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Characterization of O_2 ionosorption induced potential changing property of SnO_2 nanowire with Kelvin force microscopy (KFM)

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We have employed Kelvin force microscopy (KFM) system to measure the potential change of a single SnO_2 nanowire which had been synthesized on the Au thin film by a thermal process. By using the KFM probing technique, Rh coated conducting cantilever can approach a single SnO_2 nanowire in nano scale and get the potential images with oscillating AC bias between Au electrode and cantilever. Also, during imaging the potential status, we controlled the concentration of oxygen in measuring chamber to change the ionosorption rate. From the results of such experiments, we verified that the surface potential as well as doping type of a single SnO_2 nanowire could be changed by oxygen ionosorption.

Key words: Tin-oxide (SnO_2), nanowire, gas sensor, Conductive -AFM, Kelvin force microscopy (KFM).

Introduction

Tin oxide (SnO_2) nanowire is a one of the most widely using materials for the fabrication of various gas (O_2, CO, NO_x) detecting devices. Basically, the SnO_2 shows an n-type semiconductor property with a wide band gap, about 3.99 eV. Also, SnO_2 thin film has been known as a transparent metal oxide electrode and it is applicable for a various mobile or flexible electronic parts. Nowadays, the characterization and application of SnO_2 nanowire is performed actively since it is possible to manufacture a micro-sensor array with conventional silicon processing. However, to align a single SnO_2 nanowire on the specific site for the fabrication of integrated gas sensor device is a difficult problem. Also it is not easy to characterize the electrical property of single SnO_2 nanowire with a conventional electronic device analyzing method. To achieve a high-performance gas-sensing property with SnO_2, we have to verify a potential variation that is result from the ionosorption effect in different oxygen concentration ambient [1, 2]. In this study, Kelvin force microscopy (KFM) system has been employed to measure the potential change of a single SnO_2 nano-wire which had been synthesized on the Au thin film by a thermal process [3, 4]. By using the KFM probing technique, Rh coated conducting cantilever can approach a single SnO_2 nanowire in nano scale and get the potential images with oscillating AC bias between Au electrode and cantilever. Also, during imaging the potential status, the concentration of oxygen was varied in measuring chamber to change the ionosorption rate. The experimental results verified that oxygen detectability of single SnO_2 nanowire would be necessary for the realization of high-performance gas-sensing device.

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Experimental

SnO_2 nanowires were synthesized on the Au deposited Si wafer substrate by a VLS (vapor-liquid-solid) method. At first, 5 nm thick Au thin film was deposited on the p-type Si wafer with a sputtering method. The Au thin film was used as a catalyst for a SnO_2 nanowire. Alumina boat has been filled with Sn powder (325MESH, 99.8% purity, Acros Organics) and placed in the center of quartz tube. During the nanowire synthesis, the inner pressure of furnace has been maintained at 1 torr with a inlet gas ratio of Ar : O_2 = 610 : 40. Nanowires were grown in 750 °C for 40 min. Fig. 1 shows a schematic of SnO_2 nanowire synthesizing furnace and KFM measurement system.

The shape and morphology of synthesized nanowires were observed with a field emission scanning electron microscopy (FE-SEN, Jeol JSM-6700F) and scanning probe microscopy (SPM, Seiko, E-Sweep NanoNavi II). Also its crystalline structures were analyzed by X-ray Diffraction (XRD, Bruker D8).

To characterize the electrical property of a single SnO_2 nanowire, we needed to separate it from the surface of Si wafer and disperse into solution. The film-like synthesized nanowires were separated in the ethanol by a sonication and its solution has been dispersed on the Au (50 nm) / SiO_2 (200 nm)/p-type Si substrate [5]. And then we employed KFM to measure and evaluate a surface potential change of nanowire. The potential images have been attained under AC bias oscillating from −2.5 V to +2.5 V using a conductive

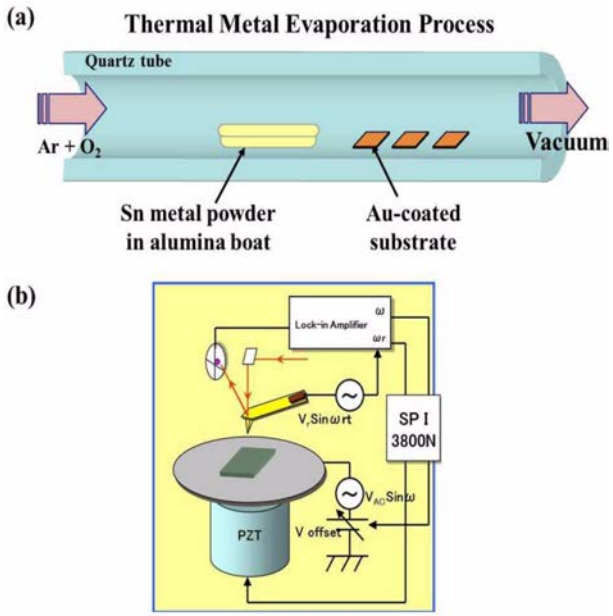

Fig. 1. Schematic of (a) SnO_2 nano-wire synthesizing furnace and (b) KFM measurement system.

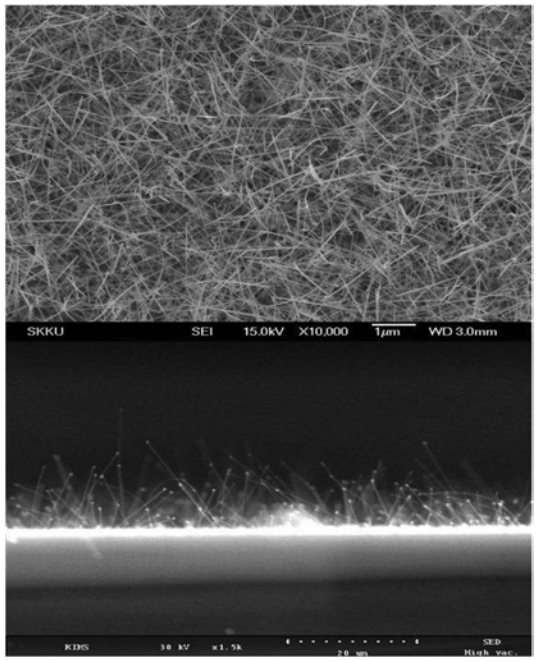

Fig. 2. In-plane and cross-sectional SEM images of SnO_2 nanowire.

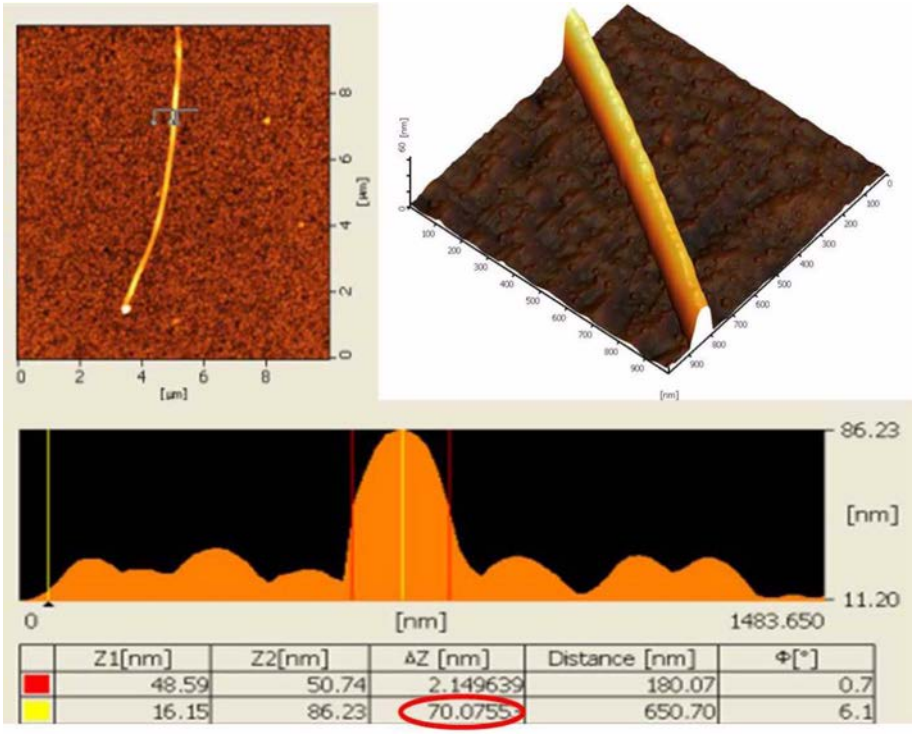

Fig. 3. Topological analysis of single SnO_2 nanowire and 3D SPM images.

metal coated cantilever tip. From the results, the change of surface potential was calculated. To verify effect of O_2 ionosorption into SnO_2 nanowire, we controlled the atmosphere condition of sample chamber. First of all, we have measured the KFM images of as-synthesized SnO_2 nanowire. And then O_2 gas was supplied to the chamber with a flow rate from 0 to 300 sccm. Lastly, to verify effect of O_2 ionosorption on the surface potential of SnO_2 nanowire, the KFM analysis has been performed again.

Results and Discussion

Figs. 2 and 3 show SEM images of as-synthesized film of SnO_2 nanowire and topological SPM analysis of single nanowire, respectively. SEM Images shows a

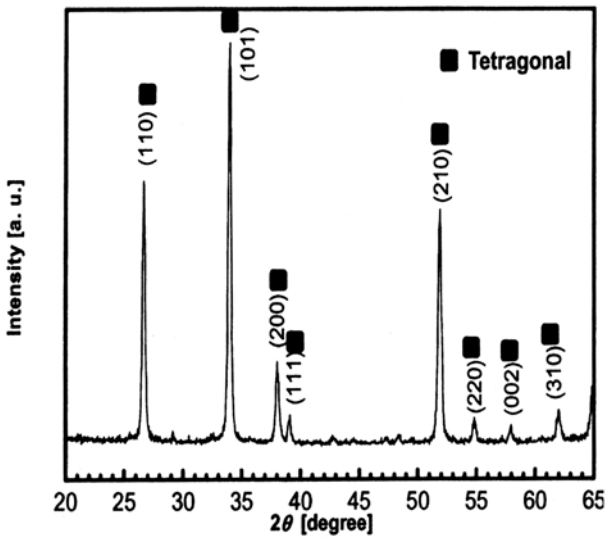

Fig. 4. X-ray diffraction patterns of as-synthesized SnO_2 nanowires.

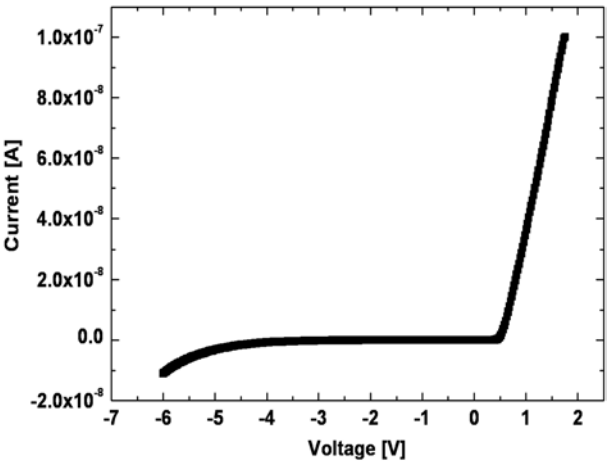

Fig. 5. Schottky diode property of n-type semiconducting as-synthesized SnO_2 nanowires.

tip of Au catalyst at the end of nano-wires. It means that nano-wires were synthesized by a vapor-liquid-solid (VLS) growing mechanism [3, 4]. As shown in Fig. 3, a length and diameter of single nanowire which used in I-V measurement was measured to be 4 μm and 53 nm, respectively.

The XRD analysis was performed to know a crystalline structure and diffraction signal of (110), (101), (200), (111), (210), (220), (002), (310) planes are measured. From these results, lattice parameter of rutile crystal structured SnO_2 nanowire was calculated to be a = b = 4.734 Å and c = 3.185 Å. (JCPDS card number 21-1250) [5]

In the previous research paper, by measuring an I-V characteristic of metal-semiconductor-metal Schottky diode structure of single SnO_2 nanowire which dispersed on the Au (50 nm) / SiO_2 (200 nm)/p-type Si substrate with conductive AFM, we verified as-synthesized nanowire has a n-type semiconductor property. (Fig. 5).

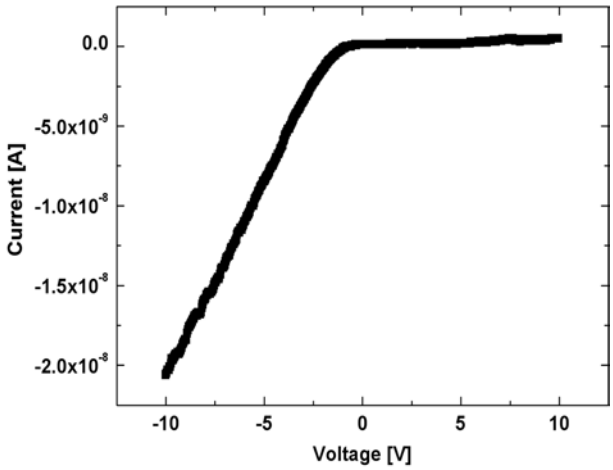

Fig. 6. Schottky diode property of p-type semiconducting O_2 exposed SnO_2 nanowires.

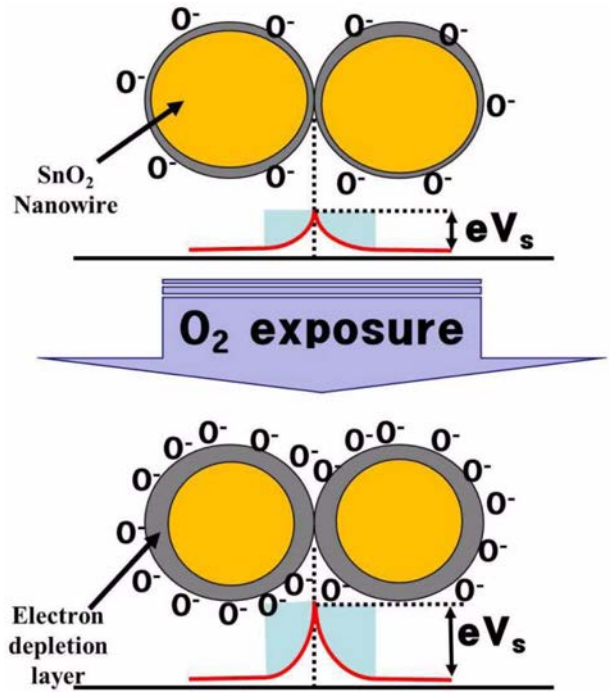

Fig. 7. Schematic diagram of O_2 ionosorption effect on SnO_2 nanowire.

After O_2 exposure, we measured I-V characteristic of metal-semiconductor-metal Schottky diode structure again to verify a type transfer of SnO_2 nanowire and the results shows in Fig. 6. The shape of I-V curve is a typical property of p-type semiconductor, therefore, it seems reasonable to conclude that the semiconducting type of SnO_2 nanowires changed from n-type to p-type when we compare the I-V result of as-synthesized (Fig. 5) and that of O_2 exposed nanowires (Fig. 6).

When the O_2 molecules adsorbed on the surface of the nanowires, the depletion layer near the surface become thick and results in increasing of the potential barrier. As a results, an increased potential barrier disturbed carrier

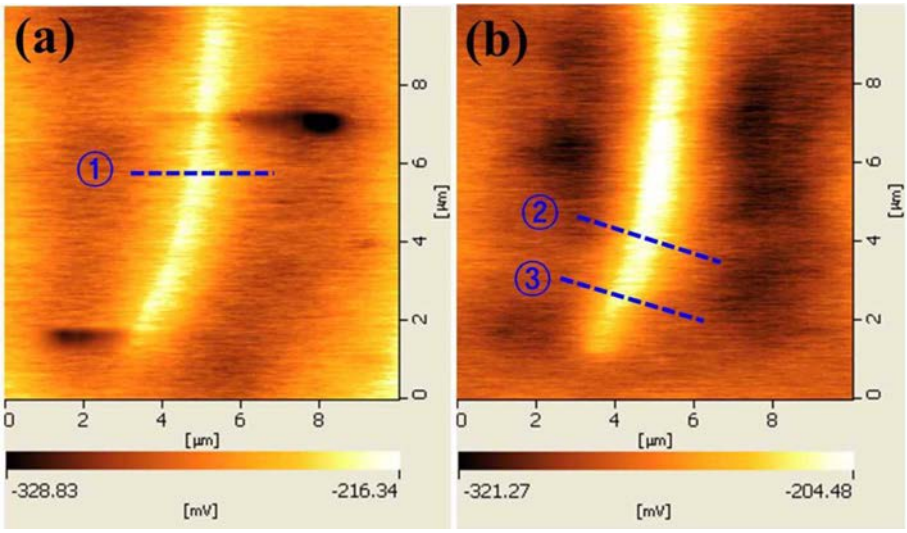

Fig. 8. KFM potential images of (a) as-synthesized SnO_2 nanowires and (b) after O_2 exposure.

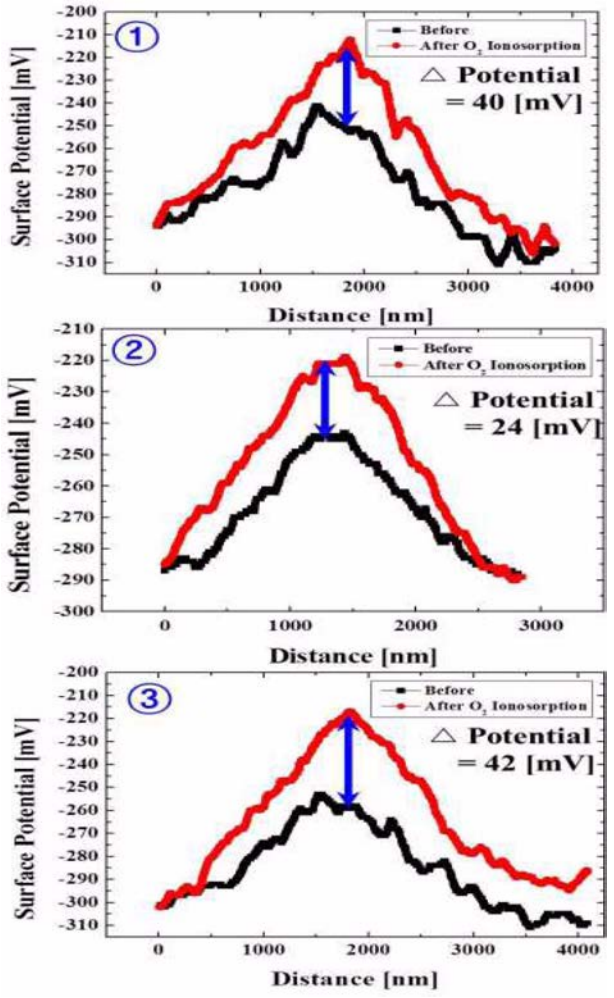

Fig. 9. Change of surface potential profile at the different position in SnO_2 nanowire.

transfer and the conductivity is getting lowered naturally [6-10]. Because ionosorpted O_2 molecules can't be separated easily, the lowered conductivity doesn't recover although concentration of O_2 becomes low.

Conclusions

Kelvin force microscopy (KFM) system has been employed to measure the potential change of a single SnO_2 nanowire which was synthesized on the Au thin film by a thermal process. By using the KFM probing technique, Rh coated conducting cantilever can approach a single SnO_2 nanowire in nano scale and get the potential images with oscillating AC bias between Au electrode and cantilever. Also, during imaging the potential status, we controlled concentration of oxygen in measuring chamber to change the ionosorption rate. From the results of such experiments, we verified that the surface potential as well as doping type of a single SnO_2 nano-wire could be changed by oxygen ionosorption. After the O_2 exposure, the value of surface potential increased and become brighter than that of as-synthesized nano-wire. It means that the doping type of nano-wire changed from n-type to p-type because of the induced depletion layer by O_2 insorption.

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