EFFECT OF GEOMETRY ON THE ELECTRICAL PROPERTIES OF ZINC OXIDE VARISTORS

PAPER NO: NOVEMBERCON/2011/184

BY

[1]EVBOGBAI M.J.E. Ph.D evbogbaiedekin@yahoo.com
[2]ANYASI F.I. Ph.D francisanyasi@aauekpoma.edu.ng
[3]MOMOH S.M. momoh_sm@yahoo.com

[1,2]DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING,
FACULTY OF ENGINEERING AND TECHNOLOGY,
AMBROSE ALLI UNIVERSITY,
P.M.B. 14,
EKPOMA, EDO STATE, NIGERIA.

[3]DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING,
SCHOOL OF ENGINEERING AND TECHNOLOGY,
FEDERAL POLYTECHNIC, AUCHI
P.M.B. 13,
AUCHI, EDO STATE, NIGERIA.

ABSTRACT

Zinc oxide varistors are effective voltage surge suppressor. They can be produced by conventional ceramics process. The effects of shape and sizes of the varistors on its electrical properties were investigated in this work. For easy fabrication and flexibility to fit into existing design, the disc shape is adopted. The result revealed that a linear relationship exists between the thickness and breakdown voltage of varistors. The surface area controls the current handling capacity, while the volume controls the transient energy handling capability.

Keywords:ZnO Varistors, Geometry, Breakdown Voltage, Energy Absorption Capability, Current Handling Capacity.

INTRODUCTION

Zinc oxide varistors are voltage dependent resistors which exhibits nonlinear current-voltage characteristics. The non ohmic property, current handling capability, transient energy absorption capability, response time and high nonlinear coefficient make it more suitable for voltage surge suppression. Varistors are produced by advance ceramics technology. Different kinds of techniques for its production are available elsewhere (Lagrange, 1991; Harris, 1999).

The conventional ceramics process of varistors production using locally available materials had been reported by the author elsewhere (Evbogbai, Edeko andAjuwa;2011)a. Optimal composition of varistors using zinc oxide and additive oxides such as bismult and cobalt in Nigeria had been formulated (Evbogbai, Ajuwa and Edeko: 2011). The nonlinear coefficient of alpha (α) as high as 71 was achieved for a locally develop varistors (Evbogbai, Edeko andAjuwa;2011)b. Device characteristics are determined at the pressing operation (Levinson and Philipp; 1986). The paste produced from the powder is pressed into a form of predetermine thickness in order to obtained the desired ratings of peak current and energy capability, the electrode area and mass of the devices are varied. The possible shapes of varistors are disc, rectangular, rod and tube (Harris, 1999).

The apparent capacitance of varistors depends on its surface area, thickness and apparent dielectric constant. The apparent dielectric constant is expressed by equation 1 (Lagrange,1991).

$$\varepsilon_g = \varepsilon v \frac{d}{e} \qquad 1$$

Where v is the dielectric constant of ZnO, d average grain size and e is the thickness of the depletion zone.

The breakdown voltage per grain barrier is characteristics of ZnO varistor when the grain breakdown voltage is evaluated by measurement of bulk sample. Einzinger (1981) proposed that the potential barrier does not exist at each grain boundary. He emphasized, that the varistor effect can be absent between two grains. He concluded that, the barriers if present have different characteristics and can be separated into “good” and “bad” barrier. As a result, the varistor electrical properties are closely correlated with the homogeneity of grain size and the homogenous distribution of the additives (characteristics of the bulk).

ZnO is inherently multi junction with varistor action shared between the various ZnO boundaries; hence the electrical characteristics of ZnO varistors are related to the bulk of materials. Therefore, tailoring the device breakdown voltage, VB is simply a matter of fabricating a varistor with appropriate number of grain size, n, in series between the electrodes. Thus to achieve a given breakdown voltage (Lagrange, 1991), the thickness (for fixed grain size) of the varistor can be change or alternatively by varying the grain size to increase the number of barriers, keeping the device thickness constant. The expression for varistor breakdown voltage is given by equation 2

$$VB = nVg = DVg / d \qquad 2$$

where, n is number of barriers, D is the electrode spacing, d the ZnO grain size and Vg is the microscopic breakdown voltage per intergrannuler layer of the ZnO varistor.

The behaviour of a ceramic varistor is determined by microstructure, grains conduction and boundary resistivity (Levison and Phillips, 1986).

When the applied pulse voltage is less than the breakdown voltage of ZnO varistors, only the capacitive charging current will be observed. The decay of the varistors voltage at the end of the pulse is associated with a negative varistors discharge current.

With pulse voltage above the breakdown value of ZnO varistors, the capacitor charging current is almost hidden by the increase conduction current and the varistors show a peak, which then decreases with increasing time.

Varistor electrical properties are closely correlated with the homogeneity of grain size and of barrier distribution and characteristics in the bulk, i.e. the homogeneous distribution of the additives (Lagrange, 1991).

In this work, the effect of geometry on the electrical properties of locally developed ZnO varistors is to be investigated. The geometries of interest are the thickness, diameter, surface area and volume of the varistors, while the electrical properties of interest the nonlinear coefficient, breakdown voltage and capacitance. The findings would be very vital to material, production and design engineers for a better, efficient and quality product that would compete favourably with the foreign ones in a competitive market. This would encourage human capacity building, sustainable local-content industrial development strategy for actualization of millennium development goals.

EXPERIMENTATION

The conventional ceramics process used in the local production of zinc oxide varistors had been described in detail by the author(Evbogbai, Edeko and Ajuwa: 2011). The disc shape varistor samples produced were of different sizes. The composition of the varistors is shown in Table 1. After sintering and polishing, the mirrored surface varistor disc samples, the thickness and diameter of the samples were measured using micrometer screw gauge and venier calipers respectively, these data were used to compute the surface areas and volumes of the disc as shown in Table 2, while, VD890G digital multimeter was used to measure the capacitance as shown in Table 3. These data were useful in determining the electrical characteristics of varistors.

Table 1: Composition Of The Zinc Oxide Varistors(Evbogbai,Edeko and Ajuwa,2011)

Samples	ZnO mol%	Bi_2O_3 mol%	CoO mol%
A	100	-	-
B	99	0.5	0.5
C	98	1	1
D	97	1.5	1.5

Table 2: Dimensions Of The Zinc Oxide Varistors Samples.

Samples	Thickness (mm)	Diameter (mm)	Disc volume $=\pi r^2 h (mm^3)$	Electrodes surface Area $=2\pi r^2$ (mm^2)
A_1	1.16	16.38	244.47	421.51
A_2	2.15	17.14	496.14	461.53
A_3	3.25	16.39	685.78	422.02
B_1	2.05	14.35	331.60	323.50
B_2	1.36	14.45	223.06	328.03
B_3	1.4	13.37	196.58	280.83
C_1	3.37	15.01	596.40	353.95
C_2	1.32	17.43	315	477.28
C_3	2.36	15.23	430	364.40
C_4	3.08	14.24	490.59	318.56
D_1	2.17	16.27	451.21	416.38
D_2	2.46	16.41	520.35	423.05
D_3	7.48	12.28	886.02	236.90

Table 3: Capacitance Of The Developed Zinc Oxide Varistors.

Samples	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3
Capacitance (pF)	95	65	16	72	50	60	30	186	55	98	73	50

RESULTS AND DISCUSSION

Sintering

Some of the ZnO varistor pellets after sintering at 1260^{O}C for 2hours, were properly densified, hence good stability, they could withstand drop impact test (about 2m) and could be handled without breakage, while some got fractured, and others got burnt due to small thickness and long sintering hours. Those with larger thickness were porous, not properly stacked, hence poorly densified and lack stability. These defects could be attributed to inadequate compactness resulting from manual pressing. The organic binder (cassava starch) used burns off at 650^{O}C leaving voids to be occupied by the additive oxides at sintering temperature of 1260^{O}C, which led to more densification of the ceramic varistor samples, while bismult is molten above 825^{O}C, thereby assisting in the final densification of varistors. At higher temperature, growth occurs, forming a structure with controlled grain size.

Capacitance Of ZnO Varistors.

The results of the capacitance measurement are shown in Table 3 for all the samples. From the results it was clear that the capacitances were due to the presence of insulating barriers on either side of each grain boundary. It was observed that the chemical composition, surface area and thickness of the ZnO varistor affects it capacitance. The thickness of the ZnO varistors samples controls the nominal voltage, the electrode surface area controls the surge current withstanding and the volume controls the transient energy capability.

The varistor voltage depends solely on the thickness of ZnO varistor since, the same ZnO grain sizes were used for the samples preparation. Figures 1-4 show the plots of varistors breakdown voltage as a function of the thickness. The result revealed that a linear relationship exist between the breakdown voltage and the thickness of the varistors for all samples.

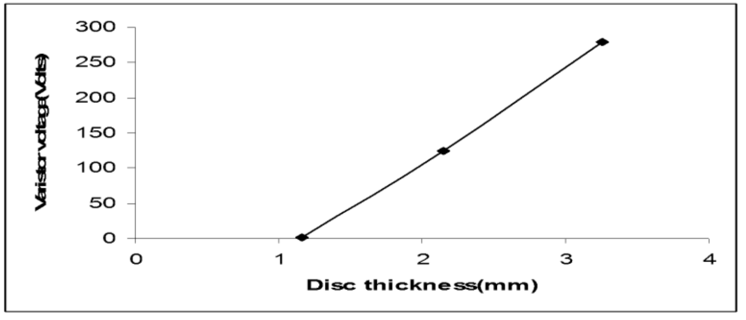

Figure 1: Dependence Of ZnO Varistor Voltages On Disc Thickness (Sample A).

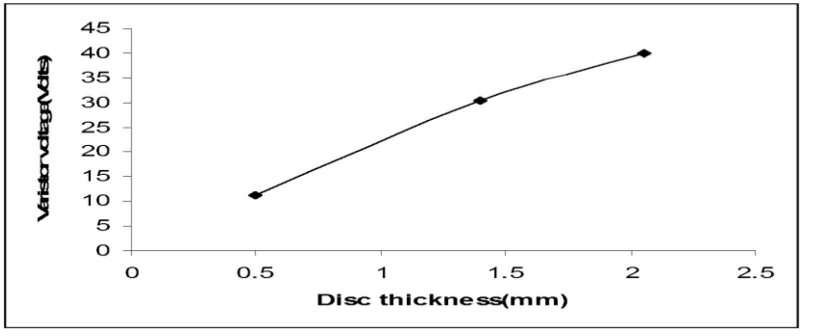

Figure 2: Dependence Of ZnO Varistor Voltage On Disc Thickness (Sample B).

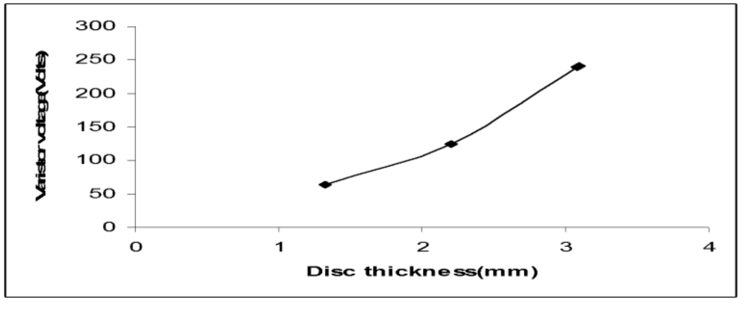

Figure 3: Dependence Of ZnO Varistor Voltage On Disc Thickness (Sample C).

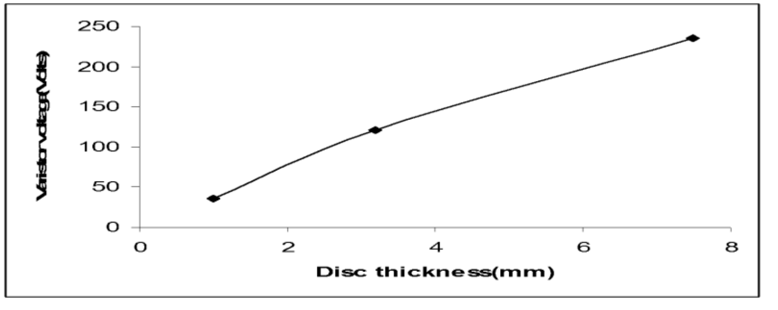

Figure 4: Dependence Of ZnO Varistor Voltage On Disc Thickness (Sample D).

The voltage breakdown of varistors depends on the number of barriers (thickness) in the direction of the electric field. The voltage breakdown per barrier had been defined to be 3V in the literatures. However Einzinger, (Einzinger, 1981) in his varistor model postulated that potential barriers doesn't exist at each grain boundary, which implies that varistor action can be absent between two grains. Therefore applying Einzinger varistor model, the variations observed in the electrical characteristics for different samples and within the samples were due to non-uniform distribution of the barriers within the volume of the ceramic and non-homogeneity of grain size.

The better the homogeneity of barrier distribution, the better is the performance of the ZnO varistors. However, this could not be achieved under the prevailing conditions of powder preparation by conventional steps of mixing and milling the elements. To improve homogeneity of the barrier distribution and grain growth control, powder preparation by a chemical method have been recommended. Several chemical methods had been reported in the literatures(Lagrange,1991). The zinc oxide grains used in all the developed ZnO samples were of the same size. Bi_2O_3 and CoO were the only additives available for these experiments. During processing (mixing and milling) these additives were located in the intergranular layer between ZnO-ZnO grain boundaries. As a result of varistors processing, the ZnO in the ZnO varistors were semi conducting, while the intergranular layer offered potential barriers.

CONCLUSION

Electrical properties of varistors are influenced by the geometry of the device. Varistors breakdown voltage depends on the thickness. The surface area controls the current handling capacity, while the volume controls the energy absorption capacity. Conclusively, since a linear relationship exists between the thickness and breakdown voltage of zinc oxide varistor samples, they can be connected in series for medium and high voltage applications.

For sustainable development of the third world, Nigeria must wake up to take its leadership role, considering the facts that she is endowed with both human and natural resources that can drive and sustain the world economy. The development of her solid mineral sector will provide the catalyst desired for the economic emancipations of all and sundry.

REFERENCES

a. Evbogbai M.J.E., Edeko F.O. and Ajuwa C.I.(2011), "Development of Zinc Oxide Varistors using locally available materials", *Global Journal of Engineering and Technology*, India, Vol.4,No.1,,Pp 29-32.

b. Evbogbai M.J.E., Edeko F.O. and Ajuwa C.I.(2011), "Nonlinear Coefficients of ZnO Varistors", *Global Journal of Engineering and Technology*, India, Vol.4, No.1, Pp 41-44.

c. Evbogbai M.J.E., Ajuwa C.I. and Edeko F.O.,.(2011).,"Optimal Composition of Zinc Oxide Varistors Developed in Nigeria", International Conference on Research and Capacity Building, 15th -16th September, 2011, Theatre Conference Hall, University of Ghana, East Legon, Accra, Ghana, Book of Abstract, *IRCAB Book Company*, Johannesburg, South Africa, Pp. 85.

Einzinger R. (1981). Grain Boundary Properties in ZnO Varistors. *Advance Ceramic* Vol.1, Pp. 359 – 374.

Harris Suppression Products(1999), Littelfuse Inc.

Hashimov A.M.., Hasanli S.M., Mehdizadeh R.N., Azizova S.M. and Bayramov .K.B.(2007), Nonlinear Resistor based on a polymer in Ceramic Composition. *Technical Physic*, Vol.56, No.8, Pp.1086 – 1088.

Lagrange A. (1991). Present and Future of Zinc Oxide Varistors. B.C.H. Steels (ed) *Electronic Ceramic Elsevier* London :21.

Levinson L.M. and Philipp H.R. (1986). Zinc Oxide Varistors – A Review. *Ceramic Bulletin* Vol.65, No. 4, Pp. 639.