DEVELOPMENT OF ZINC OXIDE VARISTORS USING LOCALLY AVAILABLE MATERIALS

BY

EVBOGBAI M.J.E * evbogbaiedekin@yahoo.com
EDEKO F.O.**
AJUWA C.I ***

* DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
AMBROSE ALLI UNIVERSITY, P.M.B. 14, EKPOMA, EDO STATE, NIGERIA.

** DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING.
UNIVERSITY OF BENIN, EDO STATE, NIGERIA.

*** DEPARTMENT OF MECHANICAL ENGINEERING
AMBROSE ALLI UNIVERSITY, P.M.B. 14, EKPOMA, EDO STATE, NIGERIA.

ABSTRACT

Zinc oxide varistors were developed using locally available materials. The composition of the samples includes ZnO, 98; Bi_2O_3 and CoO 1% respectively. The compositions were mixed in a polyethylene container using zirconia balls. Cassava starch was used as binder. The samples were pressed using steel rings as moulds. The pressed samples were sintered at 1260^{o}C for 3hours in an electric furnace. The samples were allowed to cool down to room temperature in the furnace. The electroded samples were subjected to electrical property measurements. The clamping ratio for sample 1 is 1.12, while sample 2 is 1.17. The breakdown voltages for the two samples are respectively 125volts and 240volts. The non-linear exponents α, were computed to be 71 for both samples. The production of the ZnO varistor would rejuvenate economic activities in the electrical sector, thereby promoting the development and utilization of huge solid minerals resources. It will also conserve our scare foreign exchange expended on the importation of foreign ones.

KEYWORDS:(Zinc oxide, Sintering, Electrode, Varistor, Surge Voltage, Protection)

INTRODUCTION

Electrical appliances and circuitry are designed to operate under standard voltage conditions for optimal performance. Surge voltage resulting from switching and lightning possess serious threat to both equipment and personnel, hence the need to protect them against transient over voltage. Various surge diverters, such as spark gap, silicon carbide and zener diode has been in use for along time. The drawback associated with these types of arresters includes, low response time, low transient energy capability, power frequency follow-through current, low nonlinearity coefficient and negative temperature coefficient. Metal oxide varistor, popularly known as zinc oxide varistor is a semiconductor device with non-ohmic behavior, which makes it suitable for clamping the voltage to an acceptable level when a high voltage surge comes to electrical circuit [1-4]. The non- linear voltage-current characteristics are attributed to the formation of double Schottky barriers at the zinc oxide grain boundaries [5]. The behavior of ceramic varistor is determined by microstructure, grains conduction and grain boundary resistivity [8]. The high current handling capability, surge energy absorption capability and reliability are attributes of the zinc oxide varistors. Varistor effect occurs when the electrical resistance of a material changes non-linearly with voltage applied to its terminal. Within a given current range, the current – voltage relationship can be expressed as

$$I = KV^{\alpha} \qquad (1)$$

Where, k represents a constant depending on the geometry of the varistor and the technology used and α, the non-linearity factor. The higher the value of α, the better the protection.

The macroscopic breakdown voltage per intergranular barrier is given as [10]

$$v_g = F_g d \qquad (2)$$

F_g , is the macroscopic average breakdown field at a current density of 1mA/cm and d is the grain size. The macroscopic voltage is about 3volts.

The varistor breakdown voltage is

$$V_B = nv_g \quad (3)$$

$$= Dv_g / d \quad (4)$$

Where D is the electrode spacing and n number of grains in series between the electrodes.

Using equations (3) and (4), a given breakdown voltage can be achieved by changing varistor thickness D (for fixed grain size) or by varying the grain size d to increase the number of barriers, n, while keeping the device thickness constant. The schematic diagram of the structure of zinc oxide varistor is shown in Fig.1.

Nigeria has 4.63 million metric tons reserve of zinc [11]. The effective exploitation of this mineral has the potential of kick starting the establishments of related user industries especially in the electrical sub-sector thereby contributing immensely to our national economic growth. The aim of this work therefore, is to develop zinc oxide varistors from these materials, thereby promoting economic activities in the development of our solid minerals.

EXPERIMENTAL PROCEDURE

MATERIALS

Zinc oxide was sourced locally from local producers in Abakaliki, Eboyin state. The additives were also sourced locally from chemical vendors in Lagos, Nigeria. Cassava starch was purchased from the open market.

METHODS

Ninety eight (98g) of zinc oxide and one gram each of bismuth oxide and colbalt oxide were weighed out and poured in a polyethylene container. The oxides were thoroughly mixed using zirconia balls and 20 grams of starch and 20 milliliretres of deionised water were used for ball milling. The paste formed was dried at room temperature for forty-eight (48) hours, after which it was pressed in steel ring moulds of different diameters to produced disc of different diameter and thickness. After about twenty-four (24) hours, the pellets were sintered in an electric furnace at a temperature of 1260^{o}C for three hours. The furnace is allowed to cool down to room temperature and the sintered ceramics produced were removed. The samples produced were polished using P60D and P220C waterproof silicone carbide paper. The thickness and diameter of the various discs were measured. The surface area and volume of the disc were computed. 18KT Gold spray paints (ABRO Products) was sprayed on the top and bottom side of the discs. After fifteen minutes, the first spray dries; a second spray was applied to get a better and thicker electrode coating on both side of the disc. 1.5mm copper conductors of about 5cm in length were soldered to both side of the disc to serve as lead for external connection. ABRO Epoxy steel resin and hardener were thoroughly mixed to encapsulate the prepared samples, which dries in less than twenty minutes. The samples were subjected to Volts-Ampere characteristics measurement.

The samples were connected across a variable dc current source via a (DT9205A), digital ammeter, while (DT9205A), digital voltmeter was connected across the samples. The current source was varied from microampere to milliampere range, the ammeter records the current flowing through the varistor, while the voltmeter records the voltage dropped across the device.

RESULTS AND DISCUSSION

The thickness, diameters, surface area and volume of the disc shape ZnO varistors samples are shown in Table 1. The current-voltage data obtained from the electrical measurements for the samples are shown in Tables 2 and 3. The voltage - current characteristics for sample 1 and sample 2 are shown in Fig.2 and Fig.3 respectively. The V-I characteristics of these samples are identical when compared with the foreign made type (VF10M10271K) shown in fig.4. The varistor voltage at 1mA for sample 1 is 125volt, while that of sample 2 is 240volts. The variation is due to difference in their thickness. The clamping ratio for sample 1 and 2 are respectively, 1.12 and 1.167. The more this ratio is near to 1, the better the protection. The values of the non-linear exponent α for the samples 1 and 2 were computed to be 71 due to same chemical composition.

The origin of the non-linearity is attributed to the presence of electrostatic barriers located in regions of direct ZnO grain-to-grain contact. This barrier results from the interfacial trapping of free charge within the narrow physical boundary (few A^o). The small additive oxides added to these materials, controls the electrical characteristics of the zinc oxide grain boundaries, and thus optimizes the varistor behavior. The number of grain boundaries between electrodes determines the varistor voltage itself.

CONCLUSION

The voltage-current characteristic of the samples shows that zinc oxide varistors have been synthesized. The samples clamping ratio and high nonlinear coefficient α of 71 for both samples shows a wide margin of protection and suitability of the device for voltage surge protection.

The development of zinc oxide varistors using locally available materials in Nigeria would facilitate economic activities and the development of our solid mineral sector. This would help to diversify our economy instead of the present crude oil based monoeconomy.

REFERENCES

1. Paul D. and Venugopalan S.L., (1993), " Power Distribution System Equipment Overvoltage Protection", IEEE Paper 0-7803 – 5843-0/00,Pp 21-29.
2. Knecht B. and Meith A.,(1979), "Surge Arresters: Zinc Oxide Based Non-Linear Resistances", Brown Boveri Review, Pp 739-42.

3. Kobayashi M., Mizuno M., Aizawa T., Hayashi M. and Mirani K., (1978), "Development of Zinc Oxide Non-Linear Resistors and their Applications to gapless Surge Arrester", Transactions on Power Apparatus and System, Vol. 97, No. 4, Pp1149-58.

4. .Matsuoka M.,(1971), "Non Ohmic Properties of Zinc Oxide Ceramics," Japanese Journal of Applied Physics, Vol.10, Pp736..Glot A. B.(2006), "A simple Approach Oxide Varistor Materials", Journal of material Science, Vol.41, Pp 5709-5711.

5. Levison L.M. and Philipp H.R.(1977), " ZnO Varistors for Trensient Protection" IEEE Transaction Parts, Hybrid Packaging PHP – 13, Pp 338.

6. Mahan G.D., Levinson L.M. and Philipp H.R., (1979), "Theory of Conduction in ZnO Varistors", Journal of Applied Physical, Vol. 50, Pp 2799

7. Sedky A., Abu – Abdeen M. and Aimulhem A .A., (2007), " Nonlinear I – V Characteristics in doped ZnO based – ceramic Varistors", Physic Bulletin Vol.1 Issue2, Pp266-273.

8. Tohver V., Morisetle S.L., Ledwis J.A., Tuttle B.A., Voigt J.A and Dimos D.B., (2002), "Direct –write Fabrication of Zinc Oxide Varistor", Journal of American Ceramics Society, Vol. 1 85, Issue Pp. 123 – 128

9. Zunic M., Brankovic Z., Bernik S., Goes M.S. and Brankovic G., (2007), "ZnO Varistor from Intensively milled Powders", Journal of the European Ceramic Society Vol.27, Issue 13 –1 5 Pp 3897 – 3900.

10. Levinson L. M. and Philipp H.R.(1975), "The Physic of Metal Oxide Varistor," Journal of Applied Physics, Vol. 46, Pp1332.

11. Lead/Zinc,(2004), "Technical Brief on Minerals in Nigeria", Raw Materials Research and Development Council, Pp2-4.

Table 1: Dimensions of the developed ZnO

	Thickness	Diameter (mm)	Volume	Surface Area

	(mm)		(mm^3)	(mm^2)
Sample 1	1.32	14.24	490.59	318.56
Sample 2	3.08	17.43	315.37	477.83

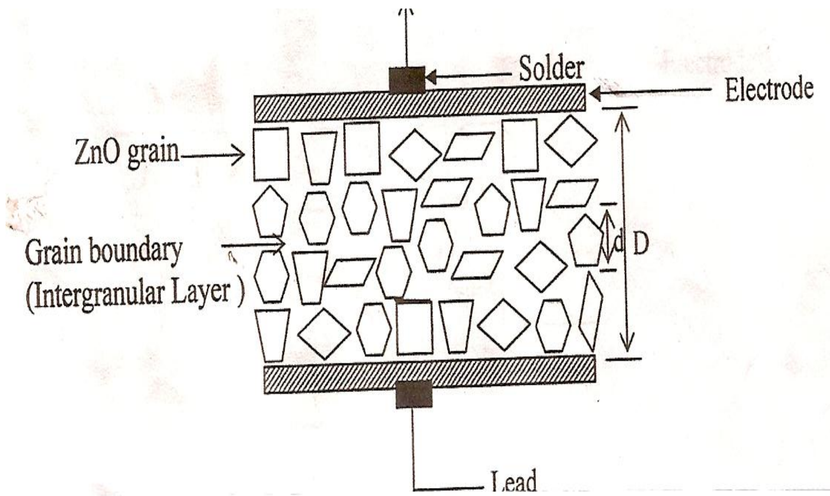

Figure 1. The schematic diagram of zinc oxide varistor

Table 2; Current-Voltage data of sample 1

I_{dc}(A)	0.000002	0.000005	0.00001	0.00005	0.0001	0.0005	0.001	0.0011	0.0012
V_{dc}(V)	15.6	39	80	110	121	124.5	125	127	140

Table 3; Current-Voltage data of sample 2

I_{dc}(A)	2E-06	4E-06	5E-06	7E-06	9E-06	1E-05	1E-05	1E-05	2E-05	2E-05	2E-05	1E-04	0.001	0.011	0.012
V_{dc}(V)	19.3	36.7	56	74	92.5	110.5	127.5	146.5	166	180	186	200	240	250	280

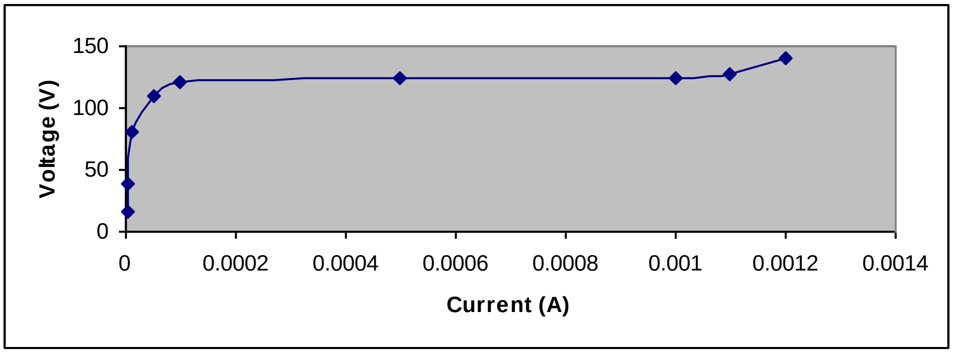

Fig. 2; V-I Characteristics of ZnO varistor (Sample 1)

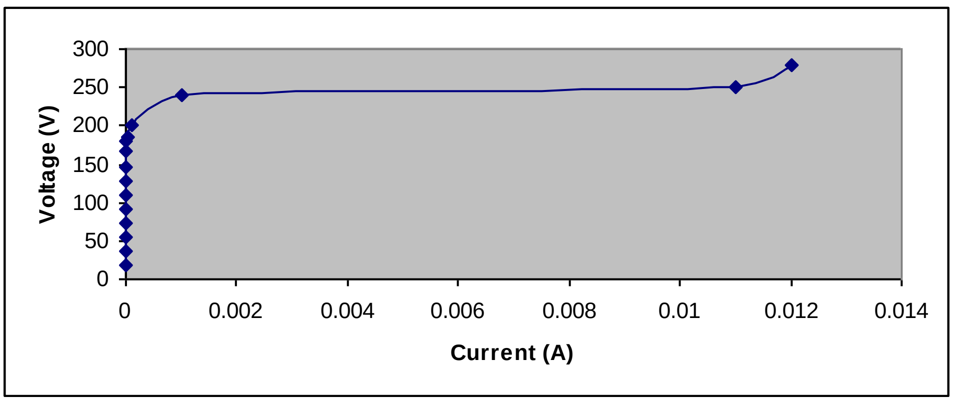

Fig.3; V-I Characteristics of ZnO varistor (Sample 2)

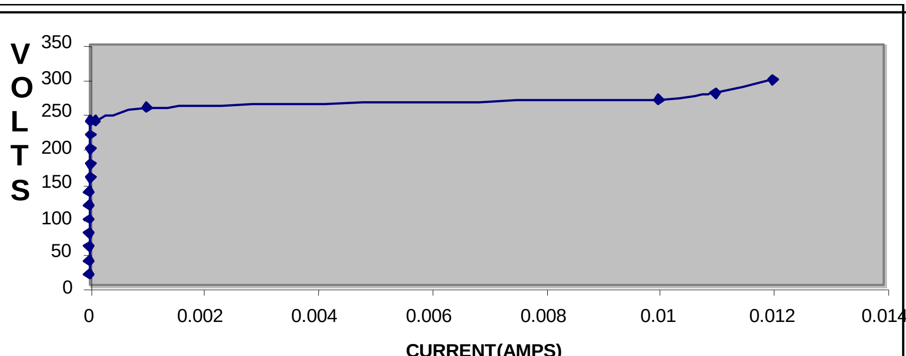

Fig.4 V-I CHARACTERISTICS OF IMPORTED ZnO VARISTOR