COMPARATIVE ANALYSIS OF THE VOLT-AMPERE CHARACTERISTICS AND APPLICATION AREAS OF ZnO-BASED COMPOSITE VARISTORS

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In the article, the application of composite varistors fabricated using ZnO particles of different thicknesses (h = 40 μm; h = 300 μm) in both low- and high-voltage technologies has been investigated. For this purpose, the volt-ampere characteristics of ZnO-based composite varistors with different particle thicknesses and varying volume percentages were measured. The effect of sample thickness on the breakdown voltage and nonlinearity coefficient of the volt-ampere characteristics was studied. At the same time, a detailed analysis of the volt-ampere characteristics was conducted for samples with identical thickness but different volume percentages.

Keywords: composite varistors, ceramic phase, geometric dimensions, thickness, volt-ampere characteristics, particle, high and low voltage.
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INTRODUCTION

It is well known that varistors are elements with nonlinear volt-ampere characteristics and serve a protective function. Conventional varistors are typically fabricated from ceramic materials based on zinc oxide (ZnO). The advantages of ZnO varistors include high thermal and electrical stability, the ability to operate within a wide voltage range, and the potential for production using relatively low-cost technology [1]. In recent years, growing interest in the development of composite varistors has introduced new approaches to this field. It has been established that the size, shape, and distribution scale of ceramic particles (such as ZnO, SiC, TiO_2) dispersed in a polymer matrix have a direct impact on the electrical properties of the varistor [2].

In the global literature, the role of the geometric dimensions of the ceramic phase in composite varistors has been particularly emphasized. It has been shown that as the size of ZnO particles decreases, the breakdown voltage of the varistor increases. However, the nonlinearity coefficient increases up to a certain limit and then stabilizes [2]. Studies have demonstrated that the composition and dimensions of interparticle boundaries play a critical role in the formation of ZnO-based microvaristors [3]. Experimental results have confirmed that in ZnO-polymer composites, the size and distribution of the ceramic phase affect both dielectric stability and energy absorption capacity [4]. Nonetheless, there is a lack of systematic and structured approaches in this area within Azerbaijani and regional research. In particular, investigating the relationship between the geometric dimensions of the ceramic phase and the voltage characteristics in composite structures under local experimental conditions holds significant scientific and practical importance.

This article investigates the effect of the particle size of the ceramic phase in ZnO-polymer-based composite varistor structures on the operating voltage and nonlinearity coefficient of the varistor. The objective is to study how the geometric dimensions, thickness, and volume percentage of composite varistors fabricated using ZnO particles of different thicknesses (h = 40 μm; h = 300 μm) influence their electrical properties and their potential applications in the energy sector. The findings, in parallel with global literature, are expected not only to pave the way for new local applications but also to contribute to the development of more efficient varistor elements in this field[4].

EXPERIMENTAL PART AND DISCUSSION OF RESULTS

Preparation of ZnO-Based Thin-Film Composite Varistors:

- The synthesis of ZnO-based thin-film composite varistors was carried out through a multi-step process. This method allows for precise control of each parameter and ensures the production of high-quality composites with desirable electrical properties [5–11].

The ZnO-based thin-film composite varistors were prepared in the following sequence:

- Preparation of the Ceramic Phase Material Selection and Weighing: The ceramic component, ZnO, was weighed with an accuracy of ±0.01 g, with a total mass of 100 g.
- Thermal Processing: The ZnO material was placed in an electric furnace for initial thermal treatment. The temperature profile was as follows: heated at a rate of 145°C/hour up to 900°C. Then, the heating continued at a rate of 180°C/hour until reaching 1240°C.
- Pellet Formation: Once the target temperature was reached, the ZnO material was compressed into pellets using a hydraulic press under a uniaxial pressure of 40 tons.

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- Sintering and Annealing Conditions: The compressed ceramic pellets were sintered in ambient air to ensure uniform oxidation.
- Annealing: The ceramic samples were annealed at 1100°C for 1,5 hours. After annealing, the samples were allowed to cool naturally inside the furnace for 7–8 hours to prevent thermal stress.
- Crushing and Size Control: The cooled samples were broken down into small particles using a mechanical crusher.
- Ball Milling: The crushed material was further milled in a porcelain ball mill to reduce particle size. As a result of this process, ceramic powders with particle sizes ≤40 μm were obtained.
- Sieving: The milled powder was sieved to ensure a uniform particle size distribution, which is essential for the subsequent formation of the composite.
- Composite Preparation and Polymer Mixing: The ceramic powders were mixed with non-linear polyethylene (PE) polymer at predetermined ratios. The choice of polymer influences the dielectric and varistor properties of the composite.
- Hot Pressing: Thin-film composites were produced from the mixture using a hot pressing technique. Pressing parameters were optimized for each polymer type. As a result, homogeneous films with a thickness of 0.018 cm were obtained.
- Thickness Measurement (d): The thickness of the composite samples was measured using a micrometer with an accuracy of ±1 μm.

Figure 1 shows the current–voltage (I–V) characteristics of ZnO-based composite varistors with different thicknesses.

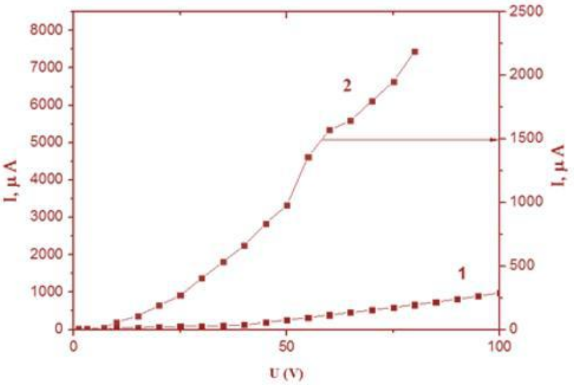

Fig. 1. Current–voltage (I–V) characteristics of ZnO-based composite varistors with different thicknesses (particle size d = 40 μm). 1-50%(C)+50%Pe(h=300μ); 2-50%(C)+50%Pe(h=40μ)

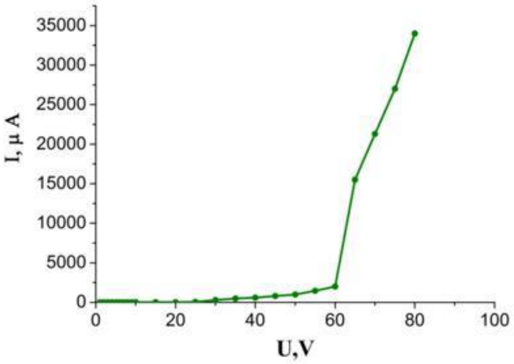

Fig. 2. Current–voltage (I–V) characteristics of a ZnO-based composite varistor with a volumetric composition of 10% ceramic (C) + 90% polyethylene (PE) (h = 40 μm) (particle size d = 40 μm).

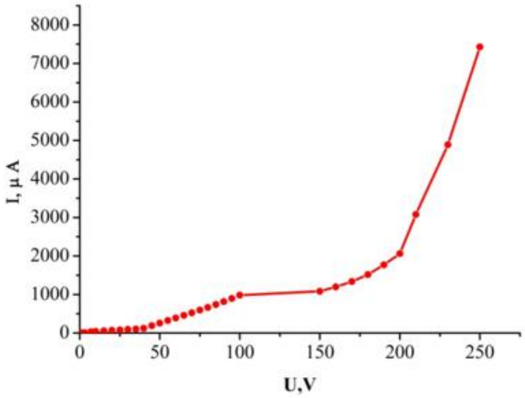

Fig. 3. Current–voltage (I–V) characteristics of a ZnO-based composite varistor with a volumetric composition of 60% ceramic (C)+ 40% polyethylene (PE) (h = 40 μm) (particle size d = 40 μm).

The current–voltage (I–V) characteristics of ZnO composite varistors with compositions of 10% ceramic (C) + 90% polyethylene (PE) and 60% ceramic (C) + 40% polyethylene (PE) are compared in Figures 2 and 3, respectively. Analysis of the figures reveals that although both varistors have the same particle size (d = 40 μm), the volume fractions of ceramic and polymer differ, which affects their response to the electric field. It is well known that the primary function of ZnO-based varistors is to provide a protective barrier against voltage fluctuations. The microstructure and electrical properties of the constituent materials significantly influence the performance of ZnO-based varistors.

The varistor composed of 10% C + 90% PE exhibits a steeper current–voltage characteristic curve, indicating a higher nonlinearity coefficient. Such varistors sharply increase current conduction even with slight voltage increases. This characteristic makes them suitable for fast response applications in low-voltage electronic devices[6–11].

Conversely, the 60% C + 40% PE composite varistor displays lower steepness and nonlinearity. These varistors are better suited for high-voltage power systems, as such applications require a wider transition region.

CONCLUSION

The analysis of the experimental results demonstrated that the electrical properties of ZnO-based composite varistors significantly depend on their thickness. Specifically, thin-film composite varistors with a thickness of 40 μm exhibit lower breakdown voltages and higher nonlinearity coefficients, making them more suitable as protective components in sensitive systems such as microelectronics. Conversely, composite varistors with a thickness of 300 μm are characterized by higher breakdown voltages and relatively lower nonlinearity coefficients, which renders them more appropriate for applications in high-voltage industrial and power transmission systems.

Furthermore, the electrical properties of ZnO-based composite varistors are strongly influenced by the composition ratios and microstructure of their constituent materials. The investigated samples revealed that composites with higher polyethylene (PE) content exhibit pronounced nonlinearity, making them suitable for low-voltage technologies, whereas composites with higher ceramic (C) content are better suited for high-voltage applications. These findings highlight the importance of selecting composite varistors according to their intended application and facilitate the design of optimized varistors tailored to diverse technological requirements.

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