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Improvement of Electrical Features of SnO2 Based Varistor Doped With Al_2O_3

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Abstract: One of the important objectives of the varistor is for a sustainable environment and reduce the pollution resulting from the frequent damage of the electrical devices and power station waste. In present work, the influence of Al2O3 additives on the non –linear electrical features of SnO2 varistors, has been investigated, where SnO2 ceramic powder doped with Al2O3 in three rates (0.005, 0.01, and 0.05), the XRD test improved that SnO2 is the primary phase, while CoCr2O4, and Al2O3 represent the secondary phases. The electrical tests of all prepared samples confirmed that the increasing of Al2O3 rates and sintering temperature improves and increase the electrical features, where the best results obtained at Al2O3 (0.05) and 1000℃, the non-linear coefficient (49), energy absorption capability (3890Joul), and breakdown voltage (4040Volt), while the leakage current passes through the varistor decreased to the minimum value ($41\mu A$).

Keywords: SnO_2 varistors; Electrical properties; Schottky barriers, Al_2O_3.

INTRODUCTION

The devices that have non-ohmic behavior are in general electronic ceramic materials which electrical features are greatly dominated by grain-boundary interface states. These non-ohmic ceramic devices are also known as "metal-oxide" varistors (variable resistors) whose applications are technologically important because of their electrical characteristics that enable them to be used as solid state switches with large-energy-handling capabilities[1-3].

Varistors are ceramic semiconductor devices with highly nonlinear current–voltage characteristics similar to back-to-back Zener diodes but with much higher current and energy handling capabilities [1, 4, 5].

Metal oxide varistors are electronic ceramic devices with primary functions of sensing and limiting transient voltage surges in electronic devices and energy-related transmission equipments. Among several metal oxides, tin dioxide SnO2-based materials have received much attention recently due to their crucial technological applications. They have been used in electro-optical equipments and glass industry, catalysts, gas sensors and varistors [2,6].

At the same time, varistors based on other ceramic systems have also been under investigation, because of the need for better properties. One of these systems are the SnO2-based varistors [4, 7]. Tin dioxide (SnO2) is an n-type semiconductor with rutile type crystalline structure and has low densification rate due to its high surface tension as diffusion coefficient at low temperatures and high SnO2 partial pressure at high temperatures, Dense SnO2-based ceramics can be achieved by introducing dopants [4,7-9].

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The current density (J) and the applied electrical fields (E) of non-ohmic ceramic materials are related by the following relationship[9-11][9]:

$J = K.E^{\alpha}$ (1)

Or

$$I = KV^{\alpha}$$

$$\alpha = \frac{\log(I_2/I_1)}{\log(V_2/V_1)} \Rightarrow \alpha = \frac{1}{log(V_{1mA}/V_{0.1mA})} \quad [12\,,13]$$

Where α is the non-linear coefficient, K is a constant that, J1= 0.1 mA cm-2, J2= mA cm-2, E1 and E2 are potential gradient corresponding to current densities 0.1 mA cm-2, I2 =1 mA, I1 = 0.1 mA, V1mA and V0.1mA represent the voltage at 1 and 0.1mA respectively [14-16].

The non-linear coefficient is conventionally obtained for current densities around 0.1 mA cm-2 [1,9,10].

The breakdown voltage (Vb) can be defined as at which the onset of nonlinearity occurs and it means that the device changes from insulating regime to conducting regime, and it be measured by the following equation:

$$V_b = 0.8\,V_{0.5\,mA}$$

Where V0.5mA the voltage when the current reach 0.5mA [5, 7, 18].

While The Leakage Current (IL) represents the current that passes through the device in the pre-breakdown region, which measured from the equation:

$I_L = 0.75\, I_{V_{0.1}}$, Where $I_{V_{0.1}}$ the current when the voltage corresponding the current 0.1 mA [2, 19-21].

Finally, the energy absorption capability can be defined as the ability of device to absorb transient energy and handle it [22].

$E = KI^{\beta+1}\, t$ (2)

Where (K) is a constant and can be calculated from the equation of the nonlinearity coefficient (α) and $(\beta = 1 / \alpha)$ [2, 19, 20].

SAMPLE PREPARATION

Preparation of the specimens was accomplished by the conventional fabrication ceramic process. The oxides of the reaction were used in rates of mol. % [(95-A) SnO2+ 1.00 Nb2O3 + 1.00 CoO + 1.00 Cr2O3], where (A= 0.000, 0.001, 0.005, and 0.05 of Al2O3).

The above-mentioned oxides mixed in glass container with deionized water using magnetic bar in magnetic stirrer for 24 hours. After mixing, the mixtures dried at 75oC for 48 hours.

After drying process the mixtures calcined for 2 hours with rate of 5o C/min at 500oC , and this process to expel the gases and the humidity from the mixture, after calcination the mixture remiled and uniaxially pressed into pellets shape of 15 mm diameter and thickness 2 mm using a pressure equals to $250\ bar$. Then the pellets sintered in air at (1050, 1100, 1150) o C with rate equals to 5o C/min for 2 hours for each sample.

Silver pastes were coated on both faces to measure the electrical properties, of the samples and the electrodes were formed by heating at 300o C for 1 hour, with diameter of 9mm.

The leakage current IL was measured at the voltage of 0.75 V1mA the nonlinear coefficient (α) measured in the range of 0.1mA to 1mA, according to the equations above, and the breakdown voltage measured at the current of 1mA, the potential.

RESULTS AND DISCUSSION

Fig.1 Illustrates XRD test results of the following samples at sintering temperature sintered 900oC, 950oC and 1000oC, with Al2O3 doping rate 0.05%.

As a result, it can be observed that SnO2 represents the primary phase, while CoCr2O4 and Al2O3 represent the secondary phase.

Fig.2 (a, b, and c) explains varistors current opposite voltage curves for the SnO2 based ceramic containing different concentration of Al2O3 , at 900oC, 950oC and 1000oC.

We can observe that the first part (onset) of the current voltage curve of represents a linear behavior and then transform to the nonlinear behavior, which means that SnO2 is an n-type semiconductor, but the doping transforms it behavior to the nonlinear.

From Fig.3 We can notice that the non-linear coefficient values of the samples increase with increasing of sintering temperature and Al2O3 rates where the maximum value of the non-linear coefficient was 49 at sintering temperature 1000oC and Al2O3 rate 0.05%, due to the increasing of the grain growth, distribution and rearrangement of SnO2 grains with increasing of temperature which leads to increasing the number and height of double Schottky barriers (Which represents the physical essential role of the varistor) between SnO2 grains and the insulating layer, while the increasing of Al2O3 rate increases O2 vacancies and the phase of CoCr2O4 insulator between SnO2 grains, and that due to the existing of Al+3 ions in the SnO2 grains because the radius of Sn+4 (0.83 Å) is larger than of Al+3 ions (0.68 Å).

The same explanation of non-linear coefficient is appropriate with leakage current, energy absorption capability, and breakdown voltage, as explained in Fig.4, Fig.5, and Fig.6 respectively.

Where the value of the leakage current decreases with increasing of the sintering temperature and Al2O3 rate, while the energy absorption capability, and the breakdown voltage increase with increasing of the sintering temperature and Al2O3 rate.

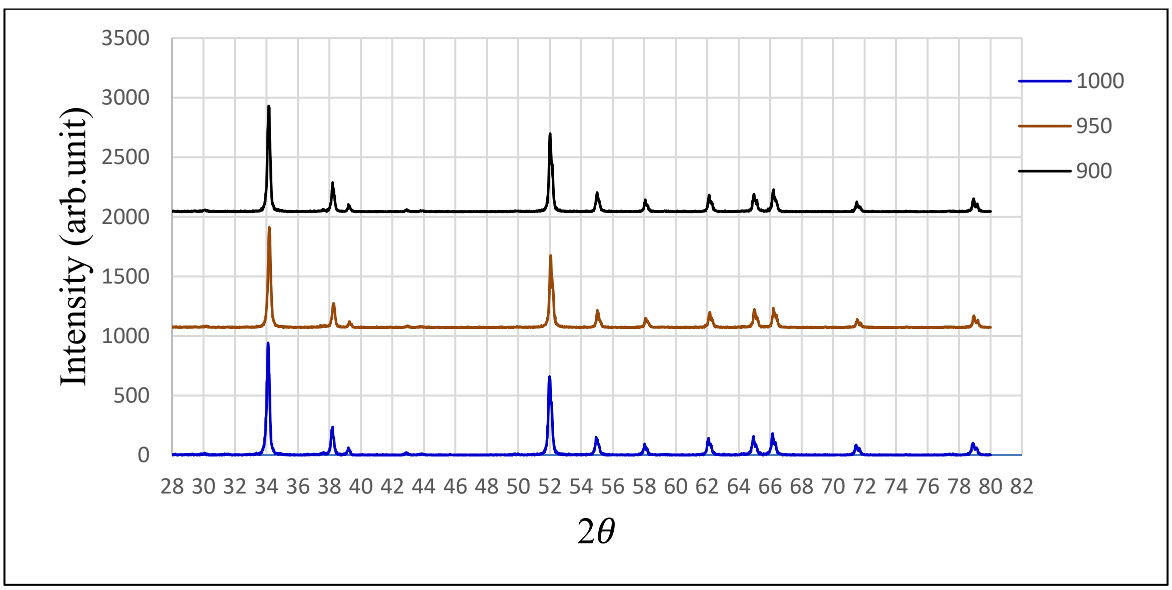

Figure (1): X-ray diffraction pattern for the SnO2- based varistor sintered at (from top to bottom) 900℃ , 950℃, and 1000℃, with Al2O3 doping rate 0.05%.

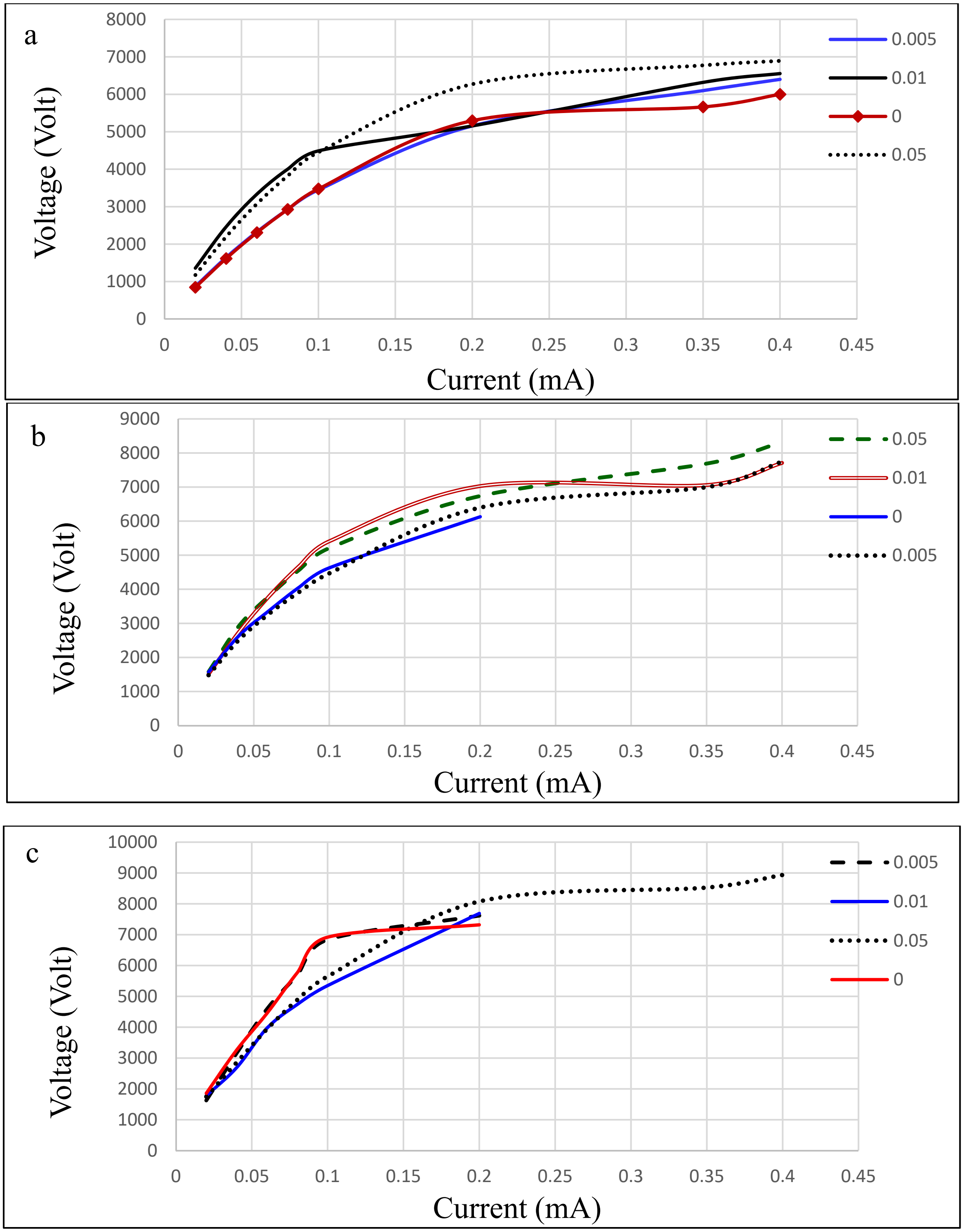

Figure (2): Current voltage characteristic of doped SnO_2 samples at 900, 950, and 1000℃.

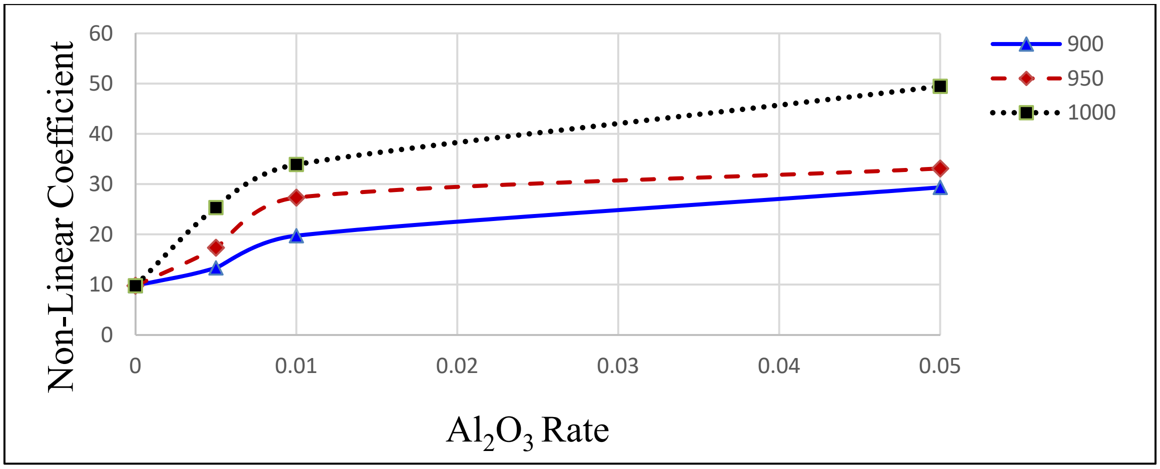

Figure (3): Non-Linear Coefficient opposite Al_2O_3 Rate at 900, 950, and 1000℃.

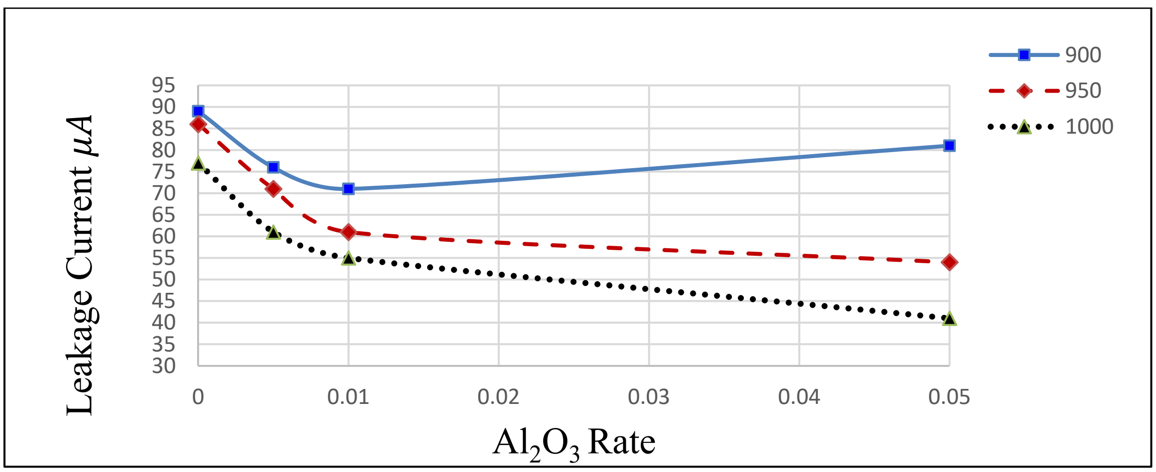

Figure (4): Leakage Current opposite Al2O3 Rate at 900, 950, and 1000℃.

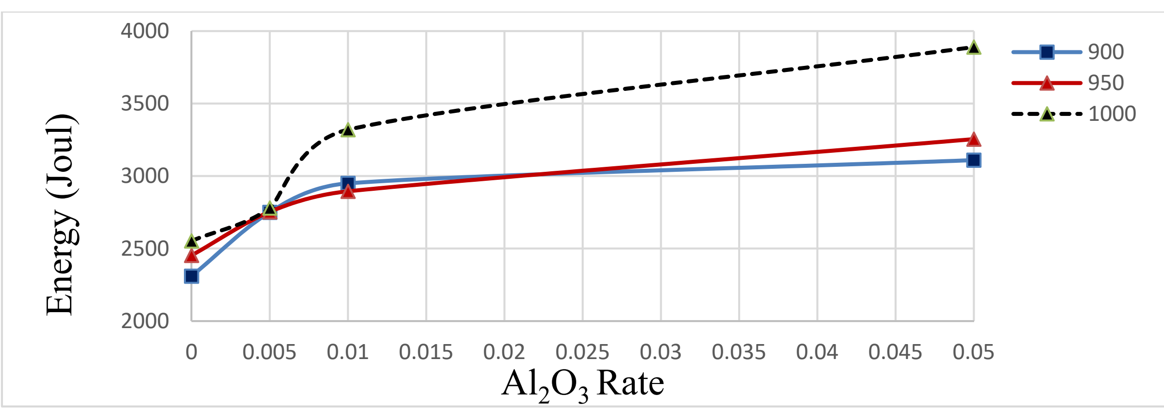

Figure (5): Energy absorption capability opposite Al2O3 Rate at 900, 950, and 1000℃.

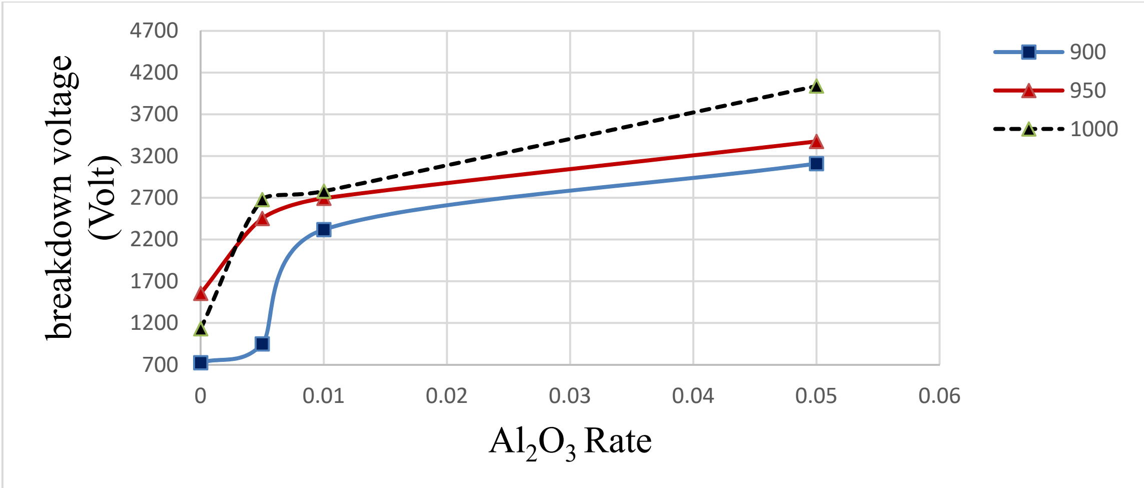

Fig (6). Breakdown voltage opposite Al_2O_3 Rate at 900, 950, and 1000℃.

CONCLUSION

SnO2 has linear electrical behavior (Ohmic material), which can be a good base for the transient voltage surge suppressers or protector (varistor), where the XRD test improves that SnO2 prepared samples are poly crystalline ceramic and the doping with some oxides can improves its electrical features, the doping with Al2O3 improves and enhances the electrical features, where the doping decrease the leakage current passes through the varistor, and in the same time increase the non-linear coefficient, energy absorption capability, and breakdown voltage, therefore it can be can be used in a high line power to protect power station and electronic equipment from the destructive transient high voltage and which leads to sustainable environment and minimizing pollution.

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