반도체및디스플레이장비학회지 제4권 제4호(2005년 12월)
Journal of the Semiconductor & Display Equipment Technology, Vol. 4, No. 4. December 2005.

Effect of Stress on Current-Voltage Characteristics of ZnO Based Ceramics

Ju Yong Jung, Yeong Cheol Kim†, Hwa Il Seo*, Dong Teak Chung, Young Jung Kim*** and Joon Won Min******

†Dept. Materials Engineering, *School of Information Technology,
**School of Mechatronics Korea University of Technology and Education, Chungnam, 330-708, Korea
***Dept. Materials Systems Engineering, Sun-Moon University, Chungnam, 336-840, Korea
****KATECH Poongsei Youngsungri 74 Chungnam, 330-912, Korea

ABSTRACT

The chemical composition and uniaxial compressive stress are varied to observe their effect on the current-voltage characteristics of ZnO based ceramics. The variation of chemical composition produces two kinds of ceramics showing ohmic and nonohmic current-voltage characteristics. The current at a fixed voltage increased with the increase of the compressive stress for both ohmic and nonohmic ceramics. Ceramics showing nonohmic behavior exhibit better reversible return of current-voltage curve when the applied compressive stress is removed from the ceramics than those showing ohmic behavior do. We found an appropriate chemical composition showing linear relation between current and stress at a fixed voltage. The ceramic materials with an appropriate chemical composition can be used as a potential sensing material in pressure sensors.

Key Words : Stress, Current-Voltage, Varistor, Nonohmic

1. INTRODUCTION

The discovery of varistor properties in ZnO based ceramics has lead to many studies directed toward the understanding of the nonlinear behavior of the device. It has been known that some oxides additives, such as Bi_2O_3 or Pr_6O_{11}, are the key materials that cause the nonlinear property of the device [1-4]. The Bi and Pr elements are segregated to the grain boundaries of the ZnO grains due to their big sizes, to change the electrical conduction of the ZnO grain boundaries from semiconducting to insulating state [5, 6] .

In contrast, very little discussion has appeared in the literature regarding the stability of the device under different environments. Especially mechanical stresses are present in the ceramic material in various ways, such as the anisotropic thermal expansion of the ZnO ceramics and the differential thermal expansion between the ZnO and other phases in the material. The mechanical stresses can be also introduced to the ceramic material from the epoxy coating of the ceramic material for packaging, and differential thermal expansion either between inner electrode and ceramic sheet of chip varistor, or between multilayer PCB and the chip varistor.

Recently, we reported that the nonlinear behavior of the device varied with different grain boundaries in the same device and its cause might be due to the variation of internal stress along the various grain boundaries [7]. In this work, we applied external uniaxial compressive stress to a disk-type ZnO based ceramic to observe its effect on the current-voltage characteristics of the device. We also varied the chemical composition of the ZnO based ceramic to observe its effect on the current–voltage charac-teristics.

2. EXPERIMENTAL

A mixture of ZnO and additives in a chemical reagent grade of 99.9% purity was pressed into disks at pressure of 350 kg/cm^2. Two kinds of ZnO based

†E-mail : yckim@kut.ac.kr

Table 1. List of oxide additives for fabrication of ZnO based ceramics [weight %]

Sample# \ Additives	Glass	Bi_2O_3	Co_3O_4	Cr_2O_3	$MnCO_3$	Sb_2O_3	TiO_2	NiO	Total
1	-	14.8	3.9	0.8	17.7	4	2.8	4	
2	0.08	14.8	6.4	3.2	13	0.5	1.2	2	42.2
3	0.2	14.8	5	3.2	13	4	0.2	4	44.4

ceramics were fabricated showing ohmic and nonohmic current-voltage characteristics. The ZnO based ceramics with various additives used in this study are listed in Table 1. The pressed bodies were sintered at 1170 for 2 hours in air and furnace cooled to room temperature. The size of the sintered sample is 12 mm in diameter and 1 mm in thickness. The sintered bodies were lapped to parallel surface and provided with ohmic electrodes on both sides made of a silver alloy.

The current-voltage characteristics of ZnO ceramics were measured by using a computerized DC power supply in a current range up to 10^{-4} A. The pressure range of 0 to 3.4 MPa was applied to the samples employing a compressive press.

3. RESULTS and DISCUSSION

Fig. 1 shows a typical current-voltage curve measured without external pressure for ZnO based ceramics (sample #2) indicating nonohmic behavior. The switch voltage where the current starts to increase abruptly is 160 V. Therefore, parallel connection of this ceramic to an electric product can serve as high voltage pass filter to protect the product from high voltage electric shock above 200 V.

Fig. 2 shows a current-voltage curve obtained under nor external stress for ZnO based ceramic (sample #1) showing ohmic current-voltage behavior. It is known that Bi segregates in grain boundaries and converts the electrical properties of grain boundaries from semiconducting into insulating state. The sample #1 contains less amount of Bi compared with sample with nonohmic current-voltage behavior, indicating that the Bi content is not enough to complete conversion of the grain boundaries of the sample from semiconducting into insulating state.

Fig. 3 shows the effect of uniaxial compressive stress to the current-voltage curve of sample with ohmic behavior (sample #1). The current increases with increasing the stress applied at a fixed voltage. When the applied stress is removed, however, the current-voltage curve does not return to the original one and the variation of current-voltage curve becomes broad. This indicates that the sample is affected irreversibly when the stress is applied. There is also an abrupt increase of current when the applied

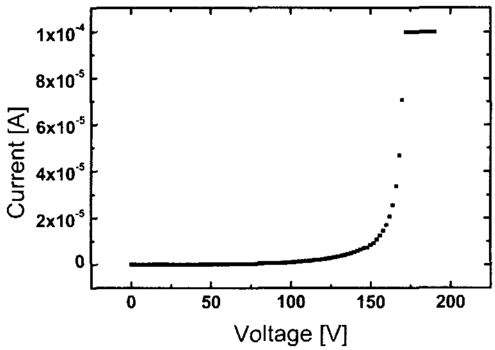

Fig. 1. Current-voltage characteristics under no external stress for ZnO based ceramics (sample #2) showing a nonohmic characteristics.

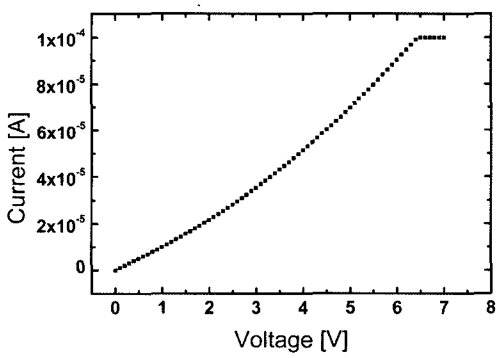

Fig. 2. Current-voltage characteristics obtained under no external stress for ZnO based ceramics (sample #1) indicating an ohmic characteristic.

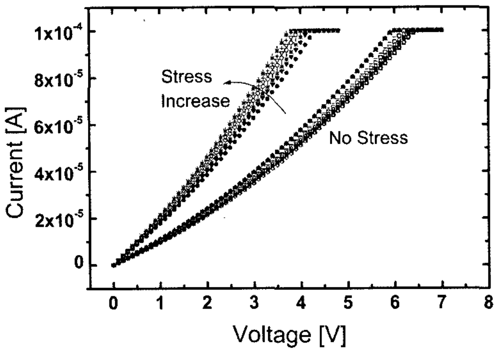

Fig. 3. Current-voltage characteristics obtained under external stresses for ZnO based ceramics (sample #1) indicating ohmic characteristics.

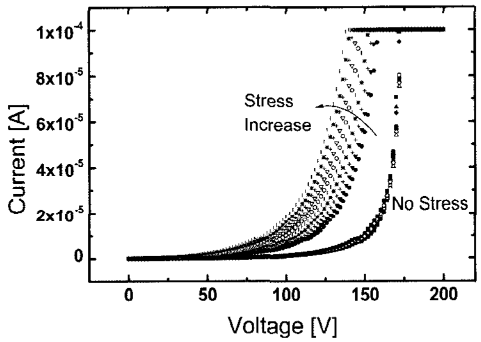

Fig. 4. Current-voltage characteristics obtained under external stresses for ZnO based ceramics (sample #2) showing nonohmic characteristics.

stress is small.

Fig. 4 shows the effect of uniaxial compressive stress to the current-voltage curve of sample showing nonohmic behavior (sample #2). The current increases with increasing the stress applied at a fixed voltage, indicating the same result as the sample showing ohmic behavior. The current variation with the applied stress is greater than that of sample #1. This sample, however, exhibits excellent return of the current-voltage curve, when the applied stress is removed. An abrupt increase of the current at initial applied stress at a fixed voltage still exists and deteriorates the linearity of the current-stress relationship.

Fig. 5 shows the effect of uniaxial compressive stress to the current-voltage curve of another sample showing nonohmic behavior (sample #3). This sample shows reversible behavior of current-voltage

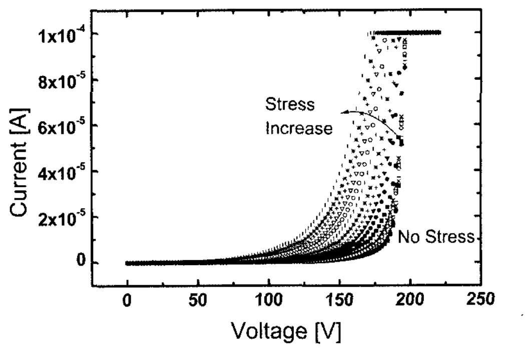

Fig. 5. Current-voltage characteristics obtained under external stresses for ZnO based ceramics (sample #3) showing nonohmic characteristics.

curve with stress removal, and at the same time excellent linearity of the current-stress relationship. This sample can be utilized as an inexpensive and simple pressure sensor material.

4. CONCLUSION

We observed the current-voltage characteristics of ZnO based ceramics as a function of uniaxial compressive stress. The chemical composition of the ZnO based ceramics was varied to improve the reversibility of the current-voltage behavior when the applied stress is removed, and also to improve the linearity of the current-stress relationship at a fixed voltage. We found an appropriate chemical composition of the ZnO based ceramic exhibiting excellent reversibility and linearity. Further study on an appropriate explanation for this sample should be conducted.

REFERENCES

1. Nahm, C. W., Shin, B. C., Park, J. A., and Yoo, D. H., "Effect of CoO on nonlinear electrical properties of praseodymia-based ZnO varistors", Materials Lett. Vol. 60, No. 2, pp. 164-167, 2006.
2. Peiteado, M., de la Rubia, M. A., Velasco, M. J., Valle, F. J., and Caballero, A. C., "Bi_2O_3 vaporization from ZnO-based varistors", J. European Ceram. Soc., Vol. 25, No. 9, pp. 1675-1680, 2005.
3. Matsuoka, M., Masuyama, T., and Iida, Y., "Voltage nonlinearity of zinc oxide ceramics doped with alkali earth metal oxide" Jap. J. Appl. Physics., Vol. 8, pp.

1275-1276, 1969.
4. Mukae, K., "Zinc oxide varistor with praseodymium oxide", Am. Ceram. Soc. Bull., Vol. 66, No. 9, pp. 1329-1331, 1987.
5. Clarke, D. R., "Grain-boundary segregation in a commercial ZnO-based varistor" J. Appl. Phys., Col. 50, No. 11, pp. 6829-6832, 1979.
6. Alles, A. B., Puskas, R., Callahan, G., and Burdick, V. L., "Compositional effects on the liquid-phase sintering of praseodymium oxide-based zinc oxide varistors", J. Am. Ceram. Soc., Vol. 76, No. 8, 2098-2102 1993.
7. Kim, Y. J., Kim, C. S., and Kim, H., "Current-voltage characteristics of abnormally grown grain ZnO ceramics". Proceedings of the 18th international Japan-Korea seminar on ceramics. pp. 124-128, 2001.