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[54] **VOLTAGE-NONLINEAR RESISTORS**

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[51] **Int. Cl.** **H01c 7/10**

[58] **Field of Search** 338/13, 20, 21; 252/518

[56] **References Cited**

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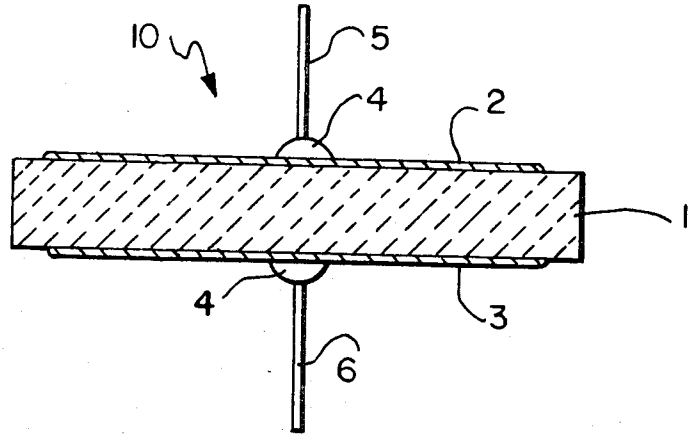
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[57] **ABSTRACT**

A voltage-nonlinear resistor has a sintered body of a composition comprising as a main constituent, zinc oxide (ZnO) and, as an additive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3) and 0.1 to 3.0 mole percent of chromium fluoride (CrF_3). Electrodes are applied to opposite surfaces of the sintered body.

6 Claims, 3 Drawing Figures



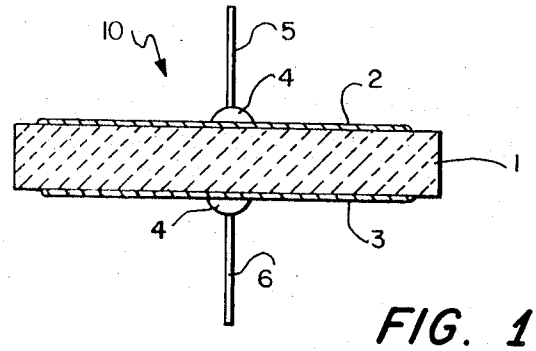


FIG. 1

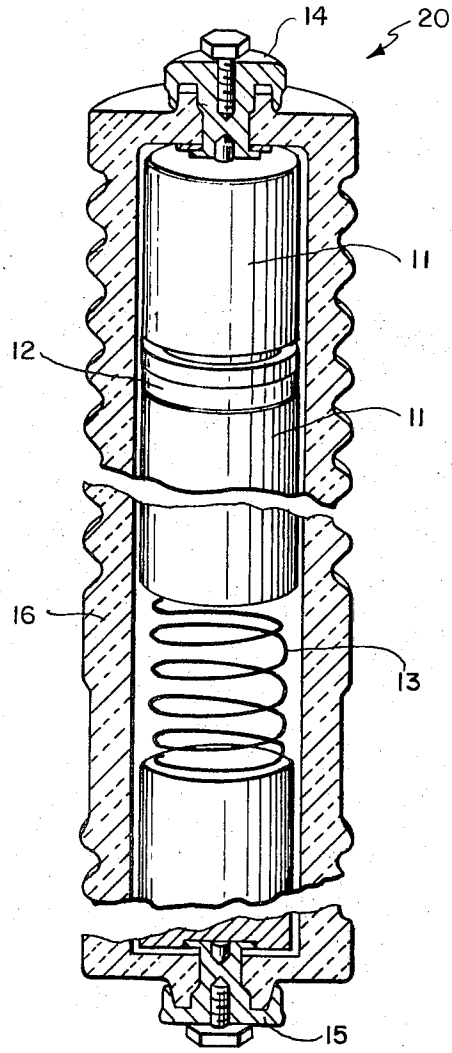


FIG. 2

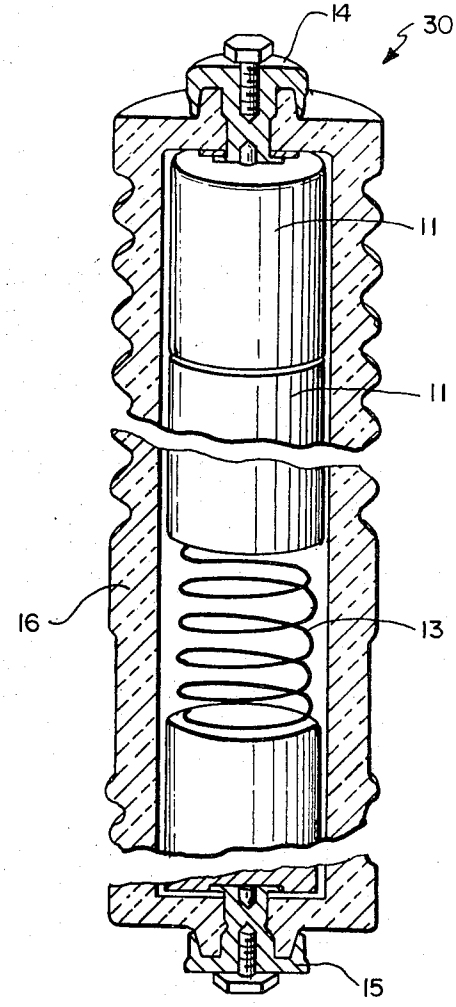


FIG. 3

VOLTAGE-NONLINEAR RESISTORS

The invention relates to voltage-nonlinear resistors having nonohmic resistance due to the bulk thereof and more particularly to varistors, which are available for characteristic elements of lightning arresters, comprising zinc oxide, bismuth oxide, antimony oxide and chromium fluoride.

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

$$I = (V/C)^n \tag{1}$$

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 exponent n is a numerical value greater than 1. The value of n is calculated by the following equation:

$$n = [\log_{10} (I_2/I_1)]/[\log_{10} (V_2/V_1)] \tag{2}$$

where V_1 and V_2 are the voltages at given currents I_1 and I_2, respectively. The desired value of C depends upon the kind of application to which the resistor is to be put. It is ordinarily desirable that the value of n be as large as possible since this exponent determines the extent to which the resistors depart from ohmic characteristics. Conveniently, n-value defined by I_1, I_2, V_1 and V_2 as shown in equation (2) is expressed by ${}_1n_2$ for distinguishing from the n-value calculated by other currents or voltages.

Nonlinear resistors comprising sintered bodies of zinc oxide with or without additives and non-ohmic electrode applied thereto, have already been disclosed as seen in U. S. Pat. Nos. 3,496,512, 3,570,002 and 3,503,029. The nonlinearity of such varistors is attributed to the interface between the sintered body of zinc oxide with or without additives and the silver paint electrode and is controlled mainly by changing the compositions of said sintered body and silver paint electrode. Therefore, it is not easy to control the C-value over a wide range after the sintered body is prepared. Similarly, in varistors comprising germanium or silicon p-n junction diodes, it is difficult to control the C-value over a wide range because the nonlinearity of these varistors is not attributed to the bulk but to the p-n junction. In addition, it is almost impossible for the varistors and germanium or silicon diode varistors to obtain the combination of C-value higher than 100 volt, n-value higher than 10 and high surge resistance tolerable for surge more than 100Ap.

On the other hand, the silicon carbide varistors have nonlinearity due to the contacts among the individual grains of silicon carbide bonded together by a ceramic binding material, i.e. to the bulk, and the C-value is controlled by changing a dimension in the direction in which the current flows through the varistors. In addition, the silicon carbide varistors have high surge resistance which is available as characteristic elements of lightning arresters. The characteristic elements are

used usually by connecting in series with discharging gaps and determine the level of the discharging voltage and the follow current. The silicon carbide varistors, however, have a relatively low n-value ranging from 3 to 7 which results in poor suppression of lightning surge or increase in the follow current. Another defect of the arrester including the discharging gaps as its components is not to respond instantaneously surge voltage having very short rise time such as below 1μs. It is desirable for the arrester to suppress the lightning surge and the follow current to the level as low as possible and respond surge voltage instantaneously.

There have been known, on the other hand, voltage-nonlinear resistors of bulk type comprising a sintered body of zinc oxide with additives comprising bismuth oxide and antimony oxide and/or chromium oxide, as seen in U. S. Pat. No. 3,663,458. These zinc oxide varistors of bulk type are controllable in a C-value by changing the distance between electrodes and have an excellent nonlinear property in an n-value more than 10 in a region of current below than 10A/cm^2. For a current more than 10A/cm^2, however, the n-value goes down to a value below than 10. The power dissipation for surge energy shows a relatively low value compared with that of the conventional silicon carbide arrester, so that the change rate of C-value exceeds 20 percent after two standard lightning surges of 4×10μs wave form in a peak current of 1,500A/cm^2 are applied to said zinc oxide varistor of bulk type. There is known another zinc oxide varistor of bulk type which contains as an additive chromium fluoride as seen in U. S. Pat. No. 3,642,664. This varistor shows an excellent nonlinear property, but an essentially weak point as an arrester element is its weakness for surge pulse. The nonlinear property of the varistor deteriorates easily even for 100Ap/cm^2 of surge pulse.

An object of the present invention is to provide a voltage-nonlinear resistor having nonlinearity due to the bulk thereof and being characterized by a high n-value even in a range of current more than 10A/cm^2.

Another object of the present invention is to provide a voltage-nonlinear resistor having high power dissipation for surge energy.

Another object of the present invention is to provide an arrester characterized by high suppression for lightning surge and low follow current.

These and other objects of the invention will become apparent upon consideration of the following description taken together with the accompanying drawing in which

FIG. 1 is a partly cross-sectional view through a voltage-nonlinear resistor in accordance with the invention and

FIG. 2 and FIG. 3 partly cross-sectional views through an arrester in accordance with the invention.

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

A voltage-nonlinear resistor according to the invention comprises a sintered body of a composition comprising, as an additive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimocy oxide (Sb_2O_3) and 0.1 to 3.0 mole percent of chromium fluoride (CrF_3), and the remainder of zinc oxide (ZnO) as a main constituent, and electrodes applied to opposite surfaces of said sintered body. Such a voltage-nonlinear resistor has non-ohmic resistance due to the bulk itself. Therefore, its C-value can be changed without impairing the *n*-value by changing the distance between said opposite surfaces. According to the invention, said resistor has high *n*-value in a region of current more than 10A/cm² and high stability for surge pulses.

The higher *n*-value in a region of current more than 10A/cm² can be obtained when said sintered body further includes one member selected from the group consisting of 0.1 to 3.0 mole percent of cobalt oxide (CoO) and 0.1 to 3.0 mole percent of manganese oxide (MnO).

According to the present invention, the higher *n*-value in a region of current more than 10A/cm² and the higher stability for surge pulses can be obtained when said sintered body comprises, as a main constituent, zinc oxide (ZnO) and, as an additive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3), 0.1 to 3.0 mole percent of chromium fluoride (CrF_3), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO) and one member selected from the group consisting of 0.05 to 3.0 mole percent of chromium oxide (Cr_2O_3), 0.1 to 3.0 mole percent of tin oxide (SnO_2) and 0.1 to 10.0 mole percent of silicon dioxide (SiO_2).

According to the present invention, the resistor is remarkably improved in the *n*-value in a regin of current more than 10A/cm² and the stability for surge pulse when said sintered body consists essentially of 99.4 to 72 mole percent of zinc oxide (ZnO) and, as an additive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3), 0.1 to 3.0 mole percent of chromium fluoride (CrF_3), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO), 0.05 to 3.0 mole percent of chromium oxide (Cr_2O_3) and 0.1 to 10.0 mole percent of silicon dioxide (SiO_2).

According to the present invention, when at least one voltage-nonlinear resistor consisting essentially of a sintered body of a composition comprising as a main constituent, zinc oxide and, as an addivtive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3) and 0.1 to 3.0 mole percent of chromium fluoride (CrF_3) and electrodes applied to opposite surfaces of said sintered body is applied to an arrester as a characteristic element, the resultant arrester is lowered in the follow current and improved in the suppression and power dissipation for lightning surge.

According to the present invention, when at least one voltage-nonlinear resistor consisting essentially of a sintered body of 99.4 to 72.0 mole percent of zinc oxide (ZnO), 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3), 0.1 to 3.0 mole percent of chromium fluoride (CrF_3), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO), 0.05 to 3.0 mole percent of chromium oxide (Cr_2O_3) and 0.1 to 10.0 mole percent of silicon dioxide (SiO_2) and electrodes applied to opposite surfaces of said sintered body is applied as a characteristic element to an arrester, the resultant arrester is further lowered in the follow current and is further improved in the suppression and power dissipation for lightning surge.

The sintered body **1** can be prepared by a per se well known ceramic technique. The starting materials in the compositions in the foregoing description are mixed in a wet mill so as to produce homogeneous mixtures. The mixtures are dried and pressed in a mold into desired shapes at a pressure from 50 Kg./cm² to 500 Kg./cm². The pressed bodies are sintered in air at 1,000° to 1,450°C for 1 to 10 hours, and then furnace-cooled to room temperature (about 15°C to about 30°C). The mixtures can be preliminarily calcined at 700° to 1,000°C and pulverized for easy fabrication in the subsequent pressing step. The mixture to be pressed can be admixed with a suitable binder such as water, polyvinyl alcohol, etc. It is advantageous that the sintered body be lapped at the opposite surfaces by abrasive powder such as silicon carbide in a particle size of 50μ in mean diameter to 10μ in mean diameter. The sintered bodies are provided, at the opposite surfaces thereof with electrodes in any available and suitable method such as silver painting, vacuum evaporation or flame spraying of metal such as A1, Zn, Sn etc.

The voltage-nonlinear properties are not practically affected by the kinds of electrodes used, but are affected by the thickness of the sintered bodies. Particularly, the C-value varies in proportion to the thickness of the sintered bodies, while the *n*-value is almost independent of the thickness. This surely means that the voltage-nonlinear property is due to the bulk itself, but not to the electrodes.

Lead wires can be attached to the electrodes in a per se conventional manner by using conventional solder. It is convenient to employ a conductive adhesive comprising silver powder and resin in an organic solvent in order to connect the lead wires to the electrodes. Voltage-nonlinear resistors according to this invention have a high stability to temperature and for the surge test, which is carried out by applying lightning surge determined by the JEC (Japanese Electrotechnical Committee)—156 Standard. The *n*-value and C-value do not change remarkably after heating cycles and surge test. It is advantageous for achievement of a high stability to humidity and high surge that the resultant voltage-nonlinear resistors are embedded in a humidity proof resin such as epoxy resin and phenol resin in a per se well known manner.

When voltage-nonlinear resistors according to this invention are used as characteristic element, the resultant arrester is improved remarkably in the follow current and the suppression property for lightning surge. FIG. **2** is the cross-sectional view of an arrester wherein reference character **20** designates, as a whole, an arrester comprising, one or more voltage-nonlinear resistors according to this invention **11** as a characteristic element are connected in series with one or more discharging gaps **12,** spring **13** and line terminals **14** and **15.** Said arrester elements are enveloped into wet-process porcelain **16.** Said arrester is kept to the level below than 1μA in the follow current and to the level higher than 2,000A/cm² in the surge dissipation. FIG. **3** is the cross-sectional view of another arrester wherein

reference character **30** designates, as a whole, an arrester comprising at least one voltage-nonlinear resistor according to this invention. In the embodiment shown FIG. **3**, reference characters identical to those of FIG. **2** have been employed to designate like elements. The arrester of FIG. **3** is characterized, in its construction, to be without discharging gap and, in its electrical property, to have response time shorter than 0.1 μs for high surge having very sharp rise in addition to its excellent properties in follow current and surge dissipation. Presently preferred illustrative embodiments of the invention are as follows.

Example 1

Starting material composed of 98.0 mole percent of zinc oxide, 0.5 mole percent of bismuth oxide, 1.0 mole percent of antimony oxide, and 0.5 mole percent of chromium fluoride is mixed in a wet mill for 24 hours. The mixture is dried and pressed in a mold into discs of 40mm in diameter and 25mm in thickness at a pressure of 250Kg/cm^2.

The pressed bodies are sintered in air at the condition shown in Table 1, and then furnace-cooled to room temperature. The sintered body is lapped at the opposite surfaces thereof into the thickness shown in Table 1 by silicon carbide abrasive in particle size of 30μ in mean diameter. The opposite surfaces of the sintered body are provided with a spray metallized film of aluminum in a per se well known technique.

The electric characteristics of resultant sintered body are shown in Table 1, which shows the C-value varies approximately in proportion to the thickness of the sintered body while the *n*-value is essentially independent of the thickness. It will be readily realized that the voltage-nonlinear property of the sintered body is attributed to the sintered body itself.

TABLE 1

Thickness (mm)	C (at 1mA)	n 0.1–1mA	Sintering Condition
initial (20)	1800	13	1200°C, 5Hrs
15	1345	13	1200°C, 5Hrs
10	900	13	1200°C, 5Hrs
5	455	13	1200°C, 5Hrs
initial (20)	1700	12	1350°C, 1Hr
15	1250	13	1350°C, 1Hr
10	840	12	1350°C, 1Hr
5	430	12	1350°C, 1Hr
initial (20)	3500	14	1000°C, 10Hrs
15	2670	14	1000°C, 10 Hrs
10	1750	15	1000°C, 10Hrs
5	880	14	1000°C, 10Hrs

EXAMPLE 2

Zinc oxide incorporated with bismuth oxide, antimony oxide, and chromium fluoride in a composition of Table **2** is fabricated into the voltage-nonlinear resistors by the same process as that of Example 1. The thickness is 20mm. The resulting electrical properties are shown in Table 2, in which the values of n_1 and n_2 are the n-values defined between 0.1mA and 1mA, and between 100 and 1,000A, respectively. The impulse test is carried out by applying two impulses of 4×10μs, 10,000A. It can be easily understood that the combined addition of bismuth oxide, antimony oxide, and chromium fluoride as additives show the high *n*-value and small change rates.

TABLE 2

Additives (mol. percent)			Electrical properties of resultant resistor			Change rates after test (percent)		
			C	n_1	n_2			
Bi_2O_3	Sb_2O_3	CrF_3	(at 1 ma.)	0.1–1 ma.	100–1,000 a.	ΔC	Δn_1	Δn_2
0.1	0.05	0.1	1,380	11	10	−18	−16	−8.0
0.1	0.05	3.0	1,050	11	10	−18	−17	−7.9
0.1	3.0	0.1	1,880	11	10	−16	−16	−7.4
0.1	3.0	3.0	1,720	12	10	−17	−16	−8.1
3.0	0.05	0.1	2,200	11	11	−15	−14	−5.1
3.0	0.05	3.0	1,950	12	11	−17	−14	−7.5
3.0	3.0	0.1	2,390	12	10	−14	−13	−4.4
3.0	3.0	3.0	2,170	11	11	−16	−14	−4.8
0.5	1.0	0.5	1,800	13	12	−13	−12	−3.9

EXAMPLE 3

Zinc oxide and additives of Table 3 is fabricated into the voltage-nonlinear resistors by the same process as that of Example 1. The electrical properties of the resulting resistors are shown in Table 3. The change rates of C and *n* values after impulse test carried out by same method as that of Example 2 are also shown in Table 3. It will be readily realized that the further addition of cobalt oxide or manganese oxide results in the higher *n*-value and smaller change rates than those of Example 2.

TABLE 3

Additives (mol. percent)					Electrical properties of resultant resistor			Change rates after test (percent)		
					C	n_1	n_2			
Bi_2O_3	Sb_2O_3	CrF_3	CoO	MnO	(at 1 ma.)	0.1–1 ma.	100–1,000 a.	ΔC	Δn_1	Δn_2
0.1	0.05	0.1	0.1	--------	900	16	12	−14	−14	−8.0
0.1	0.05	0.1	3.0	--------	1,040	17	12	−14	−12	−5.9
0.1	0.05	3.0	0.1	--------	870	17	13	−12	−11	−6.1
0.1	3.0	0.1	0.1	--------	1,290	18	12	−13	−13	−6.4
3.0	0.05	0.1	0.1	--------	1,100	17	13	−13	−14	−7.2
0.1	0.05	3.0	3.0	--------	1,080	19	14	−11	−12	−5.8
0.1	3.0	0.1	3.0	--------	1,320	20	12	−13	−12	−6.4
3.0	0.05	0.1	3.0	--------	1,280	20	11	−14	−12	−7.1
0.1	3.0	3.0	0.1	--------	1,200	20	13	−13	−11	−6.4
3.0	0.05	3.0	0.1	--------	1,150	18	12	−13	−13	−5.8
3.0	3.0	0.1	0.1	--------	1,500	18	13	−12	−13	−6.1
0.1	3.0	3.0	3.0	--------	1,480	20	11	−14	−9.9	−5.0

TABLE 3

Additives (mol. percent)					Electrical properties of resultant resistor			Change rates after test (percent)		
						n_1	n_2			
Bi_2O_3	Sb_2O_3	CrF_3	CoO	MnO	C (at 1 ma.)	0.1–1 ma.	100–1,000 a.	ΔC	Δn_1	Δn_2
3.0	0.05	3.0	3.0	-------	1,408	19	11	−11	−10	−7.4
3.0	3.0	0.1	3.0	-------	1,790	19	12	−11	−10	−4.8
3.0	3.0	3.0	0.1	-------	1,590	19	14	−13	−12	−5.9
3.0	3.0	3.0	3.0	-------	1,750	18	12	−12	−10	−6.2
0.5	1.0	0.5	0.5	-------	1,600	22	15	−10	−8.5	−3.1
0.1	0.05	0.1	-------	0.1	1,100	21	14	−14	−13	−7.5
0.1	0.05	0.1	-------	3.0	1,160	20	13	−14	−13	−6.1
0.1	0.05	3.0	-------	0.1	950	21	12	−13	−13	−6.1
0.1	3.0	0.1	-------	0.1	1,410	21	14	−13	−12	−7.2
3.0	0.05	0.1	-------	0.1	1,150	22	15	−12	−11	−5.9
0.1	0.05	3.0	-------	3.0	1,170	20	14	−11	−12	−6.3
0.1	3.0	0.1	-------	3.0	1,400	19	13	−12	−11	−7.0
3.0	0.05	0.1	-------	3.0	1,400	19	14	−13	−11	−5.9
0.1	3.0	3.0	-------	0.1	1,390	18	14	−12	−11	−5.7
3.0	0.05	3.0	-------	0.1	1,310	21	15	−13	−12	−4.8
3.0	3.0	0.1	-------	0.1	1,750	19	14	−13	−13	−6.3
0.1	3.0	3.0	-------	3.0	1,600	19	13	−11	−12	−6.7
3.0	0.05	3.0	-------	3.0	1,600	20	12	−11	−11	−5.7
3.0	3.0	0.1	-------	3.0	2,000	20	15	−12	−14	−4.9
3.0	3.0	3.0	-------	0.1	1,750	21	14	−13	−13	−5.3
3.0	3.0	3.0	-------	3.0	1,950	22	13	−11	−12	−4.7
0.5	1.0	0.5	-------	0.5	1,700	24	17	−10	−8.0	−2.9

EXAMPLE 4

Zinc oxide and additives of Table 4 is fabricated into the voltage-nonlinear resistors by the same process as Example 1. The electrical characteristics of resulting resistors are shown in Table 4. It will be easily understood that the further addition of tin oxide, chromium oxide, silicon dioxide or chromium oxide and silicon dioxide results in the higher *n*-value and smaller change rates than those of Example 3. The change rates of C and *n* values after impulse test carried out by same method as that of Example 2 are also shown in Table 4.

EXAMPLE 5

The resistors of Example 2, 3 and 4 are tested in accordance with a method widely used in the electronic components parts. The heating cycle test is carried out by repeating 5 times the cycle in which said resistors are kept at 85°C ambient temperature for 30 minutes, cooled rapidly to −20°C and then kept at such temperature for 30 minutes. The humidity test is carried out at 40°C and 95 percent relative humidity for 1,000 hrs. Table 5 shows the average change rates of C-value and *n*-value of resistors after heating cycle test and humidity test. It is easily understood that each sample has a small change rate.

TABLE 4

Additives (mol. percent)								Electrical properties of resultant resistor			Change rates after test (percent)		
									n_1	n_2			
Bi_2O_3	Sb_2O_3	CrF_3	CoO	MnO	SnO_2	Cr_2O_3	SiO_2	C (at 1 ma.)	0.1–1 ma.	100–1,000 a.	ΔC	Δn_1	Δn_2
0.1	0.05	0.1	0.1	0.1	0.1	----------		1,800	32	20	−10	−10	−5.7
0.1	0.05	0.1	0.1	0.1	0.5	----------		2,000	39	18	−9.4	−9.4	−3.9
0.1	0.05	0.1	0.1	0.1	3.0	----------		2,150	34	19	−11	−8.4	−4.2
0.5	1.0	0.5	0.5	0.5	0.1	----------		2,260	38	21	−9.7	−6.4	−3.8
0.5	1.0	0.5	0.5	0.5	0.5	----------		2,500	42	23	−8.0	−5.9	−2.5
0.5	1.0	0.5	0.5	0.5	3.0	----------		2,650	37	20	−10	−10	−4.1
3.0	3.0	3.0	3.0	3.0	0.1	----------		3,000	36	20	−10	−7.9	−3.8
3.0	3.0	3.0	3.0	3.0	0.5	----------		3,200	38	19	−11	−8.3	−5.4
3.0	3.0	3.0	3.0	3.0	3.0	----------		3,600	35	17	−11	−10	−6.2
0.1	0.05	0.1	0.1	0.1	----------	0.05	----------	2,200	35	20	−12	−9.4	−6.1
0.1	0.05	0.1	0.1	0.1	----------	0.5	----------	2,310	29	17	−10	−8.0	−4.0
0.1	0.05	0.1	0.1	0.1	----------	3.0	----------	2,500	40	20	−11	−9.1	−4.5
0.5	1.0	0.5	0.5	0.5	----------	0.05	----------	2,600	39	20	−9.3	−7.5	−5.2
0.5	1.0	0.5	0.5	0.5	----------	0.5	----------	3,000	45	25	−7.1	−6.0	−2.5
0.5	1.0	0.5	0.5	0.5	----------	3.0	----------	3,050	42	19	−9.5	−8.1	−5.3
3.0	3.0	3.0	3.0	3.0	----------	0.05	----------	3,700	40	20	−10	−9.4	−6.0
3.0	3.0	3.0	3.0	3.0	----------	0.5	----------	3,900	37	21	−10	−10	−6.4
3.0	3.0	3.0	3.0	3.0	----------	3.0	----------	4,200	36	20	−10	−9.5	−7.0
0.1	0.05	0.1	0.1	0.1	----------		0.1	2,300	36	20	−10	−10	−5.0
0.1	0.05	0.1	0.1	0.1	----------		0.5	2,500	37	21	−9.7	−9.5	−6.1
0.1	0.05	0.1	0.1	0.1	----------		10.0	5,850	40	20	−9.7	−8.4	−4.8
0.5	1.0	0.5	0.5	0.5	----------		0.1	2,770	39	19	−10	−7.2	−3.8
0.5	1.0	0.5	0.5	0.5	----------		0.5	3,200	34	20	−8.1	−5.1	−2.4
0.5	1.0	0.5	0.5	0.5	----------		10.0	5,500	40	21	−9.5	−9.0	−5.7
3.0	3.0	3.0	3.0	3.0	----------		0.1	3,600	40	20	−8.7	−9.3	−6.1
3.0	3.0	3.0	3.0	3.0	----------		0.5	4,200	39	20	−8.1	−7.2	−2.0
3.0	3.0	3.0	3.0	3.0	----------		10.5	8,700	42	21	−9.4	−9.1	−5.7
0.1	0.05	0.1	0.1	0.1	----------	0.05	0.1	2,800	40	20	−9.4	−7.9	−5.0
0.1	0.05	0.1	0.1	0.1	----------	0.05	0.5	3,110	47	21	−7.0	−7.2	−5.1
0.1	0.05	0.1	0.1	0.1	----------	0.05	10.0	4,800	41	24	−8.4	−5.9	−6.1
0.5	1.0	0.5	0.5	0.5	----------	0.5	0.1	3,210	43	23	−7.2	−6.9	−7.2
0.5	1.0	0.5	0.5	0.5	----------	0.5	0.5	4,200	50	25	−6.0	−4.8	−2.0
0.5	1.0	0.5	0.5	0.5	----------	0.5	10.0	5,300	43	22	−7.4	−5.3	−4.4
3.0	3.0	3.0	3.0	3.0	----------	3.0	0.1	4,500	43	22	−8.1	−7.5	−4.4
3.0	3.0	3.0	3.0	3.0	----------	3.0	0.5	5,120	41	20	−7.5	−6.1	−5.1
3.0	3.0	3.0	3.0	3.0	----------	3.0	10.0	9,000	39	21	−8.9	−6.1	−5.2

TABLE 5

Sample No.	Heating cycle test (percent)			Humidity test (percent)		
	ΔC	Δn_1	Δn_2	ΔC	Δn_1	Δn_2
Example 2	−4.8	−6.4	−5.0	−5.1	−6.9	−6.1
Example 3	−2.9	−5.9	−3.7	−3.6	−5.5	−3.9
Example 4	−1.9	−3.8	−1.3	−1.2	−3.8	−1.1

EXAMPLE 6

The voltage-nonlinear resistors according to Example 2, 3 and 4 are constructed to the arrester as shown in FIG. 2 by series connection of three pieces of resistor and one discharging gap. The C-value of said total pieces of voltage-nonlinear resistor is about 7,000V. The impulse test are carried out by applying two impulses of 4×10μs, 1,500A/cm² superposed on AC 3,000V. The follow current of the arrester shows the value lower than 1μA as shown in Table 6 and the change rates of electrical properties after test show same results as the impulse test of Example 2, 3 and 4.

TABLE 6

Sample No.	Follow-current
Example 2	below than 1μA
Example 3	below than 0.5μA
Example 4	below than 0.1μA

EXAMPLE 7

The voltage-nonlinear resistors according to Example 2, 3 and 4 are constructed to the arrester as shown in FIG. 3 by series connection of three pieces of resistor. The value of C of said total pieces of voltage-nonlinear resistor is about 7,000V. The impulse test are carried out by the same method as that of Example 6. The follow current shows the value lower than 1μA as shown in Table 6 and the change rates of electrical properties after test show same results as that of the impulse test in Example 2, 3 and 4. Another impulse test are carried out by applying impulse having the value of 0.01μs in rise time. The rise time of current flowing through said arrester is lower than 0.05μs.

What is claimed is:

1. A voltage-nonlinear resistor consisting essentially of a sintered body of a composition comprising as a main constituent, zinc oxide (ZnO) and, as an additive, 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3) and 0.1 to 3.0 mole percent of chromium fluoride (CrF_3) and electrodes applied to opposite surfaces of said sintered body.

2. A voltage-nonlinear resistor defined by claim **1**, wherein said sintered body further includes one member selected from the group consisting of 0.1 to 3.0 mole percent of cobalt oxide (CoO) and 0.1 to 3.0 mole percent of manganese oxide (MnO).

3. A voltage-nonlinear resistor defined by claim **1**, wherein said sintered body further includes 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO) and one member selected from the group consisting of 0.05 to 3.0 mole percent of chromium oxide (Cr_2O_3), 0.1 to 3.0 mole percent of tin oxide (SnO_2) and 0.1 to 10.0 mole percent of silicon dioxide (SiO_2).

4. A voltage-nonlinear resistor defined by claim **1**, wherein said sintered body consisting essentially of 99.4 to 72.0 mole percent of zinc oxide (ZnO) 0.1 to 3.0 mole percent of bismuth oxide (Bi_2O_3), 0.05 to 3.0 mole percent of antimony oxide (Sb_2O_3), 0.1 to 3.0 mole percent of chromium fluoride (CrF_3), 0.1 to 3.0 mole percent of cobalt oxide (CoO), 0.1 to 3.0 mole percent of manganese oxide (MnO), 0.05 to 3.0 mole percent of chromium oxide (Cr_2O_3) and 0.1 to 10.0 mole percent of silicon dioxide (SiO_2).

5. An arrester comprising at least one voltage-nonlinear resistor of claim **1** as a characteristic element.

6. An arrester comprising at least one voltage-nonlinear resistor of claim **4** as a characteristic element.

* * * * *