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Observation of Resistive Switching in ZnO Single Crystal Whiskers

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1. Introduction

Since the first observation of the bi-stable resistance states in 1960s, a lot of research has been devoted in an effort to understand the switching mechanism and to improve electrical properties for Resistance Random Access Memory (RRAM) applications. In recent years, Resistive switching (RS) effects have been reported in various materials, including perovskites [1, 2] , binary transition metal oxides such as NiO [3-5], TiO_2 [6], ZrO_2 [7], ZnO [8, 9] and Cu_xO [10], and even organics [11].Among them, binary oxides have advantages of simpler compositions, lower deposition temperatures and better compatibility with complementary metal–oxide–semiconductor (CMOS) processes, which makes them promising candidates for practical applications. As one of the most important binary oxides at present, ZnO has found wide applications, because of its versatile favorable properties and facile preparations [12, 13. Therefore, the development of ZnO-based RRAM would be of both scientific and commercial interest. In this point of view, ZnO with good resistive switching behavior have advantages. In this paper, we have investigated the resistance switching characteristics of ZnO single crystal whiskers.

2. Experimental Procedure

A horizontal tube furnace was used for the growth of ZnO single crystal whiskers. Mixture of ZnO and graphite in 1:1 ratio (by weight) was used as a source material. It was loaded on a quartz boat and placed in the center of 1 m long quartz tube. High purity argon and oxygen gases were introduced through one side of the furnace and other side of the quartz tube was connected to a water bubbler. The material was heated to 1100°C under a constant flow of 500 sccm argon. On stabilizing the temperature, the gas atmosphere was switched to 98% argon and 2% oxygen at same flow rate. The furnace was maintained under these conditions for 30 mins and then cooled to room temperature at a rate of 6ºC/min. The transparent colorless needles shaped whiskers with hexagonal cross-section were found to grow in boat the up flow direction of the gas.

The devices were structure over a SiO_2/ Si substrates. Ag paint was used to make contacts for electrical measurement. The schematic of the device structure is shown in the Fig. 1. The I-V characteristics were measured with standard two wire I-V curve method by precision source meter (Keithley 6221) and nanovoltmeter (Keithley 2281A).

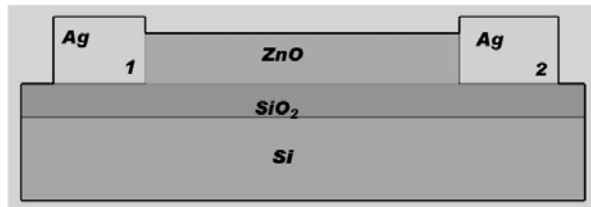

Fig. 1. Schematic of the device structure

3. Results and Discussion

In Fig. 2 ZnO single crystal whisker device used in the present investigation is shown. The I-V measurements are done between the electrodes with ~ 150 μm separation.

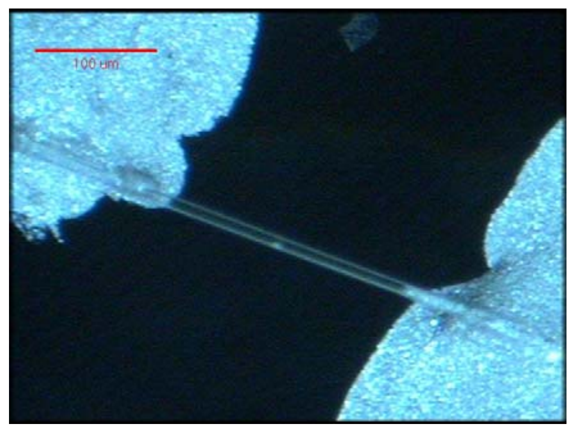

Fig. 2. ZnO single crystal whisker with Ag contacts used in the present investigation.

I-V characteristics of Ag/ZnO/Ag with current biasing is depicted in Fig. 3. The measurement current is swept from 1μA to -1 μA. The IV characteristics show two stable resistive states R1 of Low resistance for I> 0.4μA and R3 of High resistance for I< 0.3μA with intermediate resistive state R2 for 0.3μA < I <0.4 μA. There are anomalous fluctuations in resistance between R1 state and R2 state as shown in marked boxes in Figure 3, till the stable resistance state is achieved. These fluctuations are similar to what had been observed in reference [14]. R1 state can be regarded as R_{ON} state and R3 state can be regarded as R_{OFF} state.

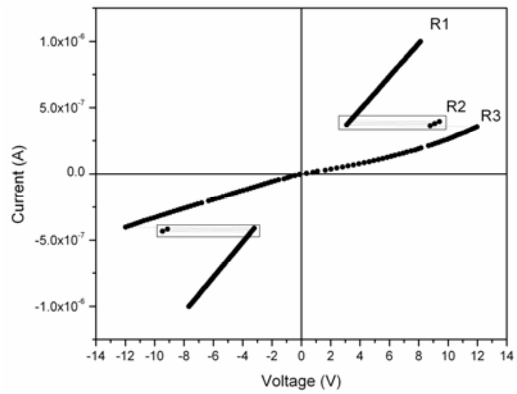

Fig. 3. I-V characteristics of ZnO single crystal whisker with current biasing.

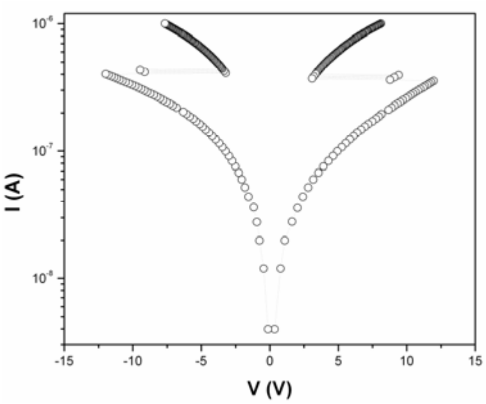

Fig. 4. I-V characteristics of ZnO single crystal whisker in log scale

The observed resistive switching is symmetric for positive and negative polarity of the biased current as shown by the I-V characteristics in logarithmic scale in Fig. 4. These resistive states do not change when the current is swept from -1 μA to 1 μA or 0 to 1 μA and similar resistive switching behavior is observed with repeated measurements. R1 state show good ohmic character as expected for ZnO and Ag contacts, because there is no barrier at the ZnO-Ag interface as the electron affinity of ZnO is 4.5 eV and the work function of Ag is 4.2 eV. The R3 state show nonlinear character. The observed phenomena give important clues on the memory switching origin in ZnO single crystal whiskers. The I-V curves which are shown to be a current-controlled negative differential resistance case suggest a percolative formation of localized filamentary conducting paths. The intermediate resistance states can be explained in terms of formation of additional percolation paths during the current stress. The microscopic nature of conducting filaments and electric-field effects on the memory switching mechanism still need further investigation.

3. Conclusions

The resistive memory switching in ZnO single crystal whiskers has been investigated. The intermediate resistance states between R_{OFF} and R_{ON} states and anomalous resistance fluctuations between intermediate resistance states and R_{OFF} state have been observed by using the current-bias method. The observed phenomena could be explained by formation and rupture of localized filamentary conducting paths as the memory switching origin. The microscopic nature of conducting filaments and electric-field effects on the memory switching mechanism still need further investigation.

Acknowledgements

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References

[1] Baikalov, Y. Q. Wang, B. Shen, B. Lorenz, S. Tsui, Y. Y.Sun, and Y. Y. Xue, C. W. Chu, Appl. Phys. Lett. 83 (2003) 957.
[2] H. T. Yi, T. Choi and S.-W. Cheong Appl. Phys. Lett. 95 (2009) 063509.
[3] S. Seo, M. J. Lee, D. H. Seo, S. K. Choi, D.-S. Suh, Y. S. Joung, I. K. Yoo, I. S. Byun, I. R. Hwang, S. H. Kim, and B. H. Park, Appl. Phys. Lett. 86 (2005) 093509.
[4] M.-J. Lee, S. I. Kim, C. B. Lee, H. Yin, S.-E. Ahn, B. S. Kang, K. H. Kim, J. C. Park, C. J. Kim, I. Song, S. W. Kim, G. Stefanovich, J. H. Lee, S. J. Chung, Y. H. Kim, and Y. Park, Adv. Funct. Mater. 19 (2009) 1587.
[5] K. Oka, T.i Yanagida, K. Nagashima, T. Kawai, J. –S. Kim and B. H Park, J. Am. Chem. Soc. 132 (2010) 6634.
[6] S. C. Chae, J. S. Lee, S. Kim, S. B. Lee, S. H. Chang, C. Liu, B. Kahng, H. Shin, D.-W. Kim, C. U. Jung, S. Seo, M.-J. Lee, and T. W. Noh, Adv. Mater. **20** (2008) 1154.
[7] Qi Liu, C. Dou,1 Y. Wang, S. Long, W. Wang, M. Liu, M. Zhang, and J. Chen, Appl. Phys. Lett. 95, 023501 (2009)
[8] Y. C. Yang, F. Pan, Q. Liu, M. Liu and F. Zeng, Nano Lett., 9 (2009) 1636.
[9] S. Lee, H. Kim, D.-J. Yun, S.-W. Rhee, and K. Yong, Appl. Phys. Lett, **95** (2009) 262113.
[10] S. H. Jo and W. Lu Nano Lett. 8 (2008) 392
[11] J. C. Scott and L. D. Bozano Adv. Mater. 19 (2007) 1452.
[12] Ü. Özgür, Y. I. Alivov, C. Liu, A. Teke, M. A. Reshchikov, S. Doˇgan, V. Avrutin, S. –J. Cho and H. J. Morkoç , Appl. Phys. 98 (2005) 041301.
[13] Z.L. Wang, Mat. Sci. and Engg., R 64 (2009) 33.
[14] D. C. Kim, S. Seo, S. E. Ahn, D.-S. Suh, M. J. Lee, B.-H. Park, and I. K. Yoo, I. G. Baek, H.-J. Kim, E. K. Yim, J. E. Lee, S. O. Park, H. S. Kim, U-In Chung, J. T. Moon, and B. I. Ryu, Appl. Phys. Lett, 88 (2006) 202102.