A Single SnO_2 Nanowire Gas Sensor

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ABSTRACT

Generally, a gas sensor is fabricated either in bulk or thin film form. But in this work, a single SnO_2 metal oxide nanowire of about 100 nm in cross-section has been used as the sensing part of the sensor. A special technique employing a focused ion beam (FIB) has been used in fabricating this device, which is a resistive type. A set of electrodes has been attached to the sensor by 30 kV Ga+ focused ion beam/chemical vapor deposition (FIB-CVD) with a current of about 10 pA. Details of the fabrication and the characterization of the sensor will be discussed.

Keywords: Nanodevice, SnO_2 nanowire, Sensor, FIB.

INTRODUCTION

Recently, nanostructures like nanowires and nanobelts have gained considerable attention due to their potential in the development of smart functional materials and devices (Ramgir et al., 2005).

Nanowires grown from a SnO_2 semiconductor may be successfully used for gas sensor applications (Li et al., 2007). These nanowires have high sensitivity and response because the reduction in grain size of tin oxide leads to an increase in sensitivity due to the high surface-to-volume ratio (Xi et al., 2008). For example, Ramgir et al., (2005) reported synthesis of Ru-doped SnO_2 nanowires, which enable the highly sensitive detection of various test gases and their distinctive response towards NO_2 and liquefied petroleum gas (LPG) in air. However, such nanowires have a grain boundaries nanostructure, so they cannot respond to some gas values.

Nanostructures comprised of a single nanowire do not have grain boundaries. Therefore, the electrical transduction effects induced by the adsorbed gas molecules onto the surface of these nanowires can be revealed straightforwardly by the electrical magnitudes of these single nanocrystals. They can be fabricated even with low gas values. For example, Hernandez-Ramirez et al., (2006) reported high response and stability in CO and humidity measurements using a single SnO_2 nanowire.

A gas sensor fabricated from a single nanowire can be prepared by attaching microelectrodes on to the wire. This can be archived by several means such as lithography processes or focused ion-beam/chemical vapor deposition (FIB-CVD). The FIB technique is suggested as a simple method of gas sensor fabrication based on a single nanowire, with only a short fabrication time. For example, Vila et al., (2005) reported fabrication of metallic contacts of nanometer-sized materials using a focused ion beam (FIB).

In this work, a single SnO_2 metal oxide nanowire in cross-section was used as the sensing part of the sensor. A special technique employing a focused ion beam was used to fabricate this resistive-type device.

MATERIALS AND METHODS

SnO_2 nanowires have been grown by various methods based on vapor-liquid-solid (VLS) mechanisms in evaporation/condensation or chemical vapor deposition processes (Li et al., 2007). In all cases, under different growth conditions, it has been possible to achieve excellent results using a single nanocrystal, which presents a different crystallographic orientation and faceting.

A SnO_2 nanowire was placed onto an already-processed SiO_2/Si substrate wafer. After being installed onto the substrate the sample was taken inside an FIB chamber. In imaging mode, it was observed that SnO_2 nanowires were dispersed on the surface of the SiO_2/Si wafer (Fig. 1). The sample was inspected using a SEM to search for individual nanowires and a single SnO_2 nanowire, 50-100 nm long and 50-100 μm wide was selected. Then, four electrodes were deposited onto the nanowire, using the FIB. A set of electrodes was attracted to the single SnO_2 nanowire by 30 kV Ga^+ FIB/CVD-assisted deposition using a gas injection system (GIS) of platinum $((CH_3)_3Pt(C_pCH_3))$ with a current of about 10 pA. In fact, a couple of contacts are fabricated near each extreme of the nanostructure, requiring as much as about 10 um. Thus the remaining significant length of the nanowire, more than several microns, is free of any feature relative to the contact fabrication (Fig. 3).

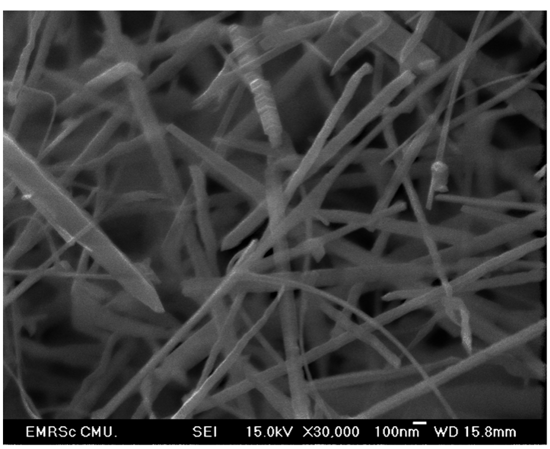


Figure 1. SEM micrograph of SnO_2 nanowires.

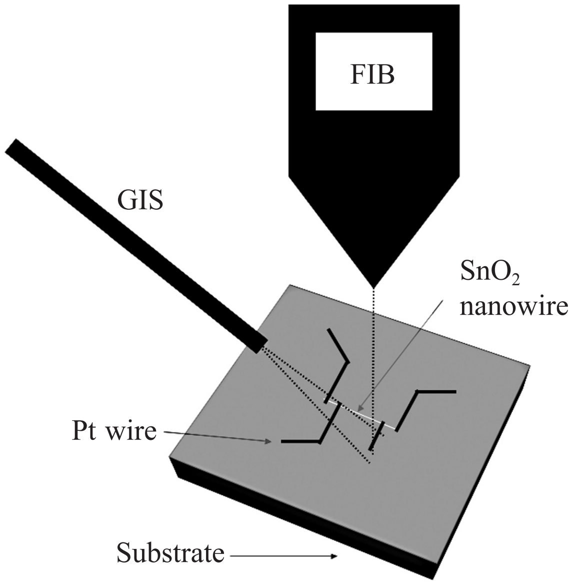


Figure 2. Diagrammatic view of FIB-assisted fabrication process.

RESULTS AND DISCUSSION

Fig. 3 shows an SEM image of a single nanowire device which has been fabricated by FIB-CVD. The device was about 90 nm in width and about 17 µm in length between two electrodes, respectively. The total fabrication time was about 30 minutes, using an ion beam current of 10 pA.

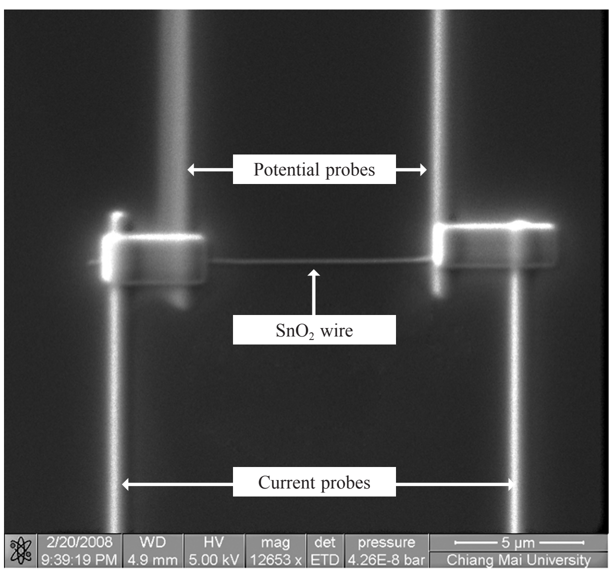
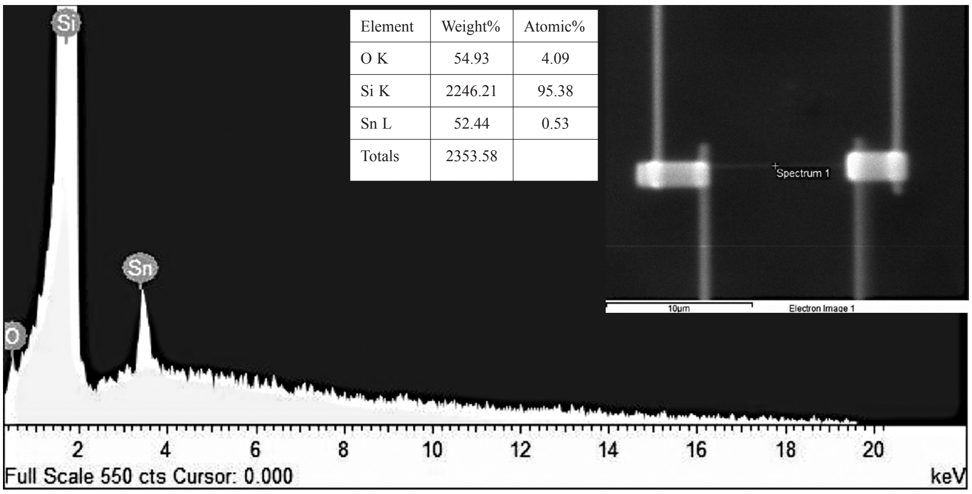


Figure 3. Close-up view of the device.

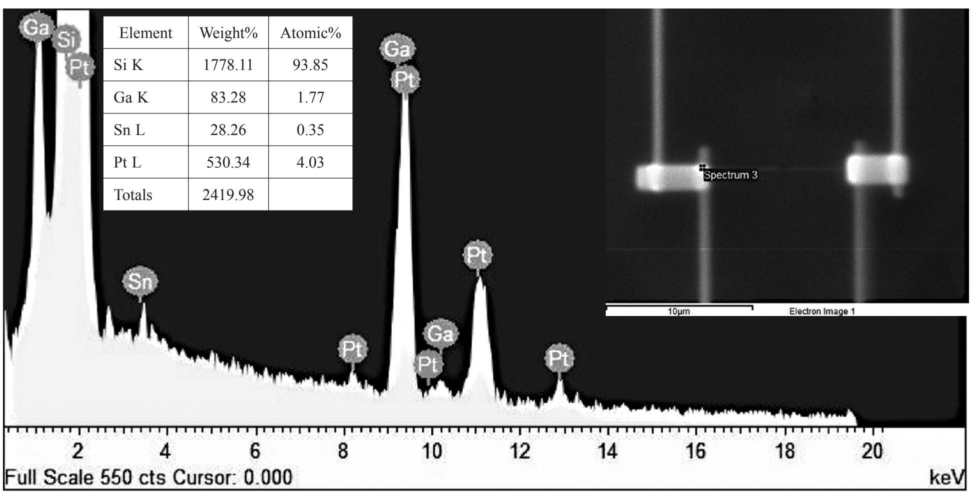
Fig. 4(a) shows the EDX result taken from the middle part of the SnO_2 wire. Three elements were found, namely Sn, O, and Si with the atomic percentages of 0.5, 4.0 and 95.4, respectively. This indicates that SnO_2 wire was the sensing part of the device.

In Fig. 4(b), an electrode which was fabricated by an FIB-CVD process has been examined. In this case Ga and Pt were also observed in addition to Sn and Si. This indicates that Ga and Pt from the fabrication process played an active role in connecting electrodes to the SnO_2 wire to form a sensor.



Element	Weight%	Atomic%
O K	54.93	4.09
Si K	2246.21	95.38
Sn L	52.44	0.53
Totals	2353.58	

Figure 4. a) EDX results taken from the middle part of the SnO_2 wire.



Element	Weight%	Atomic%
Si K	1778.11	93.85
Ga K	83.28	1.77
Sn L	28.26	0.35
Pt L	530.34	4.03
Totals	2419.98	

Figure 4. b) EDX results taken from the SnO_2 wire at the electrode region.

The fabricated device was tested for its sensing properties by means of 4-point probe measurement with ethanol concentration of about 1000 ppm, at room temperature of about 27°C.

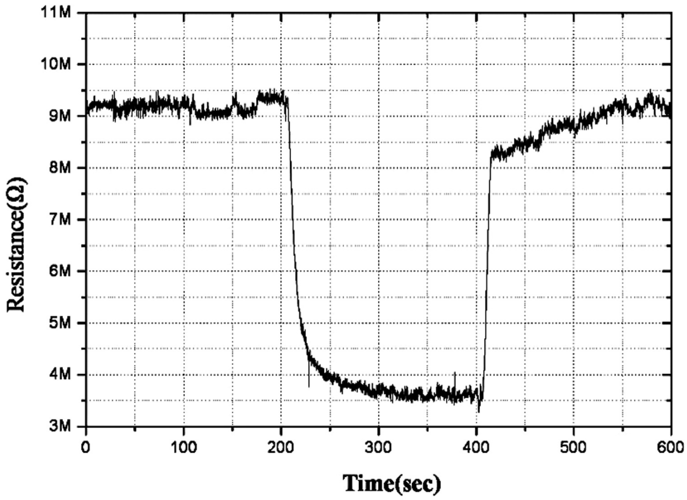


Figure 5. Response and recovery characteristics of SnO_2 nano wire sensor under ethanol vapor concentration of 1000 ppm at room temperature.

Figure 5 shows the characteristic response of the gas sensor when tested with ethanol vapor in ambient atmosphere. It was observed that its sensitivity was quite good about 2.5 with a fairly sharp response time which normally could not be observed for such a gas sensor at room temperature. Further development and study of the sensor properties will be discussed elsewhere.

CONCLUSION

In this works a single nanowire device has been fabricated by utilizing a dual focused ion beam. This demonstrates that any micro or nanodevice can be easily fabricated by this kind of machine and the device trends to have a superior characteristic compare to a conventional one.

ACKNOWLEDGEMENTS

We would like to thank the Applied Physics Laboratory, the Nanoscience and Nanotechnology Center Project, and the Network for Excellence in Functional Nanomaterials, Chiang Mai University for their support. NANOTEC, Thailand is also acknowledged.

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