EFFECT OF CoO ON NONLINEAR ELECTRICAL PROPERTIES OF ZnO VARISTORS DEVELOPED IN NIGERIA (*PAPER NO: IRCAB/SA/2012/A!!*)

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ABSTRACT

The nonlinear properties of varistors, which are composed of ZnO-Bi_2O_3-based ceramics produced by conventional ceramic process using locally available materials in Nigeria, were investigated at various CoO contents. The increase of CoO improves the densification of ceramics and could withstand a drop impact test about 2m high. The highest nonlinearity was obtained from the varistor with 1.0 mol% CoO, with 70.8 in nonlinear exponent, varistor voltage of 125V and 2μA in leakage current. The further CoO addition decreased the nonlinearity.

Keywords: ZnO Varistors, Nonlinear coefficient, Breakdown Voltage, leakage current, Densification.

INTRODUCTION

Significant development has been made in the improvement of the electrical and mechanical properties of zinc oxide varistors since its discovery by Masuka in 1970 (Evbogbai, Ajuwa and Edeko, 2011). Zinc oxide varistors are produced by advanced ceramic sintering process that give rise to structure comprised of conductive ZnO grains surrounded by electrically insulating barriers. These barriers are derived from trap states at the grain boundaries induced by additive elements such as Bi, Co, Pr, Mn (Lagrange, 1991). Small amount of these metal oxide additive added, is to control the electrical characteristics of the ZnO grain boundaries to optimize the varistor behaviour.

Different methods of its production has been reported in several literatures (Lagrange,1991). Amongst these methods, the conventional ceramic process is simplified in terms of process technology and its results are appreciable when compared with advanced Hi-Tech methods. The successful development of zinc oxide varistors by conventional ceramic process, using locally available materials in Nigeria has been reported (Evbogbai Edeko and Ajuwa, 2011a). The electrical and mechanical properties of the developed varistors, compare favourably with their foreign counterparts. Higher nonlinear coefficient of 70.8 was achieved by the locally sourced ZnO varistors (Evbogbai Edeko and Ajuwa, 2011b), as against 40 and 60 reported in some literatures (Lagrange, 1991; Brass, 2004; Bernik and Daneu, 2007). The attributes in terms of nonlinearity coefficients, current handling abilities and energy absorption capability exhibited by zinc oxide varistors at present gave it an edge over other surge voltage suppressors. In addition, zinc oxide varistors are manufactured without the use of spark gaps. No gaps meant no power frequency follow – through currents, an improved surge rate – of – rise performance, better pollution performance, and overall improved reliability due to reduced arrester complexity. Other gains were in lower arrester residual voltages, improved protective margins and lower size and weight (Lagrange, 1991, Bialek, 1999 and Brass, 2004).

The effect of geometry (Evbogbai, Anyasi and Momoh, 2011) and frequency (Evbogbai, Yeboah and Iyere, 2011) on the electrical properties of zinc oxide varistors has been reported. The results show that the locally developed varistors exhibits similar characteristics when compared with the foreign ones.

The aim of this work therefore, is to investigate the effect of cobalt oxide (CoO) on nonlinear electrical properties of zinc oxide varistor developed in Nigeria**.**

MATERIALS AND METHOD

Materials

Chemical substances used for the experiment were zinc oxide bismuth oxide (Bi_2O_3), cobalt oxide (CoO), deionized water and organic binder (Starch). The detailed apparatus used for the varistors produced in Nigeria can be found elsewhere(Evbogbai Edeko and Ajuwa, 2011a).

Experimental Procedures

Materials Preparation

The ZnO and additive oxide (Bi_2O_3 and CoO) powders were weighed in grams, which gave the corresponding %mol. The compositions of the various zinc oxide varistors is shown in Table 1.

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

The zinc oxide and additive oxide weighed were poured into 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 fortyeight (48) hours, after which it was pressed in steel ring moulds of different diameters to produced disc of different diameter and thickness. Detailed experimental procedures for the use of locally available materials for the development of Zinc oxide varistors using conventional ceramic process, the mathematical expressions (Evbogbai Edeko and Ajuwa, 2011a) and the computation of the various electrical parameters (Evbogbai, 2011) of the varistor developed in Nigeria have been reported elsewhere. The experimental data obtained for the current-voltage measurement and the computed nonlinear coefficients versus the peak current were plotted using Microsoft Office Excel 2007.

RESULTS AND DISCUSSION

After sintering, the properly densified ZnO varistor pellets were compact and had good stability. They withstood drop impact test of about 2metres without breakage. The current voltage characteristic curves for the various samples are shown in Figure 1- 4. Amongst these figures, Figure 4 depict the optimal characteristic which is analogous to the ideal and practical varistors available in the literatures (Harris, 1999).

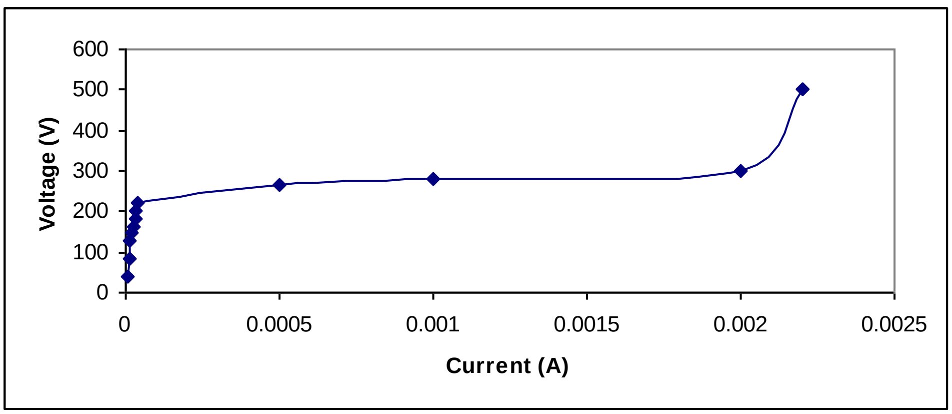

Figure 1: Current-Voltage Characteristics Of The ZnO Varistor (Sample A).

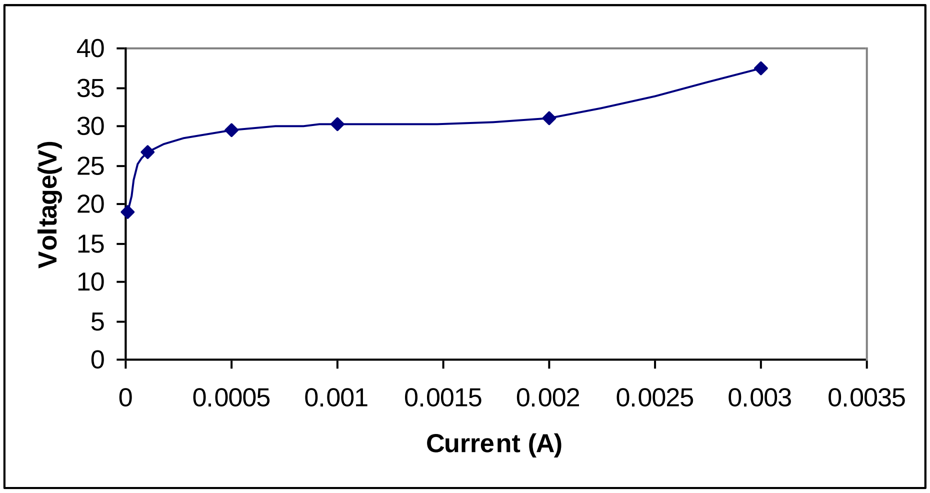

Figure 2: Current-Voltage Characteristics Of The ZnO Varistor (Sample B).

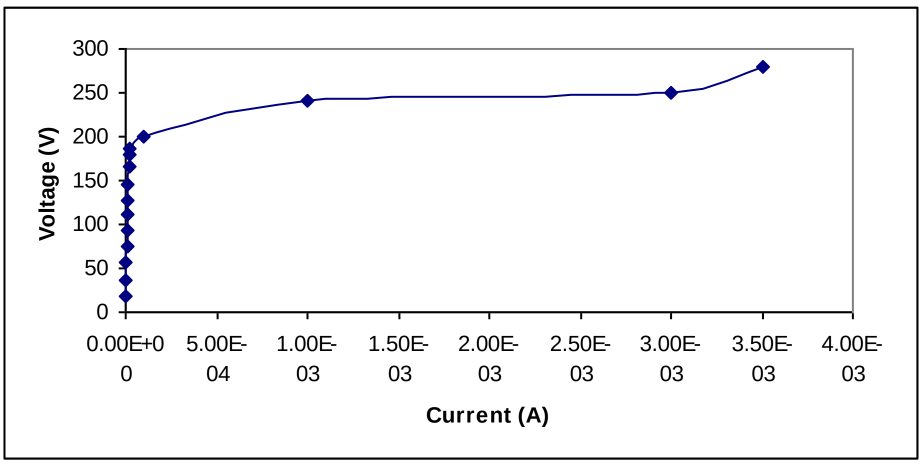

Figure 3: Current-Voltage Characteristics Of ZnO Varistor (Sample C).

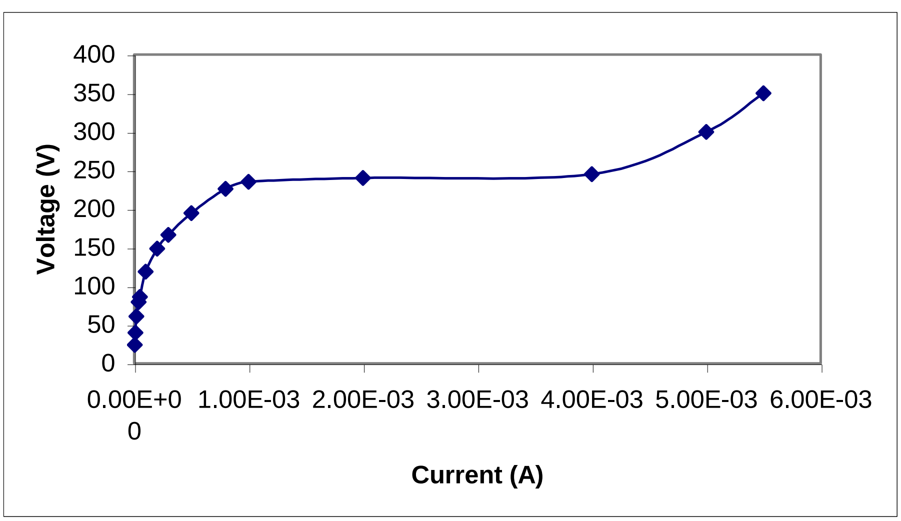

Figure 4: Current-Voltage Characteristics Of ZnO Varistor (Sample D).

Plots of nonlinear coefficients α against the peak current for the ZnO varistor samples were shown in Figures 5 – 8. From these figures it could be observed that the highest nonlinearity of 71 was displayed by sample C, while that of samples A, Band D were 13.34, 29.2 and 12.4 respectively. A critical analysis of the results further revealed that the highest nonlinear coefficients of all the samples shows that the highest value of α occur near 1_{mA}.

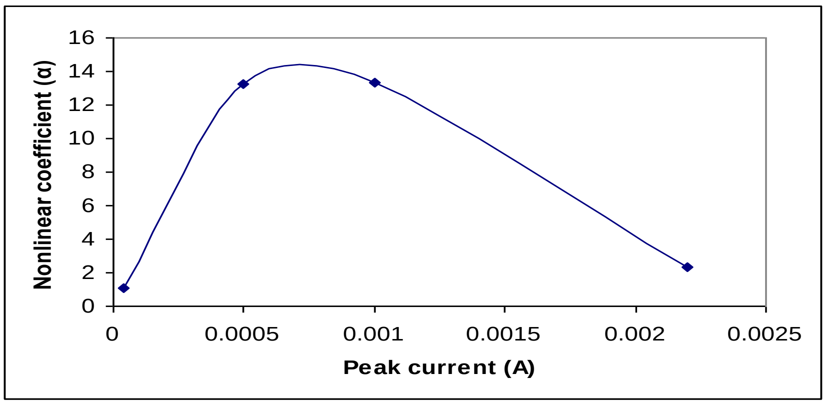

Figure 5: Variation Of Nonlinear Coefficient α With Peak Current Of The ZnO Varistor (Sample A).

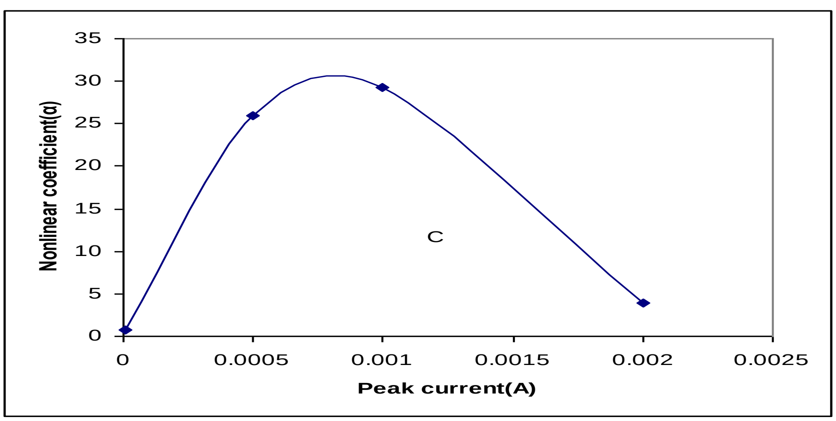

Figure 6: Variation Of Nonlinear Coefficient α With Peak Current Of The ZnO Varistor (Sample B).

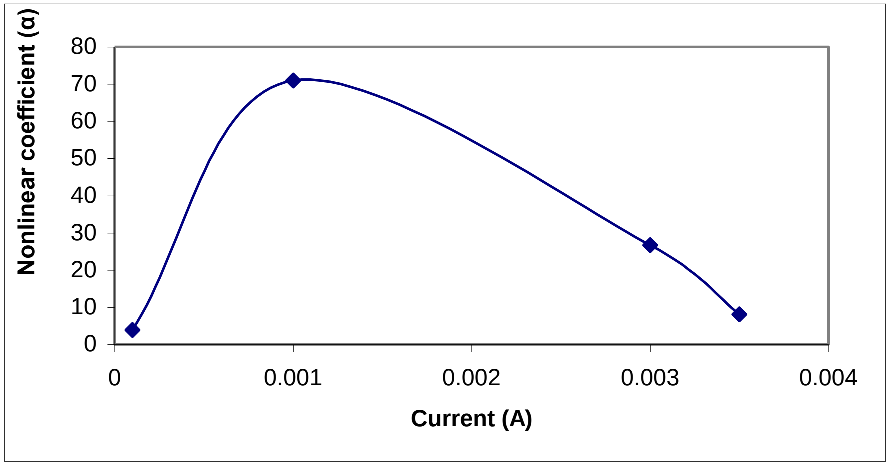

Figure 7: Variation Of Nonlinear Coefficient α With Peak Current Of The ZnO Varistor (Sample C).

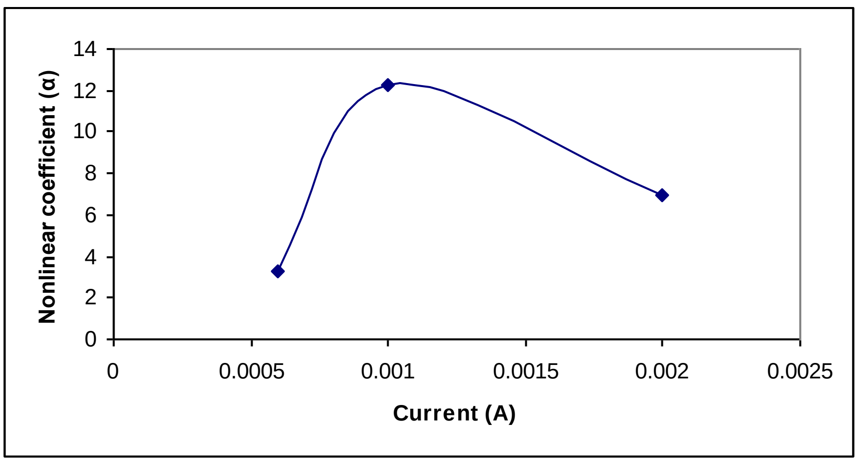

Figure 8: Variation Of Nonlinear Coefficient α With Peak Current Of The ZnO Varistor (Sample D).

A study of the voltage-clamping ratio for ZnO varistor samples shows that samples C and D voltage clamping ratios were computed to be approximately 1.

A comparative analyses of the nonlinear coefficients α based on percentage chemical composition of the ZnO varistors using Table 1, shows that the nonlinear electrical properties of the developed varistors were optimal in sample C which consist of 98 % zinc oxide and 1% each for Bi_2O_3 and CoO. The additive oxide of Bi is the basic varistor forming ingredient. The heavy elements Bi have large ionic radii, while the Co is transition metal element ingredient which enhances varistor performance (Lagrange, 1991; Buchanan, 1991). From the composition of the varistor samples in Table

1, it should be noted that sample A lack varistor forming or enhancement ingredient, hence it can be concluded that sample A is not a varistor and wouldn't perform varistor action effectively.

From the composition, it was evident that the use of additive oxides in the composition improves the nonlinear coefficient α to a great extent, further increase in the additive oxide shows a decrease in the values of α as observed in samples D. The small additive oxides added to these materials, controls the electrical characteristics of the zinc oxide grain boundaries, and thus optimizes the varistor behavior. In addition to a very high value of α in sample C, high densification and stability were equally observed.

Varistors Samples B, C and D have Bi_2O_3 and CoO as its constituents, but in different proportions as indicated in Table 1. They were varied from 0.5% to 1.5%. The maximum varistors performance was observed in sample C having 1% each for the two additives used in the experiment. From the foregoing, there exists a limit, for which additive oxides can be added for optimal varistor characteristics. Further increase of the additives beyond this limit to 1.5% in the case of sample D showed a decrease in the nonlinear coefficients α. It should be pointed out here that the Bi_2O_3 was a varistor-forming ingredient, which has effect on the basic structure, while the CoO was the varistor performance ingredient responsible for the non ohmic properties and stability of the varistor. High sintering temperature of $1260^{O}C$ and sintering time of three hours further enhanced the stability and densification of the developed ZnO varistor samples. Conclusively, the highest nonlinearity was obtained from the varistor with 1.0 mol% CoO, with 70.8 in nonlinear exponent, varistor voltage of 125V and 2μA in leakage current. The further CoO addition decreased the nonlinearity.

CONCLUSION

An optimum composition of 98 percent zinc oxide, 1 percent bismuth and cobalt oxides respectively has been established. Characterization of the nonlinear coefficient (α) against the peak current revealed that the value of α is maximum near 1mA for all zinc oxide varistor samples under study. Conclusively, a comparative analysis of the family of curves of the nonlinear electrical properties of the zinc oxide varistor samples developed in Nigeria is a subject for another day. The African indigenous research and development initiative in this work would put Nigeria in deed Africa on the world map as a major producer and exporter of zinc oxide varistors considering her abundant human and natural resources.

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