Conduction Mechanism Analysis of Low Voltage ZnO Varistor

Kyung-Uk Jang*, Myung-Ho Kim*, Joon-Ung Lee**
* Kyungwon College, ** Kwangwoon Univ.
* San 65, Bokjung-dong, Soojong-gu, Songnam-shi, Korea
** 447-1, Wolgye-dong, Nowon-ku, Seoul, Korea

Abstract

ZnO varistors have an excellent non-linearity and a large surge-energy absorption capability. For these reasons, the ZnO varistors are widely used to protect electrical/electronic circuits from an abnormal surge and/or noise signal. In order to obtain the low-voltage varistor with randomly distributed large seed grain within bulk, the ZnO varistors are made by a new three-composition seed grain method. And a conduction mechanism of varistors, which was observed in the temperature range of 30 ~ 120 ℃ and at the current range of 10^{-8} ~ 10^{2} A/cm^{2}, was classified by the three regions of different mechanism when the current was increased.

1. INTRODUCTION

ZnO varistors are nonlinear devices which are commonly used for a suppression of transient pulses and surges in electronic devices or power lines.

In this paper, it is introduced that a distribution of large grain size in ZnO for low voltage varistor is due to discontinuous grain growth and can be narrowed by using a 3-composition seed grain method. We also present the fact that the conduction mechanism of the fabricated varistor can be divided into the three region. The conduction properties of varistor, which was measured in the temperature range of 30~120℃ with the current range of 10^{-8}~10^{2}A/cm^{2}, was divided into the three region having different conduction mechanisms as the current was increased: The region Ⅰ(say, leakage-current region) in E_{int} < 25 MV/m shows an Ohmic conduction. The region Ⅱ(say, prebreakdown region) in the 25 < E_{int} < 70 MV/m can be explained by the Poole-Frenkel and Schottky conduction mechanism, and the region Ⅲ(breakdown region) in E_{int} > 70 MV/m is dominated by the tunneling effect.

2. EXPERIMENTAL

Fine powder composed with ZnO(97 mol%), $BaCO_3$(2.5 mol%) and TiO_2(0.5 mol%) were pressed at 450 kg/cm^{2}, and sintered in the furnace of 1400 ℃ for 10 hrs.

After those processes, the sintered bodies were washed in the boiled water, and then four kinds of different seed grain were obtained.

The compounds mixed with ZnO(98mol%), Bi_2O_3(1 mol%), CoO(0.5 mol%) and MnO_2(0.5 mol%), of which the seed grain contents are 0, 5, 10, 20 and 40 wt%, were pressed at 450 kg/cm^{2}. The pressed bodies were sintered in the furnace of 1300 ℃ for 2 hrs.

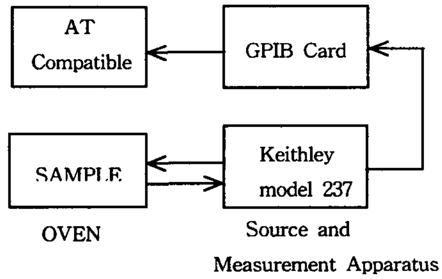

Fig. 1 Block diagram for I-V measuring apparatuses.

Electrical measurement of the sample was performed in the current range from 10^{-8} to 10^{2} A/cm^2 within the temperature range from 30 to 120 ℃, as shown in Fig 1.

3. RESULTS AND DISCUSSION

Fig. 2 shows the breakdown voltage characteristics of the samples with the various contents of seed grain.

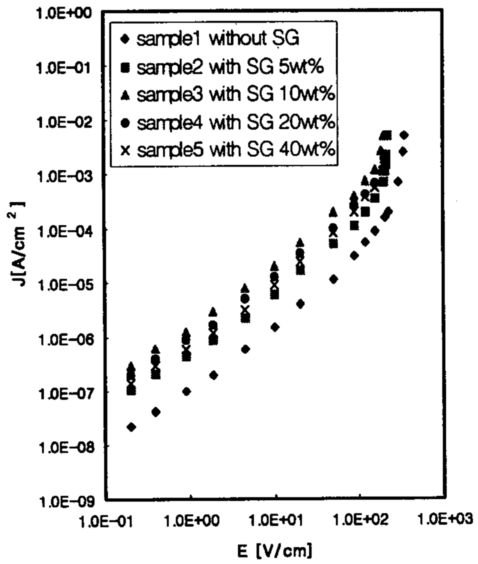

Fig. 2 Current-Voltage characteristics of ZnO varistor with the contents of the seed grain.

The optimized content rate of seed grain in the sample was 5 wt %.

The conduction mechanism of low-votage varistor with 5 wt% content of seed grain was classified by the three regions with different mechanism as shown in Fig. 3.

Fig. 3 show the temperature dependent current-voltage characterictics of the specimen added 5wt% of seed grain. The electrical conduction mechanism of the low-voltage ZnO varistor can't be decribed with one conduction mechanism. The I-V characteristic as shown in Fig. 3 can be classified as the 3 conduction mechanisms.

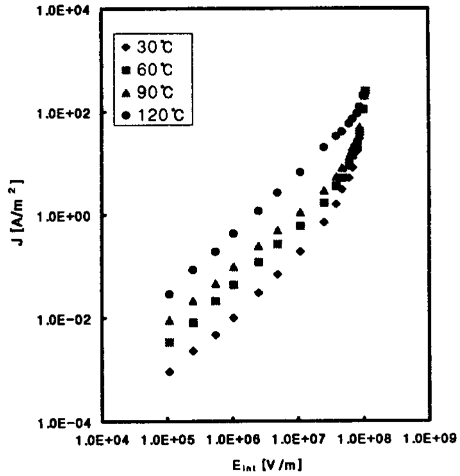

Fig. 3 Current-voltage characteristics of ZnO varistor with the content of seed grain 5 wt% for several different measuring temperatures.

(1) Conduction mechanism

The conduction current depends on the temperature and electric stress. Results of measurements are given in Fig. 3, which shows the conduction current of the ZnO varistor at constant temperature(30 and 120℃) as a function of the electric field stress.

1) Leakage current region, E_{int} < 25MV/m

Leakage current is important factor in causing the degradation of varistor, because it always flows before operation of varistor.

Fig. 4 is the Arrhenius plots of log J at steady state vs. 1/T for region I of Fig 3. The activation energy obtained from the diagram is 0.36eV.

2) Prebreakdown region, 25<E_{int}<70 MV/m

In Fig. 3, the prebreakdown region(region Ⅱ) is analyzed by the Poole-Frenkel emission theory considering the extrinsic level or trap between intergranular layers, because it has larger dependence of the electrical field than the leakage current region.

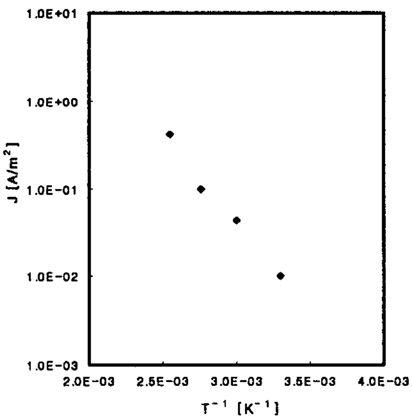

Fig. 4 Plot of log J vs. reciprocal temperature in region Ⅰ.

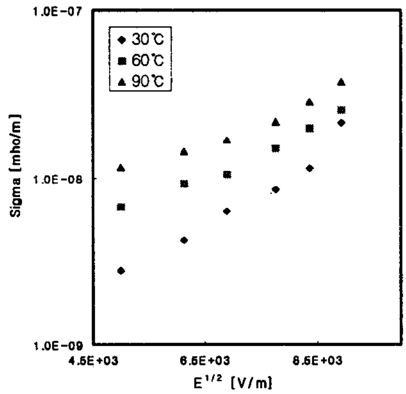

Fig. 5 Plot of log σ vs. $E^{1/2}$ in region Ⅱ.

Fig. 5 was obtained from Fig. 3, and shows the linear relationship between the log σ and $E^{1/2}$.

Thus Poole-Frenkel or Schottky conduction mechanisms may be operative in this region. To determine whether it is Poole-Frenkel or Schottky process, the slope of the straight lines in Fig. 5 are compared with the theoretically calculated slopes β_{th} from the Schottky relationship: $\beta_s = (e^3/4\pi\varepsilon_o\varepsilon_r)^{1/2}$. In Fig. 5, we found that β_{PF} is 3.4×10^{-24} and ε_r is 13, respectively.

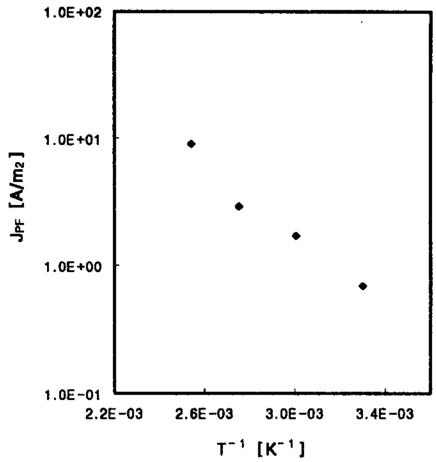

Fig. 6 Plot of J_{PF} vs. reciprocal temperature in Poole-Frenkel region.

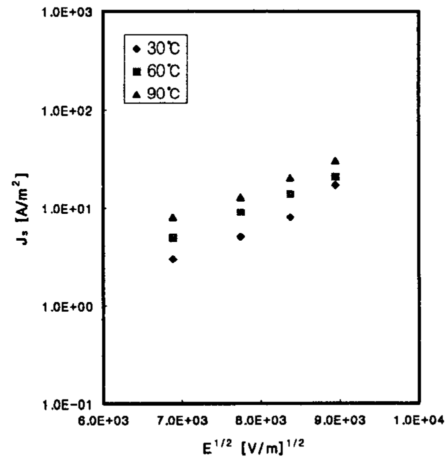

Fig. 7 Plot of logJ_s vs. $E^{1/2}$ in region Ⅱ.

The Arrhenius plot for a field of 44MV/m is shown in Fig. 6. The barrier height value is Φ= 0.7 eV.

The donor level, Φ, the potential barrier between the metal contact and dielectric material is obtained from the relationship of log(J_s/T^2) vs. 1/T at the applied field of 60MV/m (Fig.8). The donor level obtained is Φ=0.24 eV at an applied field of 60MV/m in Schottky region.

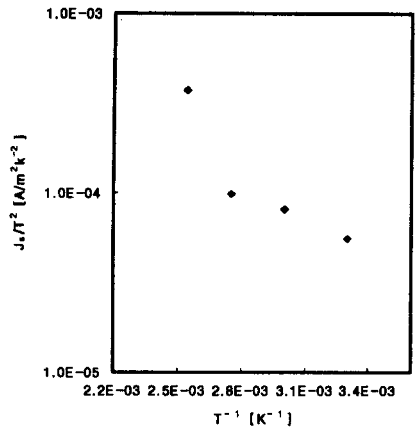

Fig. 8 Plot of log J_s vs. reciprocal temperature in region II.

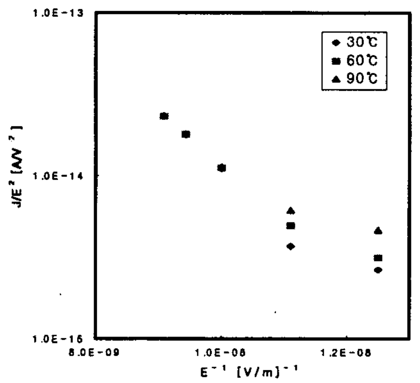

Fig. 9 Plot of the ln (J/E_{int}^2) and $1/E_{int}$ in the breakdown region.

3) Breakdown region, E_{int} > 70 MV/m

The conduction mechanism of breakdown region independenting on the ambient temperature has been proposed several theories such as space charge limited current, schottky emission theory and electron avalanche theory. However these theories are not efficiently explained the experimental phenomena in that region. The tunnel theory is applied into the breakdown region in this paper. Fig. 9 shows the log (J_{FN}/ E^2) vs. 1/E plot, and from the slope the potential barrier Φ=0.3 eV was obtained.

4. CONCLUSIONS

The results of the conduction mechanism for non-ohmic ZnO varistor by 3-composition seed grain method could be obtained as follows;

1. The knee voltage and nonlinear coefficient α of the specimen with 3-composition seed grain of 5 wt % are 5 V and 22, respectively.
2. The conduction mechanism is mainly governed by the thermoionic emission below the knee voltage but also the field emission of double Schottky model at above the knee voltage. The calculated activation energy and trap level of those region are as 0.36 and 0.70 eV, respectively.
3. The conduction mechanism for the nonlinear region above the knee voltage can be analyzed by the Fowler-Nordheim tunneling effect. The barrier height of the model in this region is 0.26 eV.

5. REFERENCES

[1] Michio Matsuoka, Takeshi Masuyama and Yoshio Lida, "Nonlinear Electrical Properties of Zinc Oxide Ceramics", J. J. Appl. Phys., Proced. 1st Conference, Vol.(39) (1970).

[2] Kazuo Eda, Atsushi Iga and Michio Matsuoka, "Degradation Mechanism of Non-ohmic Zinc Oxide Ceramics", J. Appl. Phys., Vol.(51), No.5, pp. 2678-2684 (1980)

[3] Atsushi Iga, Michio Matsuoka and Takeshi Masuyama, "Effect of Heat-Treatment on Current Creep Phenomena in Nonohmic ZnO pp.1837-1848 (1976)

[4] Kazuo Eda, Masanori Inada, Michio Matuoka, "Grain Growth Control in ZnO Varistors Using Seed Grains", J. Appl. Phys., 54 (2), pp. 1095-1099 (1983)

[5] R.C. Neville and C. A. Mead, " Tunneling Currents in Zinc Oxide", J. Appl. Phys., Vol.(41), No. 13, pp. 5285-5290 (1970)

[6] T.K. Gupta, W.G. Carlson, "Barrier Voltage and Its Effect on Ability of ZnO Varistor", J. Appl. Phys., 53(11), pp. 7401-7409 (1982)