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Electrical properties and AC degradation characteristics of low voltage ZnO varistors doped with Nd_2O_3

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Abstract

The electrical properties and degradation characteristics of low voltage ZnO varistors were investigated as a function of Nd_2O_3 content. The varistor ceramics with 0.03 mol% Nd_2O_3 sintered at 1250 °C were far more densified than those with 0.06, 0.09 and 0.12 mol% Nd_2O_3. The addition of Nd_2O_3 to the low voltage ZnO varistors greatly improved the current–voltage characteristics; the nonlinear coefficient of varistors increase from 12.2 to 34.6 with increasing Nd_2O_3 content. The samples with 0.03 mol% Nd_2O_3 showed excellent stability due to high density and relatively good *V–I* characteristics, with the nonlinear coefficient of 22.5 and the leakage current of 9.6 μA. Their variation rate of varistor voltage and nonlinear coefficient and leakage current were −4.7%, −5.4%, 18.3%, respectively, under AC degradation stress (1.0 $V_{1\ mA}$/125 °C/24 h).
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Keywords: Varistors; Degradation; Nd_2O_3; Electrical characteristics; Stability

1. Introduction

ZnO varistors with high nonlinearity in their current–voltage characteristics are extensively used as protecting devices against transient voltage in electronic and industrial equipment and as surge arrestors. The most important property of a varistor is its nonlinear current–voltage characteristic, which can be expressed by the equation $I = KV^{\alpha}$, where α is the nonlinear coefficient, which characterizes the nonlinear properties of varistors, the higher the value of α, the better the clamp. Moreover, ZnO varistors possess excellent surge withstanding capabilities [1–3].

The ZnO varistors are suited for high-voltage applications. However, an increasing number of low voltage varistors is being used for surge protection in integrated circuits and automobiles. Since the breakdown voltage (varistor voltage) is proportional to the number of ZnO grains in series between the electrodes, low voltage varistors can be obtained by either decreasing the thickness of the specimen or increasing the size of ZnO grains. The thin ZnO varistors are difficult to prepare and apt to break. Note also that the energy absorption capability of thin ZnO varistors is very poor due to its small volume. On the other hand, low voltage ZnO varistors with grains of large size have been fabricated by using grain growth-enhancing additives. TiO_2 can greatly enhance the grain growth of ZnO, thus widely used in producing low voltage ZnO varistors, but the doping of TiO_2 have restricted nonlinear current-voltage characteristics, and the α value is very low. Consequently, its microstructure exhibits a nonuniform distribution of grain size, which causes an irregular current distribution and makes the varistor susceptible to hot spots [4,5].

More recently, the published literature reported that ZnO varistors added with rare-earth metal oxides, such as CeO_2 and Y_2O_3, exhibits high nonlinearity and stability [6,7]. In this paper, the effect of Nd_2O_3 content on electrical properties and AC degradation characteristics of low voltage ZnO varistor ceramics was investigated.

2. Experimental

2.1. Sample preparation

Reagent-grade raw materials were prepared for low voltage ZnO varistors, the base composition was: 95.95% ZnO + 0.75% Bi_2O_3 + 0.8% TiO_2 + 0.5% NiO + 1.0%

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Co_2O_3 + 0.5% $MnCO_3$ + 0.5% SnO_2 (all in mol%). The other samples were Nd_2O_3-doped low voltage varistors (the base composition plus 0%, 0.03%, 0.06%, 0.09%, 0.12% Nd_2O_3). The powder mixtures were wet ball-milled in a polyethylene bottle with ZrO_2 balls of 24 h in deionized water. After dried and granulated, the powder was pressed into discs of 10 mm in diameter and 1.2 mm in thickness at a pressure of 80 MPa. The discs were sintered at 1250 °C in air for 1 h, with heating and cooling rates of 300 °C/h. The size of the final samples was about 8 mm in diameter and 1.0 mm in thickness. For the studies of electrical properties, silver paste was applied to the faces of the discs (which were subsequently heated at 600 °C for 20 min) to provide electrodes, the size of electrodes was 5 mm in diameter.

2.2. Methods characterization

Sintered density (ρ) was determined by Archimede method. The microstructure and grain size distributions were carried out using a scanning electron microscope (SEM). Average grain size (d) was measured by the linear intercept method on the micrographs. The polished samples were lightly etched with dilute solution of hydrochloric for microstructure investigations.

The current–voltage (V–I) characteristics of low voltage ZnO varistors were measured using CJ1001 meters, the varistor voltage $V_{1\ mA}$ was determined at current density of 1 mA/cm^2, the leakage current I_L was determined at 0.83 $V_{1\ mA}$. In addition, the nonlinear coefficient α was determined from $\alpha = (\log I_2 - \log I_1)/(\log V_2 - \log V_1)$, where I_1 = 0.1 mA/cm^2, I_2 = 1.0 mA/cm^2, and V_1 and V_2 are the electrical fields corresponding to I_1 and I_2, respectively [8,9].

The AC (50 Hz) degradation tests were carried out under continuous conditions, such as 1.0 $V_{1\ mA}$rms/125 °C/24 h. Simultaneously, the leakage current was monitored at interval of 1 min during stressing using CJ1001 meter. The degradation rate coefficient (K_T) was calculated from the expression $I_L = I_{L0} + K_T t^{1/2}$, where I_L is leakage current at stress time (t) and I_{L0} is I_L at $t = 0$. After the stress, the V–I characteristics were measured at room temperature.

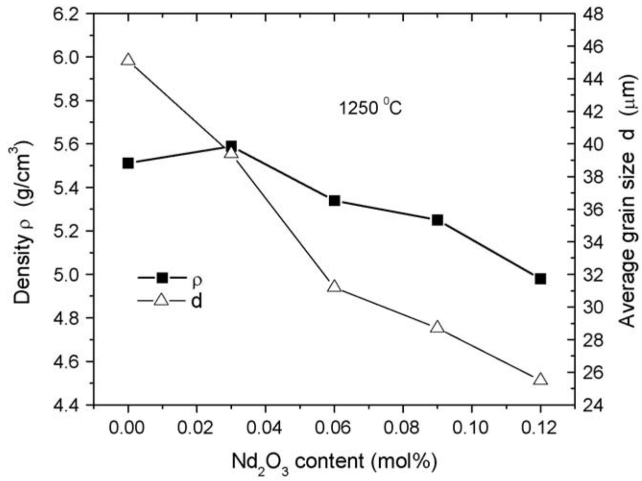

Fig. 1. The density (ρ) and average grain size (d) of low voltage ZnO varistors with Nd_2O_3 content.

The capacitance–voltage (C–V) characteristics of low voltage ZnO varistors were measured at 1 kHz with the variable applied bias in the pre-breakdown region of the V–I characteristics using a LRC meter.

3. Results and discussion

3.1. Density and microstructure

Fig. 1 shows the density (ρ) and average grain size (d) of varistor sintered at 1250 °C with various Nd_2O_3 content. The density of ceramics was gradually decreased from 5.60 to 4.79 g/cm^3, corresponding to the range of 98–85% of theoretical density (TD) of pure ZnO (TD = 5.61 g/cm^3 in ZnO). The ceramics with 0.03 mol% Nd_2O_3 sintered at 1250 °C exhibited the highest densification, reaching 98% of TD. The density greatly affects the resistance of degradation together with a leakage current. This will be discussed later in more

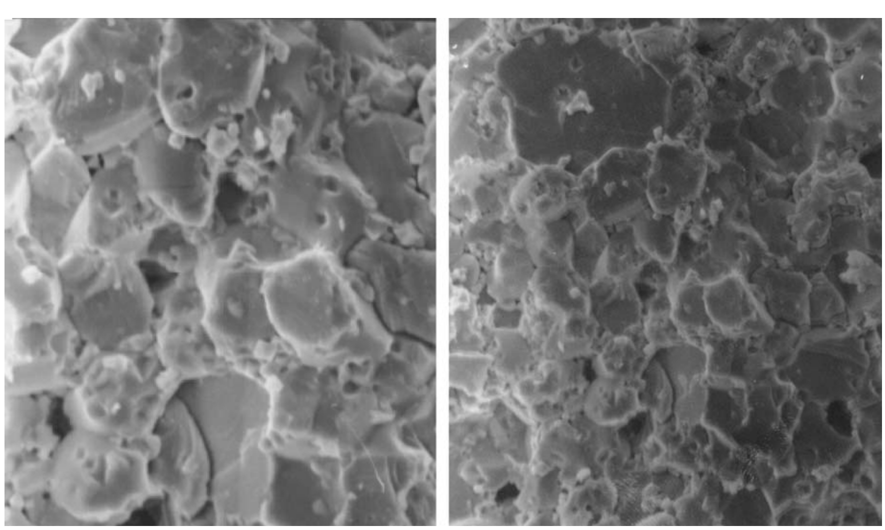

Fig. 2. SEM micrographs of varistor ceramics with various Nd_2O_3 content. (a) 0.06 mol% and (b) 0.12 mol%.