Applied Mechanics and Materials
ISSN: 1662-7482, Vols. 773-774, pp 706-710
doi:10.4028/www.scientific.net/AMM.773-774.706

Submitted: 2014-09-14
Revised: 2014-12-24
Accepted: 2015-01-19
Online: 2015-07-15

Humidity Sensor- A Review of Nanostructured Zinc Oxide (ZnO) -based Humidity Sensor

A. S. Ismail[1,a], M. H. Mamat[1,2,b], M.Rusop[1,2,c]

[1]NANO-ElecTronic Centre (NET), Faculty of electrical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia

[2]NANO-SciTech Centre (NST), Institute of Science (IOS), Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia

[a]kyrin_samaxi@yahoo.com, [b]mhmamat@salam.uitm.edu.my, [c]rusop@ salam.uitm.edu.my

Keywords: Humidity Sensor, Metal Oxide, Semiconducting Type, Ceramic Type, Humidity-Sensing, Band Gap, Sol-Gel Preparation Method.

Abstract - We have reviewed humidity sensors based on the Zinc oxide (ZnO) humidity sensor. There are only a few papers reviewing on the ZnO humidity sensor. The characteristics, structures, advantages, and fabrication methods of ZnO have been studied to understand the suitability of the ZnO to be applied at different kind of condition such as for extreme environment, low level humidity detection, and very high humidity level circumstances. The electrical and physical properties of ZnO humidity sensors such as sensitivity, response time, stability, uniformity, and crystallinity have also been discussed in this review. ZnO nanostructures have been widely used for humidity sensors because of its' good stability, high sensitivity for humidity-sensing, low cost, and has a wide band gap. Sol-gel preparation method is commonly used to for ZnO humidity sensor fabrication since it can produce a film with high uniformity, simple process and low cost.

1. Introduction

The appearance of water in surrounding sometimes can cause a problem to human. The ambient humidity levels need to be controlled in certain area such as in factory, food management, medical area and in chemical substance storage area. It is important to have a sensor that is highly sensitive to the humidity level and have a good stability in different temperature. Current development in humidity sensing device has shown a great improvement in the sensor's performance. A new combination of substrate or transducer with the sensing elements such as quartz crystal microbalances coated with SnO2-SiO2 composite and porous anodic aluminum oxide humidity sensor have shown a promising result in the performance of humidity sensor [1][2].

Metal oxide has been widely used as gas sensor because of their sensitivity, low cost and easy to be fabricated [3]. They have a good adsorbing and desorbing properties. Different kind of metal can be added to the metal oxide such as Zn, Sn, Cu, Au, Pt, and Pd metals in small amounts to improve their sensitivity and conductivity [4]. In order to obtain a high surface to volume ratio, lots of methods have been used to fabricate the metal oxide sensor [3]. There is research on the composite material which mixing the metal oxide material with another type of metal oxide to obtained a performance which is superior to the single type material [5]. There are still a few reports on the effect of optical properties on the humidity detection especially the type of metal oxide that has good electrical properties such as ZnO and TiO2 [6].

Zhao et al. has reported on the method of obtaining mesoporous metal oxide structure by using mesoporous silica as the template. The silica will act as the template to replace soft template such as co-polymer that usually used in sol-gel method. Using this method, they manage to obtain a high crystallinity thin film [7]. By synthesizing mesoporous metal oxides it has open many ways to developing new technology related to the mesoporous materials application [8].

2. Classification of Humidity Sensor

There are two types of humidity sensor which are relative humidity sensor and absolute humidity sensor. These sensors are differentiating based on their sensing unit where the relative humidity sensor unit is relative humidity (RH), is a function of temperature and the absolute humidity sensor unit is dew/frost point (D/F PT) is a function of pressure. Relative humidity sensor can be classified into ceramic, semiconductor and polymer. The sensing mechanism for each of that is slightly different since they are built with different material. The capacitive and resistive based humidity sensors are placed under the polymer type of humidity sensor. This paper will only discuss about the relative humidity sensor and anything related to it.

3. Relative Humidity Sensor

Relative humidity sensor can be classified into ceramic, semiconductor and polymer. The sensing mechanism for each of that is slightly different since they are built with different material. The capacitive and resistive based humidity sensors are placed under the polymer type of humidity sensor. Ceramic sensing material has been used in sensor application because of their good thermal and mechanical stability. The surface of ceramic material will react with gas or vapor which cause the increasing in the thickness of depletion layer and change their electrical resistance [9]. Certain ceramic material is used for the purpose of high temperature application such as polymer-derived silicon carbon nitride (SiCN) ceramics. This material has been researched to be applied in harsh environment such as turbine engine which has a very high temperature up to 1600°C along with corrosive gas [9].

In ceramic semiconducting material, the water molecule will combine with the surface of oxide layer in molecular and hydroxyl form. By adsorbing the water molecules, they can produce free electron and where the molecules will replace the previously ionized oxygen on the surface of the material and produce a new free electron (ionized oxygen from the “donor effect”).

4. Zinc Oxide (ZnO)

Zinc oxide has a band gap of 3.37 eV and a very suitable material for electronics, optoelectronics, catalysts, and gas sensors application. Various kind of methods have been used to synthesize ZnO nanostructures [3]. ZnO materials have a very good electrical and optical characteristic, high thermal, chemical and mechanical stability and low cost due to availability abundantly in nature [4] The varieties in morphologies, including nanocrystalline structures, nanorods, nanowires, and nanotetrapods is one of the reason why ZnO is suitable for humidity sensing, which have high surface-to-volume ratios that allow easy adsorption of water vapor in air [10].

ZnO0 has reported on the fabrication of high pure ZnO Colloidal nanocrystal clusters (CNCs) using hydrolyzation method. A very small size nanocluster was obtained and has a good crystallinity. The ZnO CNCs sensor were found to have high sensitivity and fast response/recovery time to humidity and also relatively stable to humidity for a long time [3].

Ates et al. has reported on the effect of Sn doping to the surface morphology and electrical characteristic using sol-gel preparation method. They found that the samples have a direct transition optical band gap and the optical band gap values of the ZnO samples were changed with Sn doping. Quartz crystalline microbalance (QCM) technique was employed to investigate sensor features of the ZnO samples. From the result the Sn-doped ZnO can be used for humidity sensor applications [4].

5. Dopant

Sn doped. Different kinds of dopant enhance the performance of the sensor by changing certain characteristic such as the sensors nanostructure, electrical performance, response, sensitivity and also stability. As reported by Ates et al. the surface structure of nanostructured ZnO has become smoother and more uniform by the increasing of atomic percent of Sn [4]. They found that the

electrical properties of Sn doped is higher compare to the undoped due to the increasing of free electron but through the characterization of humidity sensing properties, the found that by the addition of Sn, the surface structure has become bigger and less in porosity and that also contribute to the low surface volume. Due to this, the responsivity of the sensor is decrease.

Al doped. Al is one of the famous material for doping due to its low cost and suitability with different kind of metal oxide especially ZnO. As reported by Tsai et al. the nanostructured ZnO with Al doped has been used to fabricate laterally grown nanosheet [11]. They have tested the sensor under different humidity levels and found that the Al doped ZnO sensor has limitation depending on the relative humidity value where under very high humidity level (more than 50%) the sensor's response drop rapidly. The hysteresis characteristic obtained from the sensor is also good since the adsorption and desorption curve is in phase.

6. ZnO Nanostructures

There are lot kinds of ZnO nanostructures can be obtained during the fabrication process. The type of structures depend on different kind of factors such as fabrication methods, types of dopants, types of precursors, types of stabilizers and also other parameters such as temperature and environment. The different kind of nanostructure configuration may be useful for different kind of application and will also affect their physical and electrical characteristics.

Colloidal Nanoclusters. Nanoclusters structure is like a granule but it has a rough surface. As reported by Yao et al. the ZnO nanoclusters structure was obtained by doping Sn to the ZnO solution to obtain a high porosity cluster [12]. They found that the sensor has good sensing properties due to the high porosity of the surface which increase the adsorption process. The crystallinity of the structure decrease when the thickness of layer increases.

Fig. 1. Colloidal Nanoclusters

Nanorods Array. ZnO nanorods have a structure like a cylinder or hexagon rod. This structure has a good electron transfer characteristic since it shape produce a straight road for the electron to transfer. Hong et al. was deposited a nanorod structure in their sensor using Ga doped seed layer [13]. From their research, they obtained a smaller diameter of nanorods when they increased the dopant concentration. The structure is uniform and surface area is also increase by increasing the dopant concentration. Gu et al. also reported on the ZnO nanorods [14]. They have obtained nanorods structure using hydrothermal grown method. They combined the nanorods with TiO2 layer and manage to obtain a sensor with a better performance for humidity sensing where the sensitivity of the sensor increases in phase with the increasing of relative humidity.

Fig. 2. Nanorods Array

Nanosheets Structure. Compare to nanorods and nanowires, this structure is not well aligned. For humidity sensor, high surface contact with the H2O of this sheet structure will help the adsorption

process. Tsai et al. has reported on the effectiveness of using laterally oriented ZnO nanosheets for humidity sensing[11]. Using hydrothermal grown method, they have obtained nanosheets structure with high sensing response, good linearity and recovery time. The structure has high porosity but not well align.

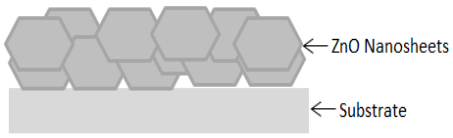

Fig. 3. Nanowires Structure

Nanowires Structure. This structure has a configuration that is almost same as the nanorods but has higher length. Just like the nanorod, this nanostructure also has a good electron mobility characterization. Longer length of each nanowires help to increase the surface structure. Hou et al. reported on the effect of the nanowires structure on their sensor's performance [15]. The response of sensor increase significantly with the existence of nanowires compare to the structure that is without nanostructure. The adsorption and desorption also increase for the sensor with nanowires.

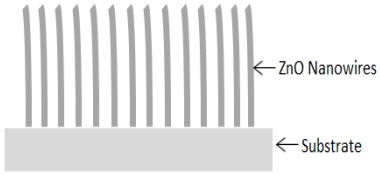

Fig. 4. Nanowires Structure

7. Metal contact structure

In this chapter, we will discuss four different types of metal contact configuration which are the interdigitated electrode array, labyrinth electrode array, the castellated electrode array and the circle electrode array as in figure 5 and how it affects the sensor performance. Chen et al. has fabricated that four types of electrode and analyze the effect of dielectrophoresis on the sensor [16]. Different electrodes have different initial frequency value where the configurations of the electrodes result in the different capacitance value. They have found that the labyrinth electrode array has the produce the highest sensitivity referring to the frequency shift when it is applied with different percentage of relative humidity.

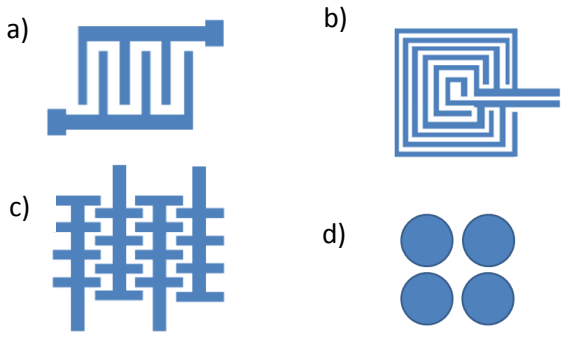

Fig.5. a) interdigitated electrode array, b) labyrinth electrode array, c) castellated electrode array, d) circle electrode array

8. Conclusion

There are lots of papers reviewing on humidity sensor and most of them focusing on general types of humidity sensor which are relative humidity sensor and absolute humidity sensor. In this paper, we discuss detail on the ZnO as metal oxide humidity sensor. There are different types of structures

can be obtained using different fabrication method, and the structure's characterization is different as well as the metal contact structure. The most suitable metal contact to be used in humidity sensor application is labyrinth.

References

[1] Ye Zhu, Junchen Chen, Huimin Li, Yongheng Zhu, Jiaqiang Xu, "Synthesis of mesoporous SnO2–SiO2composites and their applicationas quartz crystal microbalance humidity sensor", *Sensors and Actuators B: Chemical,*pp.320-325, 2014.

[2] S.W. Chen O.K. Khor M.W. Liao C.K. Chung, "Sensitivity Evolution and Enhancement Mechanism of Porous Anodic Aluminum Oxide Humidity Sensor Using Magnetic Field", *Sensors and Actuators B,* pp. 925, 2014.

[3] Shufeng Si , Shuo Li, Zhengqiu Ming, Linpei Jin, "Humidity sensors based on ZnO Colloidal nanocrystal clusters", *Chemical Physics Letters,*pp.288-291, 2010.

[4] T. Ates, C. Tatar∗, F. Yakuphanoglu, "Preparation of semiconductor ZnO powders by sol–gel method: Humidity sensors", *Sensors and Actuators A: Physical*, pp. 153-160, 2013.

[5] Nidhi Verma, SatyendraSingh, RichaSrivastava, B.C.Yadav, "Fabrication of iron titanium oxide thin film and its application as opto-electronic humidity and liquefied petroleum gas sensors", *Optics & Laser Technology*, pp. 181-188, 2014.

[6] B.C. Yadava, Ramesh C. Yadav, Prabhat K. Dwivedi, "Sol–gel processed (Mg–Zn–Ti) oxide nanocomposite film deposited on prism-base as an opto-electronic humidity sensor", *Sensors and Actuators B: Chemical,* pp. 413-419, 2010.

[7] Jing Zhao, Yinping Liu, Xiaowei Li , Geyu Lua, Lu You, Xishuang Liang, Fengmin Liu, Tong Zhang, Yu Du, "Highly sensitive humidity sensor based on high surface area mesoporous LaFeO3 prepared by a nanocasting route", *Sensors and Actuators B: Chemical*, pp. 802-809, 2013.

[8] Xiangwei Liu, Rui Wang, Tong Zhanga, Yuan He, Jinchun Tu, Xiaotian Li, "Synthesis and characterization of mesoporous indium oxide for humidity-sensing applications" *Sensors and Actuators B: Chemical*, pp. 442-448, 2010.

[9] Zhi Chen∗ and Chi Lu, "Humidity Sensors: A Review of Materials and Mechanisms", *SENSOR LETTERS*, pp. 274-295, 2005.

[10] Hoang-Si Hong1, Duy-Thach Phan, Gwiy-Sang Chung, "High-sensitivity humidity sensors with ZnO nanorods based two-port surface acoustic wave delay line", *Sensors and Actuators B: Chemical*, pp. 1283-1287, 2012.

[11] Fu-Shou Tsai, Shui-Jinn Wang, "Enhanced sensing performance of relative humidity sensors using laterally grown ZnO nanosheets", *Sensors and Actuators B: Chemical*, pp. 280-287, 2014.

[12] Mingshui Yao, Fei Ding, Yuebin Cao, Peng Hu, Junmei Fan, Chen Lu,Fangli Yuan, Changyong Shi, Yunfa Chen, "Sn doped ZnO layered porous nanocrystals with hierarchicalstructures and modified surfaces for gas sensors", *Sensors and Actuators B: Chemical*, pp. 255-265, 2014.

[13]Hoang-Si Honga,∗, Gwiy-Sang Chung, "Controllable growth of oriented ZnO nanorods using Ga-doped seed layers and surface acoustic wave humidity sensor" *Sensors and Actuators B: Chemical*, pp. 446-451, 2014.

[14] Leilei Gu, Kaibo Zheng, Ying Zhou, Juan Li, Xiaoliang Mo, Greta R. Patzke, Guorong Chen, "Humidity sensors based on ZnO/TiO2 core/shell nanorod arrays with enhanced sensitivity", *Sensors and Actuators B: Chemical*, pp. 1-7, 2011.

[15] Jei-Li Hou, Chih-Hung Wua, Ting-Jen Hsueh, "Self-biased ZnO nanowire humidity sensor vertically integrated ontriple junction solar cell", *Sensors and Actuators B: Chemical*, pp. 137-141, 2014.

[16] Leping Chen, Jian Zhang, "Capacitive humidity sensors based on the dielectrophoretically manipulated ZnO Nanorods", *Sensors and Actuators A: Physical*, pp. 88-93, 2012.