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Effect of Sintering Temperature on Zinc Oxide Varistor Ceramics

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Abstract: Zinc oxide (ZnO) varistors is a solid state electronic ceramic component whose function to protect electronic devices against over voltage surges due to their highly nonlinear electrical properties and ability in controlling the energy. In this study, ZnO varistor is prepared via solid state reaction method. The ZnO based varistor ceramics undergoes sintering temperature at 900 °C, 1100 °C and 1300 °C for 45 minutes. The used of sintering temperature from 900 to 1300 °C, has increased the grain size of ZnO and improved their crystallinity as shown from the peaks intensity of X-ray diffraction (XRD). Current-Voltage properties exhibit the value of nonlinear coefficient in the range of 1.44 to 1.76. Different sintering temperature is used to adjust the microstructure and improve the varistor ceramic characteristics where it shows a potential difference in various application of electronic devices. Increasing in sintering temperature would lead to improved grain growth for better electrical properties.

Keywords: Varistor, ZnO ceramics, sintering

1 Introduction

ZnO varistors are electronic component with highly nonlinear properties and commonly used as overvoltage protector in electronic circuits. ZnO varistor are used to protect a variety of electronic devices against overvoltage surges due to nonlinear current-voltage (I-V) properties [1]. ZnO ceramics as a based varistor usually study due to its capability and good performance [2]. The improvement of ZnO varistor capabilities is accomplish by testing their effect alone first and second was added with some metal oxide additives to improve their electrical properties. ZnO varistors are sintered with various metal oxide additives in order to enhance their nonlinear electrical properties [3]. However, complex formulation where more than five doping elements are needed to improve nonlinear properties of varistor ceramics. The microstructure and electrical characteristics of ZnO is not only influenced by the type of additives, but also by the different stages of sintering. The microstructure are related to electrical characteristics, where the varistor voltages can be significantly controlled by means of the sintering temperature [4]. The additives and the processing conditions are the most important factor of success in the development of the surge protection device [5]. The use of different sintering temperature will show the potential difference in the development of microstructure and electrical properties in doped zinc oxide. Sintering temperature gives rise to a particular microstructure of ZnO [6]. Electrical characteristics of ZnO varistor ceramics are studied intensively due to its capability and it is important to investigate the electronic states of ZnO ceramic in different sintering temperatures. Sintering has a prominent effect on the microstructure of ZnO varistors [7]. The charge transfer basically controls the electrical conduction within ZnO varistors during sintering [8].
ZnO varistor, due to their high electrical nonlinearity and energy absorption abilities have been used in electronic industries. It is important to obtain electronic samples with high energy handling capabilities for efficiency protection in electronic industries from overvoltage that can damage the electrical systems [9]. Varistor components are important in protecting various electrical equipment from overvoltage and it can be operate constantly without damage [10]. In varistor component, the most important parameter is the nonlinear coefficient ($\alpha$) where it defines how fast the change is from the high resistive to the low resistive condition, by absorb the dangerous surge to flow through the ground [11]. Significant differences in parameter used in the processing of varistor ceramics will give a better insight to the limitation of the material, therefore in this study the effect of different thermal treatment on the performance of ZnO varistor is investigate. This varistor ceramics are fabricated via solid state reaction method and analyze by XRD and I-V source measure unit.

2 Materials and Methods

ZnO micro powders with 99.0% purity (Merck) was used as the base material. Mass of the powders that used for ceramic preparation was weighed according to their weight ratio using digital analytical balance. The powder was mixed with the 1.75 wt.% polyvinyl alcohol (PVA) powder until it is fully wet and is drying by using oven. PVA powder acts as a binder to give strength to the pressed compact pellets and avoid micro-cracks. After drying, the powder was grounded using agate mortar and then sieved using a 75 micron sieve. The powder for each sample were measure again by using digital analytical balance. The powders were pressed to form a pellet with 13.0 mm diameter and 1.3 mm thickness using Hydraulic Press machine at a pressure 2.6 ton/5min. Finally, the pellet were exposed to temperature at 900 °C, 1100 °C and 1300 °C for 45 minutes in a box furnace with the heating and cooling rate at 2.66 °C/min. The crystalline phase of ZnO powders before and after sintering were measured using X-ray diffraction (XRD). A small amount sample was carried out at 20 scan over the diffraction angles from 5° to 80° at the speed of 2.00°/min. The sample pellets at different sintering temperature and duration are selected and silver conductive paint is applied on both sides of samples. Electrical characteristic of sample pellets were measured using Current-Voltage source measure unit. The nonlinearity of the samples were determined from the Equation (1),

$$
\alpha = \frac{\log_{10} I_2 - \log_{10} I_1}{\log_{10} E_2 - \log_{10} E_1}
$$

where $\alpha$ defines the degree of nonlinear property of varistor materials. $E_1$ and $E_2$ are the electric fields corresponding to the current densities $I_1$ and $I_2$.

3 Results and Discussion

3.1 XRD

The XRD patterns of ZnO samples before and after sintering are shown in Figure 1. From the XRD analysis of the samples, the pattern reveals can be identified as the hexagonal wurtzite structure of ZnO ceramic based on ICSD code: 067454 [12]. The plotted graph of figure 1 shows the change in crystallinity or grain size in ZnO ceramics after undergoes different sintering temperatures. Microstructure properties are important factors that can be modified by the means of sintering parameter which directly affects the microstructure of ZnO varistor ceramics [13]. The peaks intensity is sharp and narrow, it shows that the sample are in good crystallinity and fine grain size. The effects of different sintering temperature on ZnO microstructure was compared based on the change in their crystallinity or grain size. The XRD technique reveals the primary phase of ZnO ceramic materials and no other phases are detected confirming that the pure ZnO are crystalline in nature.
Based on the XRD spectra it was shown that as the sintering temperature increased the diffraction peaks became sharper and stronger, indicating the crystallinity improvement of the samples. As the sintering temperature increases, the average grain size abruptly increased, indicating that the microstructure became more compact and less grain boundaries [14]. The average grain size of ZnO increases due to the grain growth and pore elimination. The rapid grain growth resulted from capillary driving forces at high temperatures the grain boundaries of ZnO can drastically change the physical properties [15].

3.2 I-V

The electrical characteristics of varistor are result from the fabrication process, particularly sintering temperature. Figure 2 shows the electrical characteristics of ZnO based varistor ceramics sintered at different temperatures. The influence of sintering temperature on the nonlinear electrical properties of ZnO varistor ceramics were investigate at 900 °C, 1100 °C and 1300 °C. The change from the electrical behaviour with increased sintering temperature was assigned to the improved microstructure.
Figure 2: Current-Voltage (I-V) characteristics of sintered samples at 900 °C, 1100 °C and 1300 °C.

The good characteristics found suitable for varistor behaviour was presented by the sample sintered at 1100 °C. The variation of α as a function of grain size is exhibited in Table 1.
Table 1: Comparison of nonlinear coefficient, $\alpha$

| Compound | Sintering Temperature | Nonlinear coefficient ($\alpha$) |
|----------|-----------------------|----------------------------------|
| ZnO      | 900 ºC                | 1.71                             |
|          | 1100 ºC               | 1.76                             |
|          | 1300 ºC               | 1.44                             |

It was observed that $\alpha$ value in Table 1 increases when the temperature increased and then decreases with further increase in sintering temperature and induced the grain size of varistor ceramics. The increment of $\alpha$ value with the sintering temperature was due to the increase of grain size and improve their microstructure. The increase in nonlinear coefficient of ZnO varistor correspond to an increase in the grain size which suggests the existence of larger grain size in the grain boundaries at higher sintering temperature [16].

4 Conclusion

Preliminary studies on ZnO based varistor ceramics give a broad idea to researcher for their further research. In this present study, the XRD pattern shows the change in crystallinity through increasing the sintering temperature. The nonlinearity of ZnO varistor ceramics as a function of sintering temperature was monitored by using I-V source measurement. The $\alpha$ value increased proportionally with the increased in sintering temperature. However, a sudden drop was observed in $\alpha$ value after sintering above 1100 ºC, which suggests the existence of larger grain size in the grain boundaries at higher sintering temperature. Finally, the sintering process gives rise to a microstructure and improves the electrical properties of varistor ceramics.

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