12.5
98.5	1.0	SrO 0.5	1350	1	120	5	+7.5	-7.6	110	4	+11.4	-12.2
89.5	10.0	SrO 0.5	1350	1	515	5	+7.8	-7.7	510	4	+11.5	-12.1
80.0	10.0	SrO 10.0	1350	2	375	5	+7.9	-7.5	370	5	+11.7	-12.3
98.95	0.5	{CoO 0.5 MnO 0.05}	1350	1	645	14	+2.2	-2.5	640	12	+5.8	-7.1
98.5	0.5	{CoO 0.5 MnO 0.5}	1350	1	925	16	+2.4	-2.0	915	15	+6.0	-6.7
94.0	0.5	{CoO 0.5 MnO 5.0}	1350	1	1110	15	+2.9	-2.3	1105	13	+6.4	-6.3

TABLE 2 (Continued)

Sintering Materials				Sintering		Applied diffusant					
						Li ions			Na ions		
						Electrical characteristics of Resultant Resistor	Change Rate after Life Test	Δn (%)	Electrical characteristics of Resultant Resistor	Change Rate after Life Test	Δn (%)
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)
98.95	0.5	{ CoO 0.05 MnO 0.5	1350	1	830	15	+2.8	-2.2	825	13	+6.3
98.0	0.5	{ CoO 1.0 MnO 0.5	1350	1	950	17	+2.5	-2.1	940	15	+6.0
89.5	0.5	{ CoO 9.5 MnO 0.5	1350	2	1200	16	+2.1	-2.4	1190	14	+5.7
98.5	0.5	{ CoO 0.5 BaO 0.5	1300	1	530	24	+2.3	-2.2	525	13	+5.8
89.5	0.5	{ CoO 0.5 BaO 9.5	1300	2	920	21	+2.4	-2.3	915	20	+5.9
89.5	0.5	{ CoO 9.5 BaO 0.5	1300	2	840	20	+2.3	-2.5	830	18	+5.9

TABLE 2 (Continued)

Sintering Materials			Sintering		Applied diffusant							
					Li ions				Na ions			
					Electrical characteristics of Resulant Resistor		Change Rate after Life Test		Electrical characteristics of Resulant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
98.5	0.5	{ CoO 0.5 Sb ₂ O ₃ 0.5	1350	1	1610	28	+2.7	-2.0	1600	26	+6.6	-6.1
98.5	0.5	{ CoO 0.5 SrO 0.5	1350	1	730	25	+2.3	-2.1	725	24	+5.9	-6.3
99.85	0.05	{ MnO 0.05 SrO 0.05	1350	1	6050	5	+2.9	-2.9	6040	4	+6.7	-6.9
89.95	0.05	{ MnO 0.05 SrO 9.95	1350	2	6000	6	+2.9	-2.5	5995	5	+6.6	-6.5
89.9	10	{ MnO 0.05 SrO 0.05	1350	2	5800	5	+2.2	-2.0	5790	4	+5.8	-6.2
80	10	{ MnO 0.05 SrO 9.95	1350	2	5650	5	+2.0	-2.8	5640	4	+5.5	-6.8

TABLE 2 (Continued)

Sintering Materials				Sintering		Applied diffusant						
						Li ions			Na ions			
						Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
89.95	0.05	{ MnO 9.95 SrO 0.05 }	1350	2	7050	5	+2.1	-2.7	7045	4	+5.7	-6.6
89.95	0.05	{ MnO 5 SrO 5 }	1350	2	4510	6	+2.3	-2.9	4505	5	+5.9	-6.9
80	10	{ MnO 9.95 SrO 0.05 }	1350	2	4820	5	+2.2	-2.9	4810	4	+5.7	-6.9
80	10	{ MnO 5 SrO 5 }	1350	2	4715	6	+2.9	-2.7	4710	4	+6.6	-6.6
99.7	0.1	{ MnO 0.1 SrO 0.1 }	1350	1	2010	8	+2.7	-2.5	2005	7	+6.3	-6.5
96.8	0.1	{ MnO 0.1 SrO 3 }	1350	1	2060	8	+2.6	-2.7	2055	7	+6.1	-6.7

TABLE 2 (Continued)

Sintering Materials			Sintering		Applied diffusant							
					Li ions				Na ions			
					Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
96.8	3	{ MnO 0.1 SrO 0.1 }	1350	1	2065	8	+2.7	-2.8	2060	7	+6.3	-6.8
93.9	3	{ MnO 0.1 SrO 3 }	1350	1	2000	8	+2.7	-2.9	1990	7	+6.3	-6.9
96.8	0.1	{ MnO 3 SrO 0.1 }	1350	1	2220	8	+2.8	-2.5	2215	7	+6.3	-6.4
93.9	0.1	{ MnO 3 SrO 3 }	1350	1	2015	8	+2.9	-2.3	2010	7	+6.5	-6.2
87.0	3	{ MnO 9.9 SrO 0.1 }	1350	2	2150	8	+2.7	-2.6	2145	7	+6.3	-6.6
91	3	{ MnO 3 SrO 3 }	1350	1	2050	8	+2.7	-2.7	2040	7	+6.3	-6.7

TABLE 2 (Continued)

Sintering Materials				Sintering		Applied diffusant						
						Li ions			Na ions			
						Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
98.5	0.5	{ MnO 0.5 SrO 0.5 }	1350	1	760	13	+2.9	-2.9	750	12	+6.5	-6.8
98.5	0.5		{ MnO 0.5 BaO 0.5 }	1350	1	740	23	+2.1	-2.2	735	22	+5.7
98.5	0.5	{ MnO 0.5 Sb ₂ O ₃ 0.5 }	1350	1	1520	30	+2.0	-2.8	1510	29	+5.6	-6.8
99.85	0.05		{ BaO 0.05 SrO 0.05 }	1350	1	3850	8	+2.3	-2.0	3845	7	+5.8
89.95	0.05	{ BaO 0.05 SrO 9.95 }	1350	2	3910	8	+2.4	-2.2	3905	7	+5.9	-6.2
89.9	10		{ BaO 0.05 SrO 0.05 }	1350	2	3520	8	+2.5	-2.4	3510	7	+6.1

TABLE 2 (Continued)

Sintering Materials			Sintering		Applied diffusant							
					Li ions				Na ions			
					Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
80	10	{ BaO 0.05 SrO 9.95	1350	2	4010	7	+2.7	-2.2	4005	6	+6.3	-6.4
89.95	0.05	{ BaO 9.95 SrO 0.05	1350	2	3840	8	+2.5	-2.6	3830	7	+6.2	-6.6
89.95	0.05	{ BaO 5 SrO 5	1350	1	3770	8	+2.6	-2.7	3765	7	+6.3	-6.7
80	10	{ BaO 9.95 SrO 0.05	1350	2	360	9	+2.4	-2.2	355	8	+6.0	-6.9
80	10	{ BaO 5 SrO 5	1350	2	325	8	+2.7	-2.4	320	7	+6.5	-7.0
98.5	0.5	{ BaO 0.5 SrO 0.5	1350	1	255	28	+2.2	-2.6	345	27	+5.7	-7.3

TABLE 2 (Continued)

Sintering Materials			Sintering		Applied diffusant							
					Li ions				Na ions			
					Electrical characteristics of Resultant Resistor		Change Rate after Life Test		Electrical characteristics of Resultant Resistor		Change Rate after Life Test	
ZnO (mol.%)	Bi ₂ O ₃ (mol.%)	other additives (mol.%)	Temp-erature (°C)	Time (Hrs.)	C (at a given current 1mA) (V)	n	ΔC (%)	Δn (%)	C (V)	n	ΔC (%)	Δn (%)
98.5	0.5	{ BaO 0.5 Sb ₂ O ₃ 0.5	1350	1	730	23	+2.7	-2.7	725	22	+6.1	-7.4
98.5	0.5	{ SrO 0.5 Sb ₂ O ₃ 0.5	1350	1	625	21	+2.6	-2.9	620	20	+6.0	-7.5
97.5	0.5	{ CoO 0.5 MnO 0.5 Sb ₂ O ₃ 1.0	1300	1	1210	36	+1.7	-1.4	1205	35	+5.5	-6.7
98	0.5	{ CoO 0.5 MnO 0.5 SrO 0.5	1300	1	1420	35	+1.8	-1.3	1410	33	+5.5	-6.6
98	0.5	{ CoO 0.5 MnO 0.5 BaO 0.5	1300	1	1500	32	+1.8	-1.5	1495	30	+5.4	-6.3

Example 3.

Using starting materials consisting of 99.0 mol percent zinc oxide, 0.5 mol percent bismuth oxide and 0.5 mol percent cobalt oxide varistors were made and as in Example 2 except as to the following:

5 Sintering temperature and time: 1350°C and 1 hour.

Li compound or Na compound included in the paste: As in Table 3.

Weight of Li_2O or Na_2O in the applied paste: 1 mg/cm².

Firing temperature and time: Table 3.

The results of the tests made are given in Table 3.

10

15

TABLE 3

Weight of Applied Diffusant (mg/cm ²) (wt. converted into oxide form)		Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
				C (V)	n	ΔC (%)	Δn (%)
Li ₂ O	0.1	600	2	625	15	+4.1	-4.1
Li ₂ O	0.1	1000	1	635	18	+3.9	-4.0
Li ₂ O	0.5	700	1	625	16	+4.0	-4.2
Li ₂ O	1	600	1	630	17	+4.1	-4.1
Li ₂ O	2	800	1	635	17	+3.9	-4.0
Li ₂ O	5	900	1	645	18	+4.0	-3.8
Li ₂ O	10	600	1	645	18	+4.0	-3.8
Li ₂ O	10	1000	0.3	650	19	+3.9	-3.8
Li ₂ O	1	700	1	630	19	+3.8	-3.9
Li ₂ O	1	800	1	635	19	+3.8	-3.8
Li ₂ O	1	900	1	640	20	+3.8	-3.8
Li ₂ O	1	1000	0.5	645	20	+4.0	-4.0
Li ₂ O	1	800	5	640	18	+4.0	-4.1
LiCl	0.1	600	2	630	14	+4.2	-4.0
LiCl	1	800	1	645	17	+4.0	-4.0
LiCl	10	1000	0.3	660	20	+3.8	-3.8
Li ₂ C ₂ O ₄	0.1	600	2	630	15	+4.0	-4.1
Li ₂ C ₂ O ₄	1	800	1	640	19	+4.0	-3.8
Li ₂ C ₂ O ₄	10	1000	0.3	660	18	+3.9	-4.0
Li ₂ CO ₃	0.1	600	2	630	19	+3.8	-3.8
Li ₂ CO ₃	1	800	1	640	19	+4.0	-3.7
Li ₂ CO ₃	10	1000	0.3	660	18	+4.0	-3.9
Li ₂ CO ₃	0.1	600	2	630	15	+4.1	-3.9
LiNO ₃	1	800	1	645	18	+3.9	-3.8
LiNO ₃	10	1000	0.3	660	20	+3.7	-3.8
Li ₂ SO ₄	0.1	900	2	630	16	+4.2	-4.2

TABLE 3 (Continued)

Weight of Applied Diffusant (mg/cm ²) (wt. converted into oxide form)	Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
	Temperature (°C)	Time (Hrs.)	C (V)	n	ΔC (%)	Δn (%)
Li ₂ SO ₄ 1	900	1	640	19	+4.1	-4.0
Li ₂ SO ₄ 10	1000	0.3	665	20	+4.0	-4.1
LiI 0.1	600	2	635	17	+4.1	-4.1
LiI 1	800	1	640	17	+3.8	-4.1
LiI 10	1000	0.3	665	20	+4.0	-3.5
LiBr 0.1	600	2	635	18	+4.0	-4.1
LiBr 1	800	1	640	18	+3.9	-4.0
LiBr 10	1000	0.3	660	19	+4.0	-3.7
LiF 0.1	800	2	630	15	+4.0	-4.2
LiF 1	900	1	640	17	+4.1	-3.9
LiF 10	1000	0.3	655	19	+3.9	-4.2
LiNH ₂ 0.1	600	2	630	15	+4.1	-3.9
LiNH ₂ 1	800	1	645	18	+3.8	-4.1
LiNH ₂ 10	1000	0.3	660	19	+4.0	-3.8
LiOH 0.1	600	2	630	15	+4.1	-4.1
LiOH 1	800	1	635	19	+3.9	-3.5
LiOH 10	1000	0.3	645	19	+3.9	-4.2
Li ₂ NH 0.1	800	2	630	16	+4.0	-4.2
Li ₂ NH 1	800	1	640	18	+4.0	-4.0
Li ₂ NH 10	1000	0.3	655	18	+4.0	-3.5
LiClO ₃ 0.1	600	2	630	15	+4.2	-3.9
LiClO ₃ 1	800	1	645	17	+4.0	-4.2
LiClO ₃ 10	1000	0.3	660	20	+3.8	-3.8
Na ₂ O 0.1	650	2	620	14	+6.8	-8.2
Na ₂ O 0.1	1000	1	630	17	+6.6	-8.0
Na ₂ O 0.5	700	1	620	15	+6.9	-8.2

TABLE 3 (Continued)

Weight of Applied Diffusant (mg/cm ²) (wt. converted into oxide form)		Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
				C (V)	n	ΔC (%)	Δn (%)
		Temperature (°C)	Time (Hrs.)				
Na ₂ O	1	650	1	625	16	+6.8	-8.1
Na ₂ O	2	800	1	630	17	+6.5	-8.0
Na ₂ O	5	900	1	640	17	+6.7	-7.8
Na ₂ O	10	800	1	640	17	+7.0	-7.9
Na ₂ O	10	1000	0.3	645	18	+6.5	-7.8
Na ₂ O	1	700	1	620	17	+6.4	-7.9
Na ₂ O	1	800	1	630	18	+6.5	-7.9
Na ₂ O	1	900	1	635	19	+6.5	-7.9
Na ₂ O	1	1000	0.5	640	19	+6.7	-8.0
Na ₂ O	1	800	5	635	17	+6.6	-8.0
NaF	0.1	800	2	625	14	+6.6	-8.2
NaF	1	800	1	630	16	+6.8	-7.9
NaF	10	1000	0.3	650	18	+6.5	-8.2
NaBr	0.1	700	2	630	17	+6.6	-8.1
NaBr	1	800	1	635	17	+6.5	-8.0
NaBr	10	1000	0.3	650	18	+6.6	-7.7
NaI	0.1	650	2	630	16	+6.7	-8.1
NaI	1	800	1	635	16	+6.4	-8.1
NaI	10	1000	0.3	660	19	+6.7	-7.5
NaNH ₂	0.1	650	2	620	14	+6.8	-7.9
NaNH ₂	1	800	1	640	17	+6.5	-8.1
NaNH ₂	10	1000	0.3	655	18	+6.6	-7.8
Na ₂ C ₂	0.1	650	2	625	19	+6.8	-8.0
Na ₂ C ₂	1	800	1	630	18	+6.9	-8.2
Na ₂ C ₂	10	1000	0.3	645	18	+6.9	-8.1
Na ₂ SO ₄	0.1	650	2	635	15	+7.0	-7.9

Example 4.

- 5 Using starting materials consisting of 99.0 mol percent zinc oxide, 0.5 mol percent bismuth oxide and 0.5 mol percent manganese oxide varistors were made and tested as in Example 3, except as to the following:

Solid ingredients included in the paste: As in Table 4.

Weight of Li_2O in the applied paste: 1 mg/cm^2

Firing temperature and time: As in Table 4.

The results of the tests made are given in Table 4.

TABLE 4

Composition of Pastes Parts by weight			Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
					C	n	ΔC	Δn
Li ₂ O	others		Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
0.5	CoO	0.01	600	2	895	15	+1.9	-2.0
0.5	CoO	0.1	700	1	900	15	+1.9	-2.2
0.5	CoO	1.0	850	1	900	16	+2.0	-2.1
0.5	CoO	10	900	1	905	17	+2.0	-2.1
1.0	CoO	0.01	1000	0.5	900	15	+2.0	-2.0
1.0	CoO	0.1	800	1	905	16	+1.9	-2.1
1.0	CoO	1	700	1	905	16	+1.6	-2.0
1.0	CoO	10	600	1	910	17	+2.0	-2.2
3.0	CoO	0.01	1000	0.5	900	15	+1.9	-2.1
3.0	CoO	0.1	900	1	900	16	+1.8	-2.0
3.0	CoO	1.0	750	2	910	18	+1.8	-2.1
3.0	CoO	10	600	1	915	17	+1.8	-2.2
10	CoO	0.01	1000	0.5	890	14	+2.0	-2.3
10	CoO	0.1	800	1	895	15	+1.9	-2.1
10	CoO	1	700	1	900	16	+1.8	-2.0
10	CoO	10	600	2	905	17	+1.6	-2.0
0.5	MnO	0.01	1000	1	890	15	+2.0	-2.5
0.5	MnO	0.1	850	1	895	16	+2.0	-2.4
0.5	MnO	1	750	1	900	16	+1.9	-2.0
0.5	MnO	10	600	2	900	17	+1.9	-2.0
2.0	MnO	0.01	1000	0.5	895	15	+2.0	-2.3
2.0	MnO	0.1	900	1	895	16	+2.0	-2.1
2.0	MnO	1	850	1	900	16	+1.9	-2.0
2.0	MnO	10	600	1	900	17	+1.9	-2.0
10	MnO	0.01	1000	0.5	900	16	+1.9	-2.4
10	MnO	0.1	850	1	895	17	+1.9	-2.0

TABLE 4 (Continued)

Composition of Pastes Parts by weight			Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
					C	n	ΔC	Δn
Li ₂ O	others		Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
10	MnO	1	700	1	895	18	+1.9	-1.9
10	MnO	10	600	1	900	17	+1.8	-2.0
0.5	Ag ₂ O	0.01	1000	1	905	17	+2.0	-2.4
0.5	Ag ₂ O	0.1	900	1	905	16	+1.8	-1.9
0.5	Ag ₂ O	1	750	2	910	17	+1.5	-1.8
0.5	Ag ₂ O	10	600	1	900	16	+1.8	-2.0
2	Ag ₂ O	0.01	1000	0.5	895	17	+2.0	-2.2
2	Ag ₂ O	0.01	800	1	890	15	+1.7	-1.9
2	Ag ₂ O	1	600	1	895	17	+1.8	-2.1
2	Ag ₂ O	1	800	1	900	18	+1.5	-1.9
2	Ag ₂ O	1	1000	0.5	900	18	+1.7	-1.9
2	Ag ₂ O	10	600	1	910	19	+1.8	-2.0
2	Ag ₂ O	10	1000	1	915	18	+1.9	-2.0
10	Ag ₂ O	0.01	1000	0.5	900	16	+2.0	-2.0
10	Ag ₂ O	1	800	2	895	17	+1.7	-1.8
10	Ag ₂ O	10	600	1	900	18	+1.8	-1.7
0.5	Cr ₂ O ₃	0.01	600	2	895	15	+2.0	-2.2
0.5	Cr ₂ O ₃	1	800	1	905	16	+1.7	-2.0
0.5	Cr ₂ O ₃	10	1000	1	905	17	+1.9	-2.1
2	Cr ₂ O ₃	0.01	1000	0.5	900	15	+1.9	-2.2
2	Cr ₂ O ₃	1	800	2	910	18	+1.7	-1.9
2	Cr ₂ O ₃	10	600	1	915	17	+1.9	-2.0
10	Cr ₂ O ₃	0.01	800	1	885	16	+2.0	-1.9
10	Cr ₂ O ₃	1	600	1	895	15	+1.6	-1.7
10	Cr ₂ O ₃	10	1000	0.5	905	17	+1.6	-1.9
0.5	NiO	0.01	800	1	895	15	+2.0	-2.2

TABLE 4 (Continued)

Composition of Pastes Parts by weight			Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
					C	n	ΔC	Δn
Li ₂ O	others		Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
0.5	NiO	1	1000	1	905	17	+1.7	-2.0
0.5	NiO	10	600	1	900	16	+1.8	-2.1
2	NiO	0.01	1000	0.5	900	16	+1.9	-2.0
2	NiO	1	800	2	910	19	+1.7	-1.9
2	NiO	10	600	1	915	18	+1.8	-2.1
10	NiO	0.01	600	2	880	17	+1.7	-2.2
10	NiO	1	1000	0.5	900	16	+1.7	-1.9
10	NiO	10	800	1	900	17	+1.6	-2.0
0.5	{ CoO Ag ₂ O	{ 1 1	850	1	900	20	+1.5	-1.7
1	{ CoO Ag ₂ O	{ 5 10	850	1	905	21	+1.6	-1.8
3	{ CoO Ag ₂ O	{ 0.01 0.1	850	1	905	22	+1.5	-1.7
10	{ CoO Ag ₂ O	{ 3 3	850	1	910	21	+1.4	-1.7
1	{ CoO NiO	{ 1 1	850	1	905	20	+1.6	-1.7
1	{ CoO MnO	{ 1 1	850	1	910	19	+1.7	-1.6
1	{ CoO Cr ₂ O ₃	{ 1 1	850	1	905	20	+1.5	-1.5
1	{ MnO Ag ₂ O	{ 1 1	850	1	895	19	+1.5	-1.6
1	{ MnO Cr ₂ O ₃	{ 1 1	850	1	895	19	+1.6	-1.7

TABLE 4 (Continued)

Composition of Pastes Parts by weight		Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
				C (V)	n	ΔC (%)	Δn (%)
Li ₂ O	others	Temperature (°C)	Time (Hrs.)				
1	{ NiO 1 Cr ₂ O ₃ 1	850	1	895	18	+1.6	-1.6
1	{ MnO 1 NiO 1	850	1	895	19	+1.6	-1.6
1	{ CoO 1 MnO 1 Ag ₂ O 1	850	1	905	24	+1.5	-1.7
1	{ Ag ₂ O 1 NiO 1 Cr ₂ O ₃ 1	850	1	910	23	+1.5	-1.6
1	{ Ag ₂ O 1 CoO 1 NiO 1	850	1	915	23	+1.5	-1.3
1	{ CoO 1 MnO 1 Ag ₂ O 1 NiO 1	850	1	905	25	+1.3	-1.2
1	{ CoO 1 MnO 1 Ag ₂ O 1 Cr ₂ O ₃ 1	850	1	905	26	+1.3	-1.2

Example 5.

Using starting materials consisting of 99.0 mol percent zinc oxide, 0.5 mol percent bismuth oxide and 0.5 mol percent manganese oxide, varistors were made and tested as in Example 3 except as to the following:

Solid ingredients included in the paste: As in Table 5.

Weight of Li₂O in the applied paste: 1 10 mg/cm².

Firing temperature and time: As in Table 5.

The results of the tests made are given in Table 5.

TABLE 5

Solid Ingradient included in the Paste Percent by weight					Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
							C	n	ΔC	Δn
B ₂ O ₃	SiO ₂	Li ₂ O	Bi ₂ O ₃	PbO	Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
3.0	5.0	0.5	91.5	—	950	1	910	20	+0.6	-0.8
3.0	5.0	1	91.0	—	900	1	915	22	+0.5	-0.7
3.0	5.0	3	89.0	—	850	1	915	21	+0.5	-1.0
3.0	5.0	10	82.0	—	650	1	915	19	+0.6	-0.8
35.0	5.0	0.5	59.5	—	900	1	920	19	+0.5	-0.7
35.0	5.0	1	59.0	—	850	1	915	19	+0.4	-0.7
35.0	5.0	3	57.0	—	700	1	895	20	+0.5	-0.7
35.0	5.0	10	50.0	—	700	1	880	20	+0.5	-0.8
3.0	43.0	0.5	53.5	—	1000	1	900	19	+0.6	-0.9
3.0	43.0	1	53.0	—	900	1	905	21	+0.5	-0.7
3.0	43.0	3	51.0	—	900	1	905	20	+0.5	-0.7
3.0	43.0	10	44.0	—	700	1	905	18	+0.6	-1.0
35.0	43.0	0.5	21.5	—	1000	1	915	18	+0.5	-0.7
35.0	43.0	1	21.0	—	850	1	910	18	+0.4	-0.6
35.0	43.0	3	19.0	—	700	1	885	19	+0.5	-0.7
35.0	43.0	10	12.0	—	600	1	860	19	+0.6	-0.9
15.0	15.0	0.5	69.5	—	900	1	880	20	+0.5	-0.8
15.0	15.0	1	69.0	—	1000	1	910	20	+0.4	-0.7
15.0	15.0	2	68.0	—	850	1	905	20	+0.5	-0.7
15.0	15.0	5	65.0	—	600	1	900	21	+0.6	-0.9
15.0	15.0	10	60.0	—	700	1	920	21	+0.6	-1.0
15.0	15.0	2	68.0	—	600	1	875	20	+0.6	-0.9
15.0	15.0	2	68.0	—	700	1	890	20	+0.5	-0.7
15.0	15.0	2	68.0	—	800	1	900	20	+0.5	-0.7
15.0	15.0	2	68.0	—	900	1	910	21	+0.5	-0.8
15.0	15.0	2	68.0	—	1000	1	925	20	+0.3	-0.5

TABLE 5 (Continued)

Solid Ingredient included in the Paste Percent by weight					Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
							C	n	ΔC	Δn
B ₂ O ₃	SiO ₂	Li ₂ O	Bi ₂ O ₃	PbO	Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
15.0	15.0	2	68.0	—	850	2	905	20	+0.4	-0.9
15.0	15.0	2	68.0	—	850	5	910	20	+0.4	-0.9
3.0	5.0	0.5	—	91.5	950	1	920	19	+0.7	-0.9
3.0	5.0	1	—	91.0	900	1	925	21	+0.6	-0.7
3.0	5.0	3	—	89.0	850	1	920	20	+0.6	-1.1
3.0	5.0	10	—	82.0	650	1	925	19	+0.7	-0.9
35.0	5.0	0.5	—	59.5	900	1	930	18	+0.6	-0.8
35.0	5.0	1	—	59.0	850	1	920	18	+0.5	-0.8
35.0	5.0	3	—	57.0	700	1	905	19	+0.6	-0.8
35.0	5.0	10	—	50.0	700	1	890	19	+0.6	-0.9
3.0	43.0	0.5	—	53.5	1000	1	905	18	+0.7	-1.0
3.0	43.0	1	—	53.0	900	1	915	20	+0.6	-1.0
3.0	43.0	3	—	51.0	900	1	915	19	+0.7	-0.8
3.0	43.0	10	—	44.0	700	1	910	17	+0.7	-1.0
35.0	43.0	0.5	—	21.5	1000	1	925	17	+0.6	-0.8
35.0	43.0	1	—	21.0	850	1	920	17	+0.5	-0.7
35.0	43.0	3	—	19.0	700	1	890	18	+0.6	-0.8
35.0	43.0	10	—	12.0	600	1	880	19	+0.8	-1.0
15.0	15.0	0.5	—	69.5	900	1	895	20	+0.7	-0.9
15.0	15.0	1	—	69.0	1000	1	915	20	+0.5	-0.8
15.0	15.0	2	—	68.0	850	1	915	20	+0.6	-0.7
15.0	15.0	5	—	65.0	600	1	910	21	+0.7	-1.0
15.0	15.0	10	—	60.0	700	1	935	20	+0.7	-1.0
15.0	15.0	2	—	68.0	600	1	890	21	+0.6	-0.9
15.0	15.0	2	—	68.0	700	1	900	20	+0.6	-0.8
15.0	15.0	2	—	68.0	800	1	910	20	+0.6	-0.7

TABLE 5 (Continued)

Solid Ingradient included in the Paste Percent by weight					Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
							C	n	ΔC	Δn
B ₂ O ₃	SiO ₂	Li ₂ O	Bi ₂ O ₃	PbO	Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
15.0	15.0	2	—	68.0	900	1	920	21	+0.6	-0.8
15.0	15.0	2	—	68.0	1000	1	930	20	+0.4	-0.5
15.0	15.0	2	—	68.0	850	2	915	20	+0.4	-0.8
15.0	15.0	2	—	68.0	850	5	915	20	+0.4	-0.8

Example 6.

Using starting materials consisting of 99.0 mol percent zinc oxide, 0.5 mol percent bismuth oxide and 0.5 mol percent manganese oxide, varistors were made and tested as in Example 3 except as to the following:

Solid ingredients included in the paste:
As in Table 6.

Weight of Li₂O or K₂O in the applied paste: As in Table 6. 10

Firing temperature and time: As in Table 6.

The results of the tests are given in Table 6. 15

TABLE 6

Composition of paste. Parts by weight		Firing		Weight of Applied Li ₂ O and K ₂ O (mg/cm ²)	Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
		Temperature (°C)	Time (Hrs.)		C (V)	n	ΔC (%)	Δn (%)
Li ₂ O	K ₂ O							
1.0	1.0	1000	1	1	930	23	+0.4	-1.1
1.0	3.0	900	1	1	890	21	+0.7	-1.3
2.0	1.0	700	1	1	895	23	+0.6	-1.5
2.0	3.0	850	1	1	920	22	+0.6	-1.3
2.5	1.0	600	2	1	895	22	+0.7	-1.4
2.5	3.0	700	1	1	890	21	+0.7	-1.5
1.0	1.0	600	2	1	900	21	+0.6	-1.3
1.0	1.0	700	1	1	900	22	+0.5	-1.3
1.0	1.0	800	1	1	910	22	+0.4	-1.1
1.0	1.0	900	1	1	920	23	+0.3	-1.1
1.0	1.0	850	1	0.1	905	22	+0.3	-1.1
1.0	1.0	850	1	10	920	22	+0.3	-1.0
1.0	1.0	850	2	0.1	910	22	+0.4	-0.9

Example 7.

Using starting materials consisting of 99.0 mol percent zinc oxide, 0.5 mol percent bismuth oxide and 0.5 mol percent manganese oxide, varistors were made and tested as in Example 3, except as to the following:

Solid ingredients included in the paste: As in Table 7.

Weight of Li₂O in the applied paste: 1 10
mg/cm²

Firing temperature and time: As in Table 7.

The results of the tests made are given in Table 7.

15

TABLE 7

Solid Ingradient included in the paste (Percent by weight)			Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
					C	n	ΔC	Δn
BaO	B ₂ O ₃	Li ₂ O	Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
59.2	40.0	0.8	900	1	920	22	+0.7	-0.9
58.0	40.0	2	800	1	910	20	+0.8	-0.8
55.0	40.0	5	700	2	900	20	+0.7	-1.0
50.0	40.0	10	600	2	920	19	+0.9	-0.8
79.2	20.0	0.8	1000	1	890	20	+0.6	-0.9
78.0	20.0	2	950	1	910	20	+0.7	-0.8
75.0	20.0	5	900	1	895	20	+0.7	-0.7
70.0	20.0	10	800	2	890	19	+0.7	-0.8
80.0	10.0	10	700	2	925	18	+0.8	-0.7
60.0	30.0	10	850	1	915	22	+0.6	-0.6

WHAT WE CLAIM IS:—

1. A method of making an electrical resistor which includes the step of diffusing into a surface of a sintered body including zinc oxide exhibiting inherent non-linear resistance properties, lithium or sodium ions or both. 35
2. A method of making an electrical resistor which includes the steps of providing a sintered body including zinc oxide having inherent non-linear resistance properties, providing electrodes on spaced surfaces of said body, and diffusing lithium ions or sodium ions into a further surface of said body. 40
3. A method according to claim 2, wherein said spaced surfaces are generally parallel and said further surface is a surface extending substantially between said spaced surfaces. 45
4. A method according to claim 3, wherein said spaced surfaces are flat and parallel, and said further surface is a surface of the body substantially completely peripheral of the body between the spaced surfaces. 50
5. A method according to any of the preceding claims, wherein said body is a rod or disc, and the electrodes are provided on the end of the rod or on major surfaces of the disc. 55
6. A method according to any of claims 1 to 4, wherein said body is platelike and said electrodes are provided on the major parallel surfaces of the body. 60
7. A method according to any of the preceding claims in which said body comprises, as a major part, 99.9 to 80.0 mol percent zinc oxide, and, as additives, 0.05 to 10.0 mol percent bismuth oxide (Bi₂O₃) and a total of 0.05 to 10.0 mol percent of at least one member selected from the group consisting of cobalt oxide (CoO), manganese oxide (MnO), antimony oxide (Sb₂O₃), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO). 65
8. A method according to any of the preceding claims, wherein said ions are diffused into said sintered body to a depth of more than 0.01 mm.
9. A method according to any of the preceding claims, in which said ions are diffused by applying to said body a paste and firing said paste.
10. A method according to claim 9, wherein said paste includes as solid ingredients, 0.5 to 10.0 parts of lithium oxide (Li₂O) and at least one member selected from the group consisting of 0.01 to 10.0 parts of cobalt oxide (CoO), 0.01 to 10.0 parts of manganese oxide (MnO), 0.01 to 10.0 parts of silver oxide (Ag₂O), 0.01 to 10.0 parts of chromium oxide (Cr₂O₃) and 0.01 to 10.0 parts of nickel oxide (NiO), all in parts by weight.
11. A method according to claim 9, in which said paste comprises, as solid ingredients in percentages by weight, 0.5 to 10.0% 65



TABLE 7

Solid Ingradient included in the paste (Percent by weight)			Firing		Electrical Characteristics of Resultant Resistor		Change Rates after Life Test	
					C	n	ΔC	Δn
BaO	B ₂ O ₃	Li ₂ O	Temperature (°C)	Time (Hrs.)	(V)		(%)	(%)
59.2	40.0	0.8	900	1	920	22	+0.7	-0.9
58.0	40.0	2	800	1	910	20	+0.8	-0.8
55.0	40.0	5	700	2	900	20	+0.7	-1.0
50.0	40.0	10	600	2	920	19	+0.9	-0.8
79.2	20.0	0.8	1000	1	890	20	+0.6	-0.9
78.0	20.0	2	950	1	910	20	+0.7	-0.8
75.0	20.0	5	900	1	895	20	+0.7	-0.7
70.0	20.0	10	800	2	890	19	+0.7	-0.8
80.0	10.0	10	700	2	925	18	+0.8	-0.7
60.0	30.0	10	850	1	915	22	+0.6	-0.6

WHAT WE CLAIM IS:—

1. A method of making an electrical resistor which includes the step of diffusing into a surface of a sintered body including zinc oxide exhibiting inherent non-linear resistance properties, lithium or sodium ions or both.
2. A method of making an electrical resistor which includes the steps of providing a sintered body including zinc oxide having inherent non-linear resistance properties, providing electrodes on spaced surfaces of said body, and diffusing lithium ions or sodium ions into a further surface of said body.
3. A method according to claim 2, wherein said spaced surfaces are generally parallel and said further surface is a surface extending substantially between said spaced surfaces.
4. A method according to claim 3, wherein said spaced surfaces are flat and parallel, and said further surface is a surface of the body substantially completely peripheral of the body between the spaced surfaces.
5. A method according to any of the preceding claims, wherein said body is a rod or disc, and the electrodes are provided on the end of the rod or on major surfaces of the disc.
6. A method according to any of claims 1 to 4, wherein said body is platelike and said electrodes are provided on the major parallel surfaces of the body.
7. A method according to any of the preceding claims in which said body comprises, as a major part, 99.9 to 80.0 mol percent zinc oxide, and, as additives, 0.05 to 10.0 mol percent bismuth oxide (Bi₂O₃) and a total of 0.05 to 10.0 mol percent of at least one member selected from the group consisting of cobalt oxide (CoO), manganese oxide (MnO), antimony oxide (Sb₂O₃), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).
8. A method according to any of the preceding claims, wherein said ions are diffused into said sintered body to a depth of more than 0.01 mm.
9. A method according to any of the preceding claims, in which said ions are diffused by applying to said body a paste and firing said paste.
10. A method according to claim 9, wherein said paste includes as solid ingredients, 0.5 to 10.0 parts of lithium oxide (Li₂O) and at least one member selected from the group consisting of 0.01 to 10.0 parts of cobalt oxide (CoO), 0.01 to 10.0 parts of manganese oxide (MnO), 0.01 to 10.0 parts of silver oxide (Ag₂O), 0.01 to 10.0 parts of chromium oxide (Cr₂O₃) and 0.01 to 10.0 parts of nickel oxide (NiO), all in parts by weight.
11. A method according to claim 9, in which said paste comprises, as solid ingredients in percentages by weight, 0.5 to 10.0% 65



- lithium oxide (Li_2O), 3.0 to 35.0% boron trioxide (B_2O_3), 5.0 to 43.0% silicon dioxide (SiO_2) and 12.0 to 91.5% bismuth oxide (Bi_2O_3) or lead oxide (PbO).
- 5 12. A method according to claim 9, in which said paste comprises, as solid ingredients in percentages by weight, 0.8 to 10.0% lithium oxide (Li_2O), 50.0 to 80.0% barium oxide (BaO) and 10.0 to 40.0% boron trioxide (B_2O_3).
- 10 13. A method according to claim 9, in which said paste comprises, as solid ingredients, 1.0 to 2.5 parts by weight of Li_2O and 1.0 to 3.0 parts by weight of K_2O .
- 15 14. A method according to claim 2 or any of the claims 3 to 13 when appendant to claim 2, wherein said electrodes are provided by vacuum deposition.
- 20 15. A method according to claim 2 or any of the claims 3 to 13 when appendant to claim 2, wherein said electrodes are provided by firing a coating of conductive paint.
- 25 16. A method according to claim 2 or any of the claims 3 to 13 when appendant to claim 2, wherein said electrodes are provided by metal spraying.
- 30 17. A method according to claim 2 or any of the claims 3 to 13 when appendant to claim 2, including attaching electric terminal means to said electrodes.
- 35 18. A method according to claim 17, and including attaching lead wires to said electrodes by solder or conductive adhesive.
- 40 19. A method of making an electrical resistor in accordance with any of the Examples herein given.
- 45 20. A method of making an electrical resistor substantially as herein described.
21. A sintered body including zinc oxide having an inherent non-linear resistance characteristic, and ions of lithium or sodium or both diffused into a surface thereof to a depth of at least 0.01 mm.
22. A sintered body including zinc oxide having an inherent non-linear resistance characteristic, electrodes upon two spaced surfaces of said body, and ions of lithium or sodium or both diffused into a further surface of said body.
23. A body according to claim 22, wherein said spaced surfaces are generally parallel and said further surface is a surface extending substantially between said spaced surfaces.
24. A body according to claim 23, wherein said spaced surfaces are flat and parallel, and said further surface is a surface of the body substantially completely peripheral of the body between the spaced surfaces.
25. A body according to any of claims 22 to 24, wherein said body is a rod or disc, and the electrodes are provided on the end surfaces of the rod or on major surfaces of the disc.
26. A body according to any of claims 22 to 24, wherein said body is platelike and said electrodes are provided on the major parallel surfaces of the body.
27. A body according to any of claims 21 to 26, in which said body comprises, as a major part, 99.9 to 80.0 mol percent of zinc oxide, and, as additives, 0.05 to 10.0 mol percent bismuth oxide (Bi_2O_3) and a total of 0.05 to 10.0 mol percent of at least one member selected from the group consisting of cobalt oxide (CoO), manganese oxide (MnO), antimony oxide (Sb_2O_3), barium oxide (BaO), strontium oxide (SrO) and lead oxide (PbO).
28. A body according to any of the claims 21 to 27, wherein said ions are diffused into said sintered body to a depth of more than 0.01 mm.
29. A body of material in accordance with claim 21 or 22 as described with reference to any of the Examples herein.
30. A body of material in accordance with claim 22 or any of the claims appendant thereto with electric terminal means attached to said electrodes.
31. A varistor substantially as described.

A. A. THORNTON & CO.,
Chartered Patent Agents,
Northumberland House,
303/306 High Holborn, London, W.C.1.