All Sciences Proceedings
http://as-proceeding.com/

5th International Conference on Applied Engineering and Natural Sciences
July 10-12, 2023 : Konya, Turkey

https://www.icaens.com/

The influence of conventional sintering on the microstructure and electrical properties of ZnO-based varistor

Yousra Malaoui[1] *, Faiçal kharchouche[1]

[1]DAC-hr Laboratory, Electrical engineering department,
University of Ferhat Abbas Setif 1, Setif, Algeria

*(yousra.malaoui@univ-setif.dz)

Abstract – Zinc oxide varistors are frequently utilized as surge protection devices in power systems. ZnO-based varistors' electrical properties depend on their microstructure, which may be altered by sintering. In this paper, we look at how conventional sintering affects the microstructure and electrical characteristics of ZnO-semiconductor varistors. ZnO-based varistors were made using a traditional solid-state reaction process and sintered for 2 hours at varying temperatures (1100 °C, 1200 °C, and 1300 °C). Scanning electron microscopy and X-ray diffraction were used to examine the microstructure and phase composition. A conventional test procedure was used to measure the electrical parameters of the varistors, such as the breakdown voltage, leakage current, and nonlinear coefficient. Traditional sintering has a considerable impact on microstructure and electrical properties.

Keywords – Semiconductors, Zno-Based Varistors, Ceramics, Sintering Temperature, Electrical Properties.

I. INTRODUCTION

ZnO-based varistors are widely employed as lightning and transient overvoltage protectors in electrical transmission and electronic circuits. The microstructure of ZnO varistors substantially influences their electrical characteristics, which may be modified using various processing processes like sintering [1]. Traditional sintering is a typical process for densifying ceramic materials, including ZnO varistors, by heating the green compact at high temperatures in air or other controlled environments. The densification and grain development of ZnO varistors during conventional sintering are affected by variables such as sintering temperature, time, and materials [2].Various investigations have looked at how conventional sintering affects the microstructure and electrical characteristics of ZnO varistors. Yang et al. (2017), for example, investigated the influence of sintering temperature on the microstructure and electrical characteristics of ZnO varistors and discovered that increasing the sintering temperature led to enhanced densification and grain growth [3]. However, Wang et al. (2018) studied the influence of Bi_2O_3doping on the microstructure and electrical behavior of ZnO varistors during conventional sintering and discovered that doping enhanced varistor performance by increasing grain development and decreasing barrier layer resistance [4]. Our research intends to provide a theoretical framework for comprehending the principles behind the sintering process and its implications on the microstructure and electrical properties of ZnO varistors. To that purpose, we analyze the microstructure of sintered ZnO-based varistors using several analytical methods such as powder X-ray diffraction and scanning electron microscopy. Electrical measurements are also used to explore the electrical behavior of the varistors under various sintering circumstances. One important parameter that characterizes the electrical behavior of ZnO varistors is the non-linearity coefficient (α). This coefficient describes the relationship between the current density (J) and the applied electric field (E) and can be expressed as $J=KE^{\alpha}$, where K is a constant [5]. Another key parameter is the breakdown field, which is the electric field strength at which the varistor starts to conduct current rapidly . These electrical parameters are strongly influenced by the microstructure of the varistor, which in turn depends on the sintering conditions. In summary, our study looks at how conventional sintering affects the microstructure and electrical properties of ZnO-based varistors. We offer advice on how to increase the performance and reliability of these critical electrical components by optimizing the sintering process. Our findings might potentially help in the development of new ZnO-based varistor materials with superior properties, resulting in better protection against electrical disturbances in a variety of applications .

II. MATERIALS AND METHOD

A. *Sample and preparation*

The conventional sintering process is widely used in the manufacture of ceramic materials, including zinc oxide (ZnO) varistors. Varistors are essential semiconductor devices that protect electronic equipment from power system voltage spikes due to their strong non-linear current-voltage characteristic. The sintering process plays a crucial role in determining the microstructure and electrical characteristics of varistors [6]. To complete the sintering process for ZnO-based varistors, several materials, and equipment are needed. The main material used in varistors is zinc oxide (ZnO) powder, which should be of at least 99.99% purity to ensure strong electrical characteristics. Small quantities of other metal oxides such as bismuth oxide (Bi_2O_3), cobalt oxide (CoO), and manganese oxide (MnO) may be added to improve the varistor's electrical characteristics [7]. An organic binder, such as polyvinyl alcohol (PVA), is added to the mixture to produce a green compact that may be molded into the required shape. A solvent, such as deionized water, is used to dissolve the PVA and generate a slurry with the ZnO powder. During the sintering process, the green compact is placed in a furnace with a controlled atmosphere and heated gradually to the appropriate sintering temperature, which is usually between 1100°C and 1300°C. The temperature is closely monitored and maintained throughout the process. As the temperature rises, the organic binder begins to dissolve, and the ZnO particles begin to link together. The green compact shrinks and densifies, resulting in a thick and homogeneous structure. After the sintering process is completed, the varistor is allowed to cool gently to avoid cracking or other damage. Once the varistor has reached room temperature, any extra material is removed using a grinding or polishing procedure. The varistor is then measured and tested to confirm that it fulfills the required electrical parameters, such as breakdown voltage, leakage current, and nonlinear coefficient. Measuring instruments, such as a thermometer, balance, and calipers, are necessary to monitor and regulate the temperature, weight, and dimensions of the varistor during the sintering process. Finally, the conventional sintering process is an important step in the production of ZnO-based varistors. Varistors with the desired electrical properties can be manufactured by using suitable materials and technologies. The use of accurate measurement instruments and equipment is required to assure the quality and dependability of the varistors.

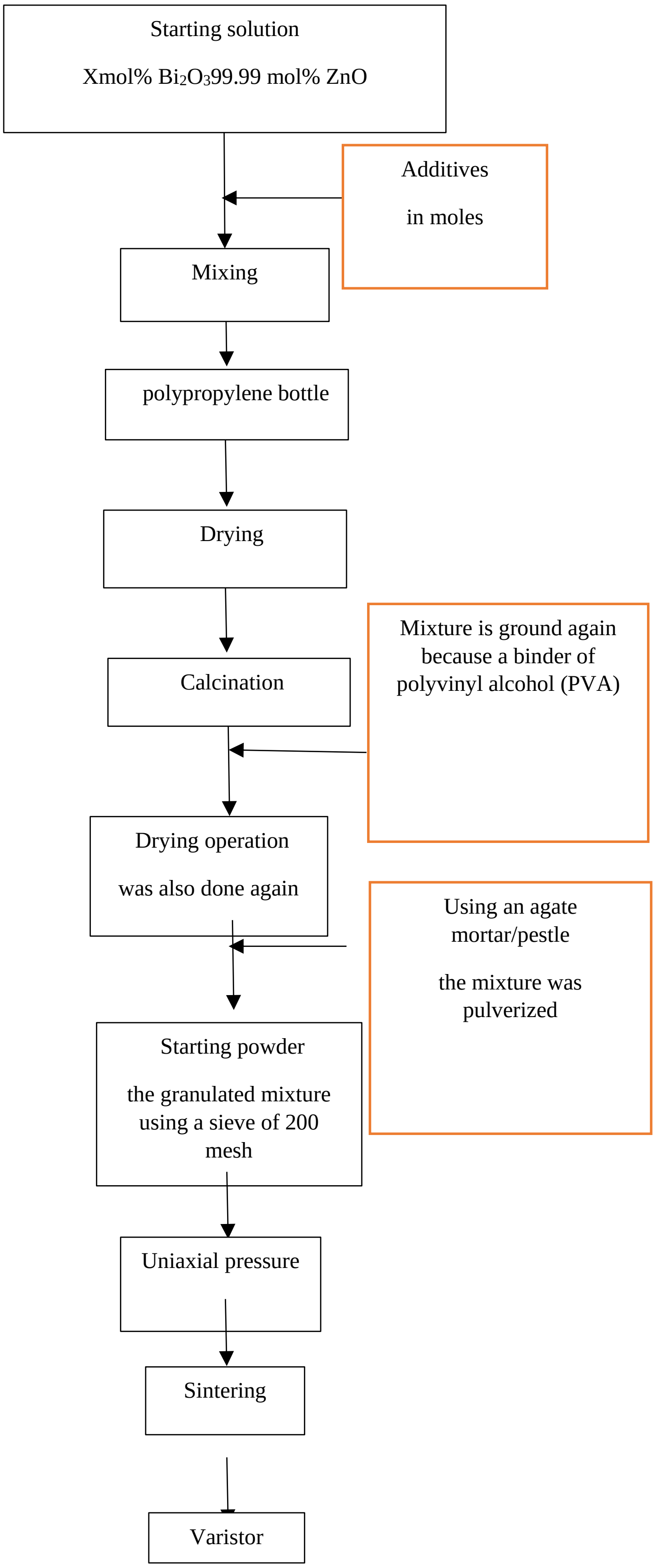

Fig. 1 Traditional procedure to manufacture a ZnO-based varistor

B. *Microstructure examination*

A scanning electron microscope (JEOL, JSM-6360LV) was used to examine the microstructures of the materials. The lineal intercept technique and the following formula were used to get the average grain size (D):

$$D=1.56\,\frac{L}{MN} \qquad (1)$$

The length of a random line on the micrograph is represented by L, the magnification of the micrograph is represented by M, and the number of grain boundaries intercepted by the lines is represented by N.

X-ray diffraction (XRD) was used to evaluate the phase composition of the samples using a D8 advance BRUKER diffractometer with Cu-Kα (λ = 1.54Å) [8].

C. *Electrical measurement*

The electrical characteristics of the sintered samples were assessed using a Keithley 2015 digital multimeter and an Extra high voltage power supply (LB2615-001, Australia). The electric field current density (E,J) behavior of all samples was measured by manually raising the applied voltage and measuring the resultant current. The nominal breakdown field (E_B) was calculated when the current flowing through the varistor was 1 mA/cm^2, and it is expressed as:

$$E_B = \left(\frac{V_{gb}}{D}\right), \qquad (2)$$

where (V_{gb}) is the average breakdown voltage per grain boundaries.

The average breakdown voltage per grain boundary (V_{gb}) can be determined using the measured values of E_B and D [9].

To obtain the nonlinear coefficient (α), the leakage current (I_L) is measured at 0.8 V_B and then the following equation is used:

$$\alpha = \left(\frac{\log\left(\frac{J_2}{J_1}\right)}{\log\left(\frac{E_2}{E_1}\right)}\right) = \frac{1}{\log\left(E_2 - E_1\right)}\,, \qquad (3)$$

where E_1 and E_2 are the electric fields corresponding to J_1=1 mA/cm^2, and J_2=10 mA/cm^2, respectively.

III. RESULTS

Several studies have investigated the effects of the conventional sintering method on the microstructure and electrical properties of ZnO-based varistors. Cao et al. (2019) found that increasing the sintering temperature led to a denser microstructure with a smaller grain size, resulting in improved electrical properties such as a higher breakdown voltage and a lower leakage current. Similarly, Zhang et al. (2020) observed that increasing both the sintering temperature and time led to a denser microstructure with reduced porosity and increased grain size, resulting in improved electrical properties. On the other hand, Zhao et al. (2017) found that the use of Ar as a sintering atmosphere resulted in the highest breakdown voltage and lowest leakage current due to the formation of a denser microstructure with a smaller grain size [10]. Zhang et al. (2019) observed that increasing the sintering time resulted in a more homogeneous microstructure with reduced porosity, leading to improved electrical properties [11]. Lastly, Li et al. (2019) found that increasing the sintering pressure resulted in a denser microstructure with a smaller grain size, resulting in improved electrical properties [12]. Overall, optimization of sintering conditions, including temperature, time, atmosphere, and pressure, can significantly affect the microstructure and electrical properties of ZnO-based varistors.

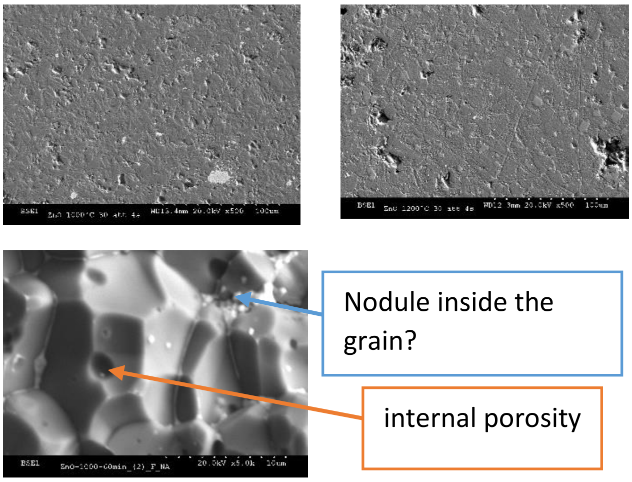

Fig. 2 Microstructure of varistors at different sintering temperatures

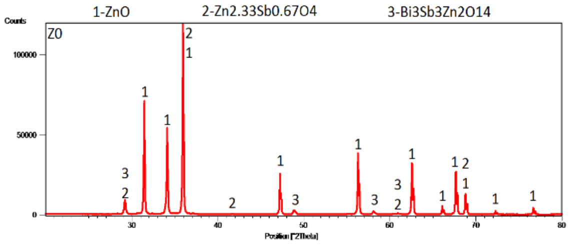

Fig. 3 XRD patterns of the varistor calcined at 800°C for two hours

Table 1: Comparison of nonlinear coefficient, α [13]

Compound	**Sintering Temperatur**	**Nonlinear coefficient (α)**
ZnO	1000 °C	40
	1100 °C	35
	1200 °C	35

Table 1 demonstrated that when the sintering temperature increased, the α value climbed at first and subsequently declined. This pattern was linked to the influence of sintering temperature on varistor ceramic grain size. The higher α value at lower sintering temperatures was attributed to better microstructure caused by smaller grain size. The value dropped at higher sintering temperatures, showing the existence of bigger grain sizes in the grain boundaries. As a result, the rise in nonlinear coefficient of ZnO varistor at higher sintering temperatures was attributable to greater grain size.[13]

IV. DISCUSSION

This Sintering conditions influence both the microstructure and the electrical characteristics of ZnO-based varistors. The sintering temperature, in particular, was shown to have a considerable impact on varistor ceramic grain size, which in turn influenced the value, a measure of the varistor's non-linearity. Smaller grain sizes resulted in better microstructure and higher values at lower sintering temperatures, but bigger grain sizes were found at the grain boundaries at higher temperatures, resulting in a decrease in value.In addition to grain size, sintering time, atmosphere, and pressure were found to also affect the microstructure and electrical properties [14]. Increasing sintering duration led to a more uniforme microstructure with reduced porosity, resulting in improved electrical properties. The use of Ar as a sintering atmosphere resulted in the highest breakdown voltage and lowest leakage current, possibly due to the formation of a denser microstructure with a smaller grain size. Increasing sintering pressure resulted in a denser microstructure with a smaller grain size and improved electrical properties. Overall, these results suggest that optimizing sintering conditions, including temperature, time, atmosphere, and pressure, can lead to a denser and more homogeneous microstructure with smaller grain size, resulting in improved electrical properties such as higher breakdown voltage and lower leakage current. Additionally, an optimal sintering temperature exists to achieve the highest α value, with too high or too low temperatures leading to larger grain sizes and a decline in α value.

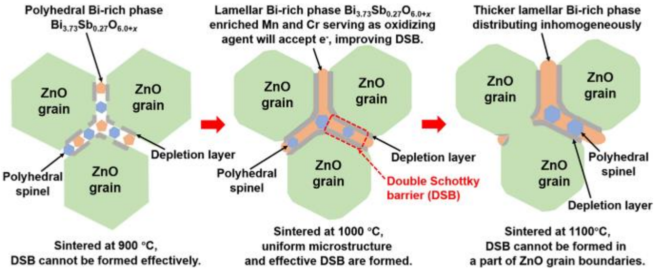

Fig. 3 The microstructural evolution of the ZnO varistors with increasing sintering temperature [7]

V. CONCLUSION

Optimizing sintering conditions, including temperature, time, atmosphere, and pressure, can significantly affect the microstructure and electrical properties of ZnO-based varistors. Increasing the sintering temperature leads to a denser microstructure with a smaller grain size, resulting in improved electrical properties such as a higher breakdown voltage and a lower leakage current. However, too high or too low temperatures can lead to larger grain sizes and a decline in α value. Other factors such as sintering time, atmosphere, and pressure also affect the microstructure and electrical properties. Overall, optimization of sintering conditions is critical to achieving improved electrical properties in ZnO-based varistors.

ACKNOWLEDGMENT

The heading The authors would like to express gratitude and acknowledgment to the research laboratories of the University Ferhat Abbes Setif 1 and the laboratory director DAC-hr and his team.

References

[1] T. Perel *et al.*, ‘Electrical properties of conventional and spark plasma sintering ZnO based varistors’, in *2011 Annual Report Conference on Electrical Insulation and Dielectric Phenomena*, Cancun, Mexico: IEEE, Oct. 2011, pp. 149–152. doi: 10.1109/CEIDP.2011.6232618.

[2] P. Figiel, M. Rozmus, and B. Smuk, ‘Properties of alumina ceramics obtained by conventional and non-conventional methods for sintering ceramics’, *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 48, no. 1, 2011.

[3] T. Tian *et al.*, ‘Effects of sintering on the microstructure and electrical properties of ZnO-based thermoelectric materials’, *Materials & Design*, vol. 132, pp. 479–485, Oct. 2017, doi: 10.1016/j.matdes.2017.07.033.

[4] D. Szwagierczak, J. Kulawik, and A. Skwarek, ‘Influence of processing on microstructure and electrical characteristics of multilayer varistors’, *J Adv Ceram*, vol. 8, no. 3, pp. 408–417, Sep. 2019, doi: 10.1007/s40145-019-0323-7.

[5] M. Reza, ‘Metal Oxide ZnO-Based Varistor Ceramics’, in *Advances in Ceramics - Electric and Magnetic Ceramics, Bioceramics, Ceramics and Environment*, C. Sikalidis, Ed., InTech, 2011. doi: 10.5772/23601.

[6] M. S. M. Ghazali, M. S. Shaifudin, W. R. W. Abdullah, W. M. I. W. M. Kamaruzzaman, M. F. M. Fekeri, and M. A. Zulkifli, ‘Conventional Sintering Effects on the Microstructure and Electrical Characteristics of Low-Voltage Ceramic Varistor’, in *Sintering Technology - Method and Application*, M. Liu, Ed., InTech, 2018. doi: 10.5772/intechopen.78652.

[7] F. Kharchouche, ‘Effect Of sintering temperature on microstructure and electrical properties of ZnO-0.5 mol%V2O5-0.5 mol%Cr_2O_3 varistors’, *J Mater Sci: Mater Electron*, vol. 29, no. 5, pp. 3891–3897, Mar. 2018, doi: 10.1007/s10854-017-8327-y.

[8] T. Tian *et al.*, ‘Effects of sintering on the microstructure and electrical properties of ZnO-based thermoelectric materials’, *Materials & Design*, vol. 132, pp. 479–485, Oct. 2017, doi: 10.1016/j.matdes.2017.07.033.

[9] T. Tian *et al.*, ‘Effects of sintering on the microstructure and electrical properties of ZnO-based thermoelectric materials’, *Materials & Design*, vol. 132, pp. 479–485, Oct. 2017, doi: 10.1016/j.matdes.2017.07.033.

[10] X. Zhao *et al.*, ‘Cold sintering ZnO based varistor ceramics with controlled grain growth to realize superior breakdown electric field’, *Journal of the European Ceramic Society*, vol. 41, no. 1, pp. 430–435, Jan. 2021, doi: 10.1016/j.jeurceramsoc.2020.09.023.

[11] Y. Mei *et al.*, ‘Processing and characterizations of flash sintered ZnO-Bi_2O_3-MnO_2 varistor ceramics under different electric fields’, *Journal of the European Ceramic Society*, vol. 40, no. 4, pp. 1330–1337, Apr. 2020, doi: 10.1016/j.jeurceramsoc.2019.11.013.

[12] J. Li, K. Tang, S. Yang, and D. Zhu, ‘Effects of Sb2O3 on the microstructure and electrical properties of ZnO–Bi2O3-based varistor ceramics fabricated by two-step solid-state reaction route’, *Ceramics International*, vol. 47, no. 14, pp. 19394–19401, Jul. 2021, doi: 10.1016/j.ceramint.2021.03.276.

[13] S. M. Syaizwadi, S. S. Noradilah, M. G. M. Sabri, W. A. W. Rafizah, K. Syara, and O. J. Lee, ‘Effect of Sintering Temperature on Zinc Oxide Varistor Ceramics’, *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 440, p. 012037, Oct. 2018, doi: 10.1088/1757-899X/440/1/012037.

[14] A. Bouchekhlal and F. Hobar, ‘Effect of sintering temperature on microstructure and nonlinear electrical characteristics of ZnO varistor’, *J. Adv. Dielect.*, vol. 08, no. 02, p. 1850014, Apr. 2018, doi: 10.1142/S2010135X18500145.