Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp830-831

Conductance of Zinc Oxide Nanocontacts Studied by *In Situ* Transmission Electron Microscopy

Toshikazu Kase and Tokushi Kizuka

Institute of Materials Science, University of Tsukuba, Tsukuba, Ibaraki 305−8573, Japan
Phone: +81-289-853-5261, E−mail: kizexp2006@ims.tsukuba.ac.jp

1. Introduction

Oxide electronics have been generating research interests in the past years due to their unique properties and applications of nanometer-sized devices. In particular, ZnO is an important optical and electronic material. Previously, various ZnO nanostructures have been synthesized [1-3]. Recently, the applications of ZnO nanostructures have been intensely studied, e.g., field-effect transistors [4], sensors [5] and optical electronics [6]. For these applications, it is necessary to understand the current-voltage (*I-V*) characteristics of individual ZnO nanostructures. A theoretical researches have been carried out to understand the characteristics [7]. In this report, we investigated the relationship between the structures and the *I-V* characteristics of ZnO nanocontacts (NCs) by *in situ* transmission electron microscopy (TEM).

2. Method

We used a high-resolution transmission electron microscopy combined with subnanonewton force measurements used in atomic force microscopy and electronic conductance measurements used in scanning tunneling microscopy [8]. ZnO was deposited by sputtering on a nanometer-sized tip of a gold (Au) plate. The nanometer-sized Au tip on a silicon cantilever for atomic force microscopy was brought into contact with an opposing edge surface of the plate by piezomanipulation inside the microscope. The cantilever tip was then retracted to elongate the contact. Simultaneously, alternating voltages were applied between the tip and the plate. A series of these manipulations was performed in a vacuum of 10^{-5} Pa at room temperature. The structural dynamics during the procedure was observed *in situ* by lattice imaging using a television capture system. The images were captured with an interval of 17 ms. The force applied between the tip and the plate was simultaneously measured by optical detection of the cantilever deflection. The electrical conductance was measured using a two-terminal method with a sampling rate of 480 /s. The high-resolution imaging and signal detection in this system were simultaneously recorded and analyzed for every image using our own software.

3. Result and discussion

Figure 1 shows high-resolution images of ZnO NCs. The cantilever tip and the plate were observed as dark contrast, as shown in the upper and the lower regions of each frame of Fig. 1, respectively. The ZnO NCs between them locate in the middle of the frames. Figure 1(a) shows a ZnO NC before bias voltage applied. The (002) lattice fringes of wurtzite (WZ) ZnO were observed on the NC. Figures 1(b)–1(d) show the ZnO NCs after bias voltage applied. The thickness of the NCs corresponds to five, three, two, and one of the (001) layers, respectively. Figure 2 shows *I-V* curves for the ZnO NCs presented in Figs 1(b)–1(d). The conductance of each NC in Figs. 1(b)–1(d) is estimated to be 2.4 × $10^{-3}G_0$, 4.4 × $10^{-3}G_0$ and 9.9 ×

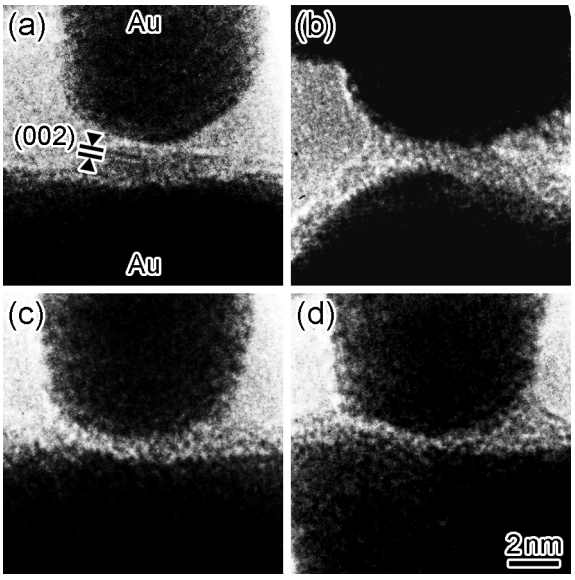

Fig. 1 High-resolution images of ZnO NCs. (a) Before applying bias voltage, NCs in (b)–(d) show conductances of 2.4 × $10^{-3}G_0$, 4.4 × $10^{-3}G_0$ and 9.9 × $10^{-3}G_0$, respectively.

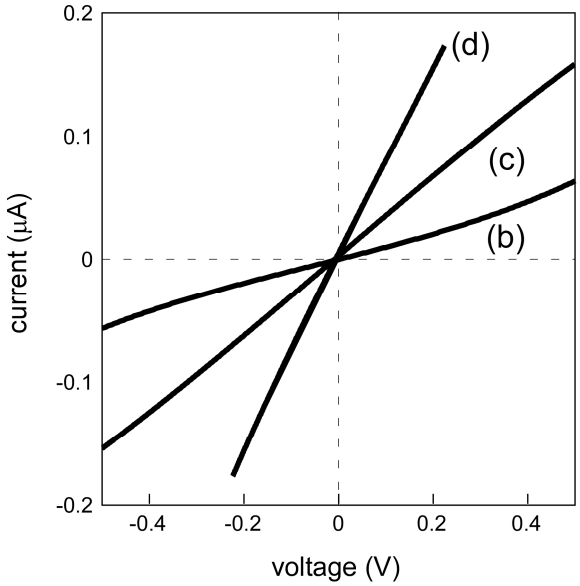

Fig. 2 Current-voltage curves of ZnO NCs. The curves (b)–(d) were measured for the structures presented in Figs. 1(b)–1(d), respectively.

$10^{-3}G_0$, respectively. These conductances are hundredths of G_0; the NCs show nonballistic conduction, as opposed to the conduction of Au NCs. Note that the conductance of these NCs depends on their own cross-sectional area and the length. As displayed in Fig. 2, the *I-V* characteristics of the ZnO NC shows no current rectification, as reported with micrometer ZnO wires [9-13]. As proposed by Harnack *et al*., rectifying behavior is induced by the alternating Zn and O layers parallel to the (001) plane. The alternating produces a dipole moment which leads to a potential gradient and then introduce the asymmetry of current flow along the c axis. This is based on the noncentral symmetricity and the layered distribution of cations and anions in the wurtzite structure. However, the size of the present ZnO NCs is very small compared with the specimens of Harnack *et al.* As also proposed by Lao *et al.* [11], the factor of rectifying behavior is the asymmetry of the contact between ZnO and electrodes; it becomes a Schottky contact. Although the present ZnO NCs have asymmetric forms, as shown in Fig. 1, no rectifying behavior is observed. The curve (d) in Fig. 2 deviates from a linear relationship, implying that inelastic scattering increases in larger NC. According to calculations by Yang *et al*., the resistivity of ZnO nanobelts and nanowires is ~10^{-4} Ω·m [7]. They also pointed out that ballistic transport is dominant in a WZ ZnO nanowire containing 48 atoms in four layers (two Zn-O double layers). The resistivity estimated from our result is 2×10^{-1} Ω·m. This value is 10^3 times as large as that of ZnO nanobelts and nanowires.

4. Conclusion

We investigated the relationship between the structure and the *I-V* characteristic of ZnO NCs with thickness of five, three, two, and one ZnO layers by *in situ* TEM. Their conductance is 2.4–9.9 × $10^{-3}G_0$ and the resistivity is 2×10^{-1} Ω·m. The present results will be useful to develop new ZnO nanodevices.

Acknowledgment

This work was partly supported by a Grant-in-Aid from the Ministry of Education, Culture, Sport Science and Technology, Japan (No. 22310065).

References

[1] P. M. Gao, Y. Ding, W. J. Mai, W. L. Hughes, C. S. Lao, and Z. L. Wang, Science **309** (2005) 1700.

[2] X. Y. Kong, Y. Ding, R. Yang, and Z. L. Wang, Science **303** (2004) 1348.

[3] Z. W. Pan, Z. R. Dai, and Z. L. Wang, Science **291** (2001) 1947.

[4] M. S. Arnold, P. Avouris, Z. W. Pan, and Z. L. Wang, J. Phys. Chem. B **107** (2003) 659.

[5] H. T. Wang, B. S. Kang, F. Ren, L. C. Tien, P. W. Sadik, D. P. Norton, S. J. Pearton, and J. Lin, Appl. Phys. Lett. **86** (2005) 243503.

[6] S.-W. Chung, J.-Y. Yu, and J. R. Heath, Appl. Phys. Lett. **76** (2000) 2068.

[7] Z. Yang, B. Wen, R. Melnik, S. Yao, and T. Li, Appl. Phys. Lett. **95** (2009) 192101.

[8] T. Kizuka, Phys. Rev. B **77** (2008) 155401.

[9] Z. Fan, D. Wang, P.-C. Chang, W.-Y. Tseng, and J. G. Lu, Appl. Phys. Lett. **85** (2004) 5923.

[10] Y. W. Heo, L. C. Tien, D. P. Norton, B. S. Kang, F. Ren, B. P. Gila, and S. J. Pearton, Appl. Phys. Lett. **85** (2004) 2002.

[11] C. S. Lao, J. Liu, P. Gao, L. Zhang, D. Davidovic, R. Tummala, and Z. L. Wang, Nano Lett. **6** (2006) 263.

[12] C. Li, W. Guo, Y. Kong, and H. Gao, Appl. Phys. Lett. **90** (2007) 223102.

[13] O. Harnack, C. Pacholski, H. Weller, A. Yasuda, and J. M. Wessels, Nano Lett. **3** (2003) 1097.