CHARACTERIZATION OF PIEZOELECTRIC PROPERTIES OF ZnO NANOWIRE USING AFM

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Abstract: The accurate measurement of piezoelectric properties of nanowires (NWs) is a fundamental issue because it is essential for developing new high efficient materials and designing the nanogenerator. To date, several attempts have been made to characterize the piezoelectric properties of NWs using conductive atomic force microscopy (AFM) techniques. However, the results were not satisfactory because there was a considerable uncertainty in the measurement result. In the present study, therefore, it was attempted to develop a novel method for resolving this problem. Cantilever type specimens with one end of NW attached on Pt electrodes were fabricated using microelectromechanical systems (MEMS) process in combination with the arrangement technique of individual NWs. The change of the Schottky barrier characteristic with increasing strain was examined, and piezoelectric characteristics of GaN and ZnO NWs were investigated by measuring the current generated during the bending process.

Keywords: ZnO/GaN nanowire (NW), AFM based bending test, Schottky barrier, Piezoelectric properties.

INTRODUCTION

With the threat of global warming and energy crises, searching for renewable and "green"-energy resources is one of the most urgent challenges to the sustainable development of human civilization [1,2]. Energy generation using piezoelectric properties of nanoscale materials is a new eco-friendly concept, which extracts electrical energy from mechanical energy of human motion or micro vibration existing in surroundings. This technology is expected to improve and further resolve technical limitations of micro/nano devices, which were mostly raised by their small size and limited battery life. To date, most researches on the electricity generation using piezoelectric nanowires (NWs), such as ZnO, GaN, etc., have been dedicated to how to fabricate an efficient electricity generation device (i.e., nanogenerator). It is noted, however, that the accurate measurement of piezoelectric properties of NWs is a more fundamental issue because it is essential for developing new high efficient materials and designing the nanogenerator. Several attempts have been made to characterize the piezoelectric properties of NWs using a conductive AFM technique [3]; as NW vertically standing on the substrate is bent by Pt coated probe tip, positive and negative potentials are induced on the tension and compression sides of the bent NW, respectively. Then, with the progress of bending, the probe tip makes contact with the compression side of the bent NW and this allows the flow of current by escaping charges accumulated under Schottky barrier, finally making it possible to measure the voltage potential induced. However, some problems, which can give rise to a considerable uncertainty in the measurement result, have been pointed out for this technique: (1) the uncertainty in the dimension of NW (the direct use of NWs vertically standing on the substrate as test specimens makes it difficult to exactly measure the dimension of tested NW); (2) contact configuration between a Pt coated probe tip and NW surface, which significantly influences the resistance, finally affecting the current and voltage measured; (3) Schottky barrier characteristic of the contact between a Pt coated probe tip and NW, which restricts current flow, making it difficult to measure the voltage induced, especially at the moment in which low voltage is induced. A novel method was developed to resolve these problems in the present study. Cantilever type specimens with one end of NW attached on Pt electrodes were fabricated using MEMS process in combination with the arrangement technique of individual NWs. Test specimens were bent by a probe tip at center and quarter position of the span length, and the voltage potential induced were measured by making a circuit connecting both electrodes. During the test, a voltage bias was applied to the specimen to reduce or remove the Schottky barrier, and this made it possible to measure the low voltage induced. Current-voltage (I-V) characteristics of ultranano-crystalline diamond (UNCD)/ZnO schottky contact was studied with applying bias on the specimen stage during the bending of NW. The change of the Schottky barrier characteristic with increasing strain was examined by measuring the I-V curves at several stages of the bending process. In addition, piezoelectric characteristics of ZnO NW was compared with those of GaN NW by measuring the current generation during the bending process.

EXPERIMENTAL DETAILS

AFM which can control each NW was used to measure the current by bending of NW. When cantilever shape NW is deflected from probe tip indenting, nanowire has a potential. Current was measured through probe tip from potential. To perform an accurate nano-bending experiment, the reliability of force, deflection of NW and current measurement system are required.

1. AFM based measurement system

1.1 Force

To measure the exact force applied on NW, correct AFM cantilever spring constant should be calibrated. There are several methods to calibrate the spring constant of AFM cantilever. Among them, Nano Force Calibrator (NFC) is recognized to be the most accurate one, based on the comparison results with cantilever-on-cantilever, Sader, and thermal nosie method [4].

1.2 Deflection

Displacement of Z scanner from measured in AFM system is sum of deflection of NW and deflection of AFM cantilever [5]. So, NW deflection can be obtained by subtracting force divided by AFM cantilever spring constant from Z scanner displacement.

1.3 Current measurement system

Current was measured by installing conductive AFM module on XE-150 model at Park systems. This module has 43 fA input noise current and can measure from -10 to 10 nA. Conductive NaDiaProbes were used. They are diamond probe with the cantilever and the probe tip made of electrically conductive UNCD® with a resistivity less than 1 ohm-cm. In addition to being electrically conductive, NaDiaProbes display superior wear properties and long life times. The probe with a spring constant of 35 N/m was chosen in the present study to fully deflect NW.

2. Sample preparation

N-type ZnO NW was grown by chemical vapor deposition process. Gold electrode was made by MEMS process. NWs were arranged on gold electrode by contact printing method and then Pt was deposited on one end of NW.

RESULTS AND DISCUSSION

1. I-V characteristics of UNCD/ZnO Schottky contact

I-V curve was obtained during the bending of cantilever shape of NW with certain force and it was also taken on NW attached on gold electrode. Sample bias is applied on sample stage. When negative voltage is given on the specimen, forward bias is applied between NW and probe tip and current can flow. Since schottky contact is formed between NW and probe tip, it acts rectifying behavior [6]. Figure.3 shows that the

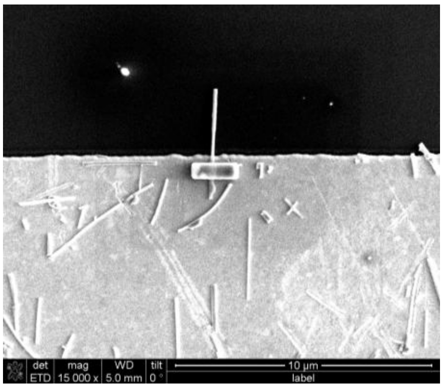


Fig. 1: SEM micrograph showing the test sample.

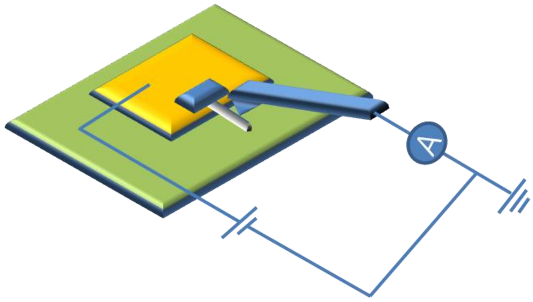
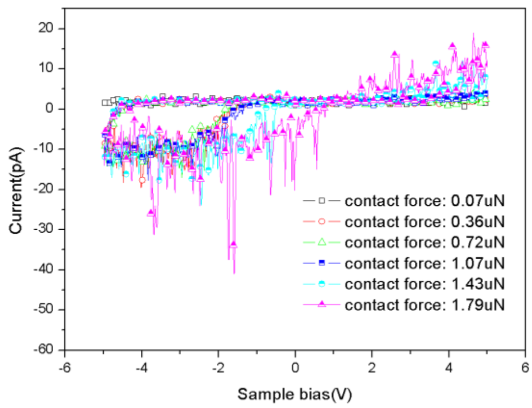


Fig. 2: Schematic diagram showing the testing and measurement principles.

a)



b)

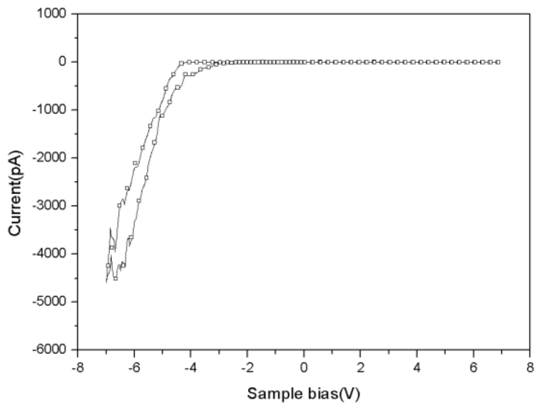


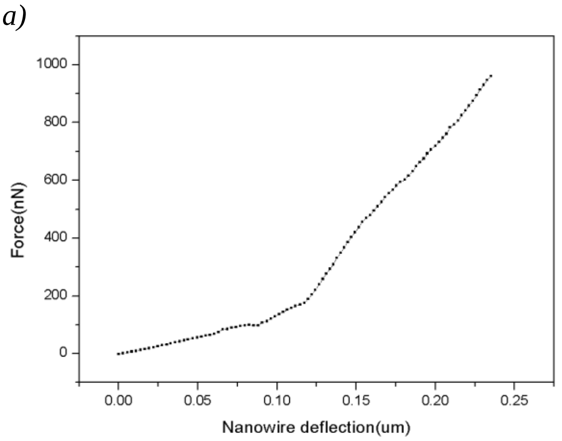
Fig. 3: a) I-V curves of ZnO NW measured at six stages of the bending process and b) I-V curve of ZnO NW entirely attached on gold electrode.

more contact force, less cut-in voltage. Schottky barrier was reduced with increasing strain. But in reverse bias, current is several pico amperes. Also, lager current flow is found from NW attached on gold electrode entirely than cantilever shape of NW. It seems to be that contact resistance is small with good contact. But also current is very small with several pico amperes until 7 V in reverse bias. The reverse bias breakdown voltage is larger than 7 V as measured.

2. Deflection and current characteristics of ZnO and GaN NWs

Xu et al. measured generated voltage by indenting probe tip on stretched side of GaN NW. Current can flow with reduced or eliminated Schottky barrier from certain deflection length of NW [7]. Experiments were performed to know applicable to ZnO NW and what length of deflection makes current flow at stretched side of NW. As you can see figure.4 and figure.5, several nano ampere flew from GaN NW, but in case of ZnO NW there was few current with 35nm deflection. This cause may be difference of piezoelectric characteristics of GaN NW and ZnO NW and incorrect of measurement.

a)



b)

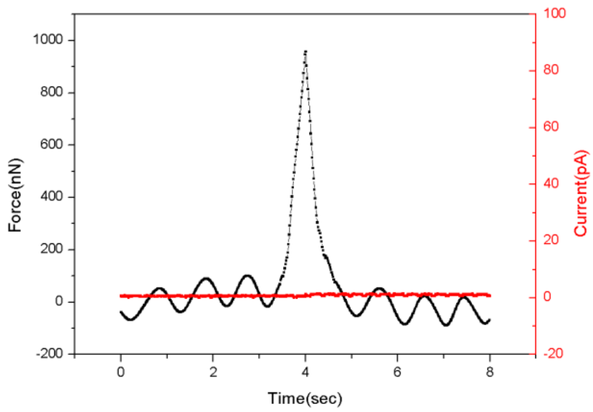


Fig. 4: (a) Deflection–force curve and (b) current generation during the bending of ZnO NW.

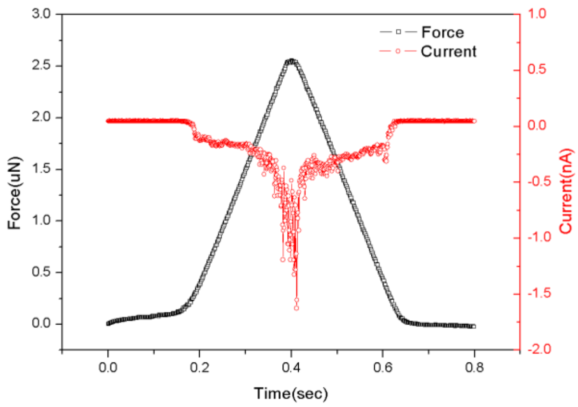


Fig. 5: Current measurement of GaN NW.

CONCLUSIONS

We obtained I-V curve during the bending of NW after making cantilever shape of ZnO NW specimens and measured current according to deflection of NW. Cut-in voltage is changed with contact force. Schottky barrier was reduced with increasing strain. In reverse bias, there was few current without contact force effect. In I-V curve, real NW deflection wasn't obtained. So actual NW deflection should be obtained in further research. And piezoelectric characteristic was compared between GaN NW and ZnO NW by measuring the current flowing through bent NW. Although current was measured from GaN NW, there was few current from ZnO NW with deflection. There is possibility of difference of piezoelectric characteristics between ZnO and GaN NWs and incorrect measurement with contact problem between probe tip and NW.

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