

ISSN 1726-5479

SENSORS & TRANSDUCERS

12^{vol. 111}/09



Sensor Market Trends

International Frequency Sensor Association Publishing





Editors-in-Chief: professor Sergey Y. Yurish,
Phone: +34 696067716, fax: +34 93 4011989, e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific

Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

- Abdul Rahim, Ruzairi**, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Northern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Monitors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, VIT University, Tamil Nadu, India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Université de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevic, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ. of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Grael, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia

Kim, Min Young, Kyungpook National University, Korea South
Ko, Sang Choon, Electronics and Telecommunications Research Institute, Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S., National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raouf, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politècnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politécnica de Catalunya, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemeni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shearwood, Christopher, Nanyang Technological University, Singapore
Shin, Kyuho, Samsung Advanced Institute of Technology, Korea
Shmaliy, Yuriy, Kharkiv National Univ. of Radio Electronics, Ukraine
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymannpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sunriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vaseashta, Ashok, Marshall University, USA
Vazquez, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Advanced Micro Devices, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung Univ. of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufera Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zamani, Cyrus, Universitat de Barcelona, Spain
Zeni, Luigi, Second University of Naples, Italy
Zhang, Minglong, Shanghai University, China
Zhang, Quintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhang, Xueji, World Precision Instruments, Inc., USA
Zhong, Haoxiang, Henan Normal University, China
Zhu, Qing, Fujifilm Dimatix, Inc., USA
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 111
Issue 12
December 2009

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Effect of Uncertainty in the Reliability of the COTS based Hardware System and its Sensitivity Analysis <i>Y. B. Acharya and Vivek Goswami</i>	1
cLite – A Capacitive Signal Conditioning IC <i>Krauss Gudrun</i>	10
Fabrication Challenges for Realization of Wet Etching Based Comb Type Capacitive Microaccelerometer Structure <i>Shankar Dutta, R. Pal, P. Kumar, O. P. Hooda, J. Singh, Shaveta, G. Saxena, P. Datta and R. Chatterjee</i>	18
Stray Capacitances of an Air-Cored Eddy Current Sensor <i>Yi Jia, Henning Heuer, Susanne Hillmann, Norbert Meyendorf</i>	25
Design and Simulation of MOEMS Thermal Sensor Based on a Bimetallic Mechanism <i>Shahriar Kouravand</i>	38
Directivity Analysis of Piezoelectric Micromachined Ultrasonic Transducer Array <i>Yunlong Geng, Limei Xu, Xuesheng Li, Leon Xu</i>	45
Design of RF MEMS Switch with High Stability Effect at the Low Actuation Voltage <i>Bandana Mishra, Rajiv Panigrahi, Z. C. Alex</i>	58
Study of the Stability of Copper Fixed Point in Sealed Cells for Calibration of Noble Metal Thermocouples <i>Yasser A. Abdel-Aziz and Faten M. Megahed</i>	65
Reconfigurable Antenna for Medical Applications <i>Elizabeth Rufus and Zachariah C. Alex</i>	71
Numerical Analysis of an Oscillating Micromixer <i>B. Dennai, R. Khelifaoui, B. Benyoucef, A. Slimani, A. Maazouzi and A. Missoum</i>	79
Investigation of Wireless Sensor Deployment Schemes for In-Situ Measurement of Water Ice near Lunar South Pole <i>Jayesh P. Pabari, Y. B. Acharya and U. B. Desai</i>	86
Single-mode D-type Surface Plasmon Resonance Optical Fiber Sensor: Review <i>Ming-Hung Chiu</i>	106
Multimode D-type Optical Fiber Sensor Based on ATR Effect in Temperature Detection <i>Ming-Hung Chiu, Po-Chin Chiu, Liu-Yi Hsien, Wei-Ching Chuang and Fuh-Shyang Juang</i>	125

A Comparative Assessment of Performance of Moisture Controllers for a Real Time Industrial Paper Machine Model <i>K. Ramkumar and A. Ramakalyan</i>	132
Photoresponse of LAPS with Different Species Membranes: Modeling and Simulation <i>Ferdinand Gasparyan</i>	141
Effect of Firing Temperature on Humidity Sensing Properties of SnO₂ Thick Film Resistor <i>R. Y. Borse and A. S. Garde</i>	155

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm>

International Frequency Sensor Association (IFSA).

SENSORDEVICES 2010: The First International Conference on Sensor Device Technologies and Applications

July 18 - 25, 2010 - Venice, Italy



The inaugural event SENSORDEVICES 2010, The First International Conference on Sensor Device Technologies and Applications, initiates a series of events focusing on sensor devices themselves, the technology-capturing style of sensors, special technologies, signal control and interfaces, and particularly sensors-oriented applications. The evolution of the nano- and microtechnologies, nanomaterials, and the new business services make the sensor device industry and research on sensor-themselves very challenging.

Conference tracks

Sensor devices
Sensor device technologies
Sensors signal conditioning and interfacing circuits

Medical devices and sensors applications
Sensors domain-oriented devices, technologies, and applications
Sensor-based localization and tracking technologies

Important dates

Submission (full paper): February 20, 2010
Notification: March 25, 2010
Registration: April 15, 2010
Camera ready: April 20, 2010



<http://www.iaria.org/conferences2010/SENSORDEVICES10.html>

Effect of Firing Temperature on Humidity Sensing Properties of SnO₂ Thick Film Resistor

R. Y. Borse and A. S. Garde

Thin and Thick film laboratory, Department of Electronic Science and Department of Physics,
M S G College, Malegaon Camp, Malegaon, Dist- Nasik-423 105, (MS), India
Tel: +91-(02554) 252077, +91-9423287992, fax-+91-(02554) 251705
E-mail: ratanborse@yahoo.co.in, arungarde@yahoo.co.in

Received: 17 September 2009 /Accepted: 22 December 2009 /Published: 30 December 2009

Abstract: Thick films of SnO₂ were prepared using standard screen printing technique. The films were dried and fired at different temperatures. Tin-oxide is an n-type wide band gap semiconductor, whose resistance is described as a function of relative humidity. An increasing firing temperature on SnO₂ film increases the sensitivity to humidity. The parameters such as sensitivity, response times and hysteresis of the SnO₂ film sensors have been evaluated. The thick films were characterized by XRD, SEM and EDAX and grain size, composition of elements, relative phases are obtained. *Copyright © 2009 IFSA.*

Keywords: Thick film resistors, Tin oxide, Humidity, Sensitivity, XRD

1. Introduction

Recent developments in automated systems have made ever-increasing demands for various kinds of physical and chemical sensors. As humidity is a very common parameter in our environment, measurements and /or control of humidity are important not only for human comfort but also for a broad spectrum of industries and technologies. so for many methods of sensing humidity and moisture have been introduced, and almost all of them are still in use. Sensors of great variety of application have been developed, numerous materials have been utilized for humidity sensing of which the metal oxides that are physically and chemically stable, have been extensively used at both room and elevated temperature [1-3]. The sensing materials are roughly classified in to three groups, i.e. electrolytes,

organic polymers and porous ceramics. In spite of the differences in materials, most sensors utilize a common phenomenon, that is physical or chemical adsorption (or absorption) of water molecules [4].

Among the different types of humidity sensors, those based on electrical properties such as resistance and capacitance is best suited to modern automatic control systems. Various sensors for humidity have been introduced [4, 5], some recent ones [4] of which are of miniature solid state type. Different materials are used for these solid state sensors [4-11]. The semiconductor humidity sensors are characterized by their conductance change due to chemical absorption of water molecules, thus resulting in electron conductivity. These types of humidity sensors are now under development by several researchers [4, 8, 11-14]. Stannic Oxide (SnO_2) is an n-type wide band gap semiconductor of which electrons are majority carrier, and electron concentration of conduction band affected by gas. The resistance of SnO_2 thick film resistors is reported to be a function of relative humidity (RH) [8]. It is widely used as a gas sensor for inflammable gases [11, 15]. Sensors based on change in resistance and capacitance is preferred. In this paper we report the resistance type humidity sensing studies of SnO_2 thick film resistors fabricated by standard screen printing technique on alumina substrate. [16, 17]

2. Experimental Methods

Tin oxides films were prepared on alumina substrates by using screen printing technique [18-20]. The SnO_2 powder (99.99 % Pure, AR grade, Loba Chemicals) was weighed and calcinated in air at $400\text{ }^\circ\text{C}$ ($\pm 2\text{ }^\circ\text{C}$) for 2 hours. The calcinated SnO_2 powder was crushed and mixed thoroughly with glass frit as permanent binder and ethyl cellulose as a temporary binder. The mixture was then mixed with butyl carbitol acetate as a vehicle to make the paste. The paste was then screen printed onto the surface of alumina substrate. After screen printing the films were dried under IR-lamp for 1 hour and then fired at $580\text{ }^\circ\text{C}$, $680\text{ }^\circ\text{C}$ and $780\text{ }^\circ\text{C}$ ($\pm 2\text{ }^\circ\text{C}$) for 30 minutes. The SnO_2 Paste are found to have good printability and thixotropic.

The thickness of the SnO_2 thick film resistors was measured by using Taylor-Hobson (Taly-step UK) system. The thickness of the films was observed in the range of $10\text{ }\mu\text{m}$ – $20\text{ }\mu\text{m}$.

Using X-ray diffraction (Miniflex Model, Rigaku, Japan, DMAX-500) analysis from 20 – 80° , 2θ was carried out to examine the final compositions of the SnO_2 films samples. The average grain size of tin oxide thick film samples were calculated by using the Seherrer formula [21]

$$D = \frac{0.9\lambda}{\beta \cos \theta}, \quad (1)$$

where D is the average grain size, $\lambda = 1.542\text{ AU}$ (X-ray wavelength), and β is the peak FWHM in radiation and θ is diffraction peak position. The microstructure and elemental composition of the films were analyzed using a scanning electron microscope [SEM model JEOL 6300 (LA) Germany] coupled with an energy dispersive spectrometer (EDS JEOL, JED-2300, Germany).

2.1. Humidity Measurement System

Fig. 1. shows the schematic diagram of the closed humidity system used for measurement of relative humidity (RH). It consists of a closed flask (total volume 500 ml) with two necks for inserting thermometers and the thick film sensor. The flask is partially filled with water and kept in a cooling container [3, 17, 22, 23].

The % RH of the air in the system is given by [24]

$$RH\% = \frac{E_w(T_w)}{E_w(T_s)} \times 100, \quad (2)$$

where $E_w(T_w)$ is the saturated vapour pressure at the temperature of the water bath T_w and $E_w(T_s)$ is the saturated vapour pressure at the temperature of thick film sensor element (T_s) (connected at a time). The RH is adjusted by changing the temperature of the humidity system. The thick film sensor is either kept and stabilized inside the system (for sensitivity and hysteresis measurement) or is to be inserted in it within a second (for response time measurement).

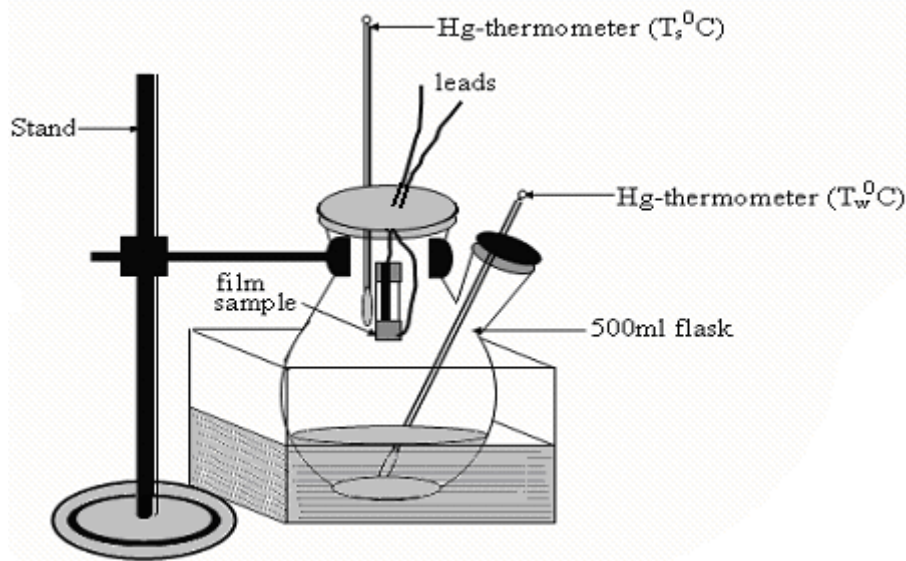


Fig. 1. Humidity measurement system.

The D.C resistance of the thick films was measured by using half bridge method a function of temperature described elsewhere [25]. The films were set a temperature-controlled (± 1 °C) atmosphere. A load resistor R_L was connected in series with the thick film and a D.C voltage was applied to the circuit. The values of the thick film resistor were obtained by measuring output voltage across the load resistor R_L . A chromel-alumel thermocouple was used to indicate the operating temperature (± 1 °C). The thick film resistance, (R_f) was calculated by the relation

$$R_f = [(V_{app.} / V_o) - 1] R_L,$$

where $V_{app.}$ is the applied voltage;
 V_o is the voltage across load resistor R_L .

2.1.1. Sensitivity

It is defined as the change in resistance due to a change in %RH with respect to the initial resistance R_a , i.e. % S = $[(\Delta R / R_a) / RH] \times 100$; It is measured by keeping the sample at different RH values at stabilized condition.

2.1.2. Response Time

Response time is the time taken by the thick film sensor to attain 90 % of maximum value of resistance upon exposure to humidity and recovery time is the time taken by the film sensor to attain 10 % of maximum value of resistance.

For measuring the response and reverse response (recovery) time of SnO₂ thick film sensors, two adjacent humidity systems, one at 20 %RH and the other at 80 %RH, respectively, are used. The stabilized resistance is measured in one system, and then the sample is transferred to the other system within a second. Then the variation in resistance is measured with respect to time to study the response time.

2.1.3. Hysteresis

For hysteresis measurements with the sample kept inside the system, the humidity in the system is decreased initially by cooling it down and the corresponding change in resistance is measured. Within 60 minutes the system achieves the minimum humidity level (20 %). To increase the humidity, the system temperature is increased in an open atmosphere without any external heat energy (within 40 minutes). It must be noted that the system response time is very large with respect to the response time of the sensor.

After completing one cycle, the system is allowed to equilibrate (to room temperature and pressure) for 50-60 minute and then the samples are cycled again.

3. Results

3.1. X-ray Diffraction Studies

X-ray diffraction studies of the thick films were carried out using X-ray diffractometer (Miniflex model Rikagu, Japan). Fig. 2. shows the X-ray diffraction pattern of SnO₂ thick films fired at 580, 680 and 780 °C plotted in the range of 20-80° (2θ) versus intensity having several peaks of tin oxide phases indicating polycrystalline nature. The observed peaks match well with the reported ASTM data of tin-oxide confirming the polycrystalline nature of the film material. The average grain size was determined by using Scherrer formula and was estimated to be 37, 41 and 54 nm (± 2nm) for the firing temperatures of 580, 680 and 780°C respectively. Table 1 illustrates the percentage of relative phases of tin oxide present in thick film samples.

Table 1. Presence of % relative phases of the SnO₂.

Firing temperature (°C)	% relative presence of phases					
	T (SnO ₂)	O (SnO ₂)	Sn ₃ O ₄	Sn ₂ O ₃	Al ₂ O ₃	Average grain size (±2nm)
580	32.00	34.82	22.00	1.937	9.248	37.00
680	32.98	26.92	19.139	2.172	18.79	41.00
780	34.38	29.38	17.07	2.928	16.24	54.00

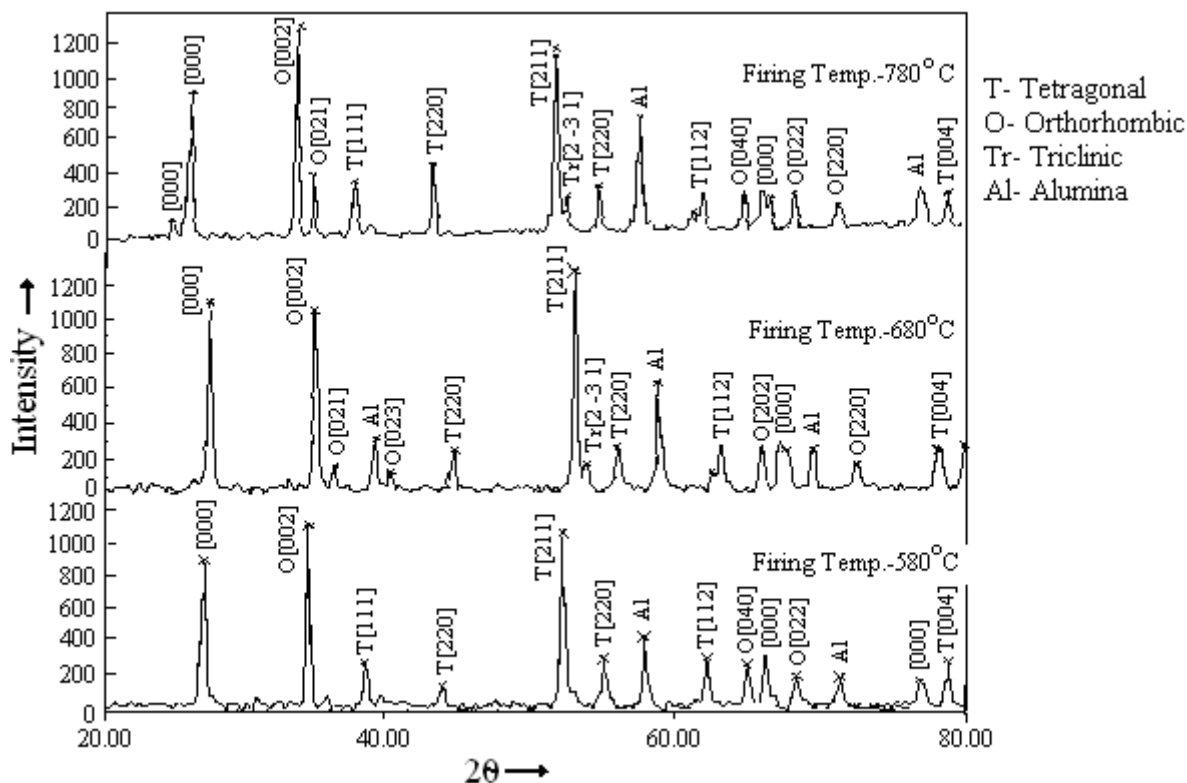


Fig. 2. XRD patterns of SnO₂ thick film samples fired at (a) 580; (b) 680; and (c) 780°C.

3.2. Microstructural and Elemental Analysis

Scanning electron microscopic (SEM) studies were carried out using SEM model JEOL 6300 (LA) Germany. Fig. 3. depicts SEM images of SnO₂ thick films fired at 580, 680 and 780 °C. The micrograms show uniform polycrystalline nature of the films indicating increased grain size with firing temperature. The micrograms show voids between the particles basically due to evaporation of the organic solvent during the firing of the films.

The elemental analysis of the films was carried out using EDS (JEOL, JED-2300, Germany). The constituent elements of SnO₂ thick films are tin and oxygen and no other impurity elements are present in the composition. Also from the EDS spectra it is seen that wt% and at% are nearly matched. Table 2 illustrates the quantitative elemental analysis.

Table 2. Quantitative elemental analysis.

Sample	Wt %	Firing temperature(°C)					
		580		680		780	
		Sn	O	Sn	O	Sn	O
SnO ₂	Mass %	88.22	11.78	89.69	10.31	89.57	10.43
	At %	50.23	49.77	53.97	46.03	53.65	46.35
	Error %	0.48	0.11	0.41	0.09	0.44	0.10

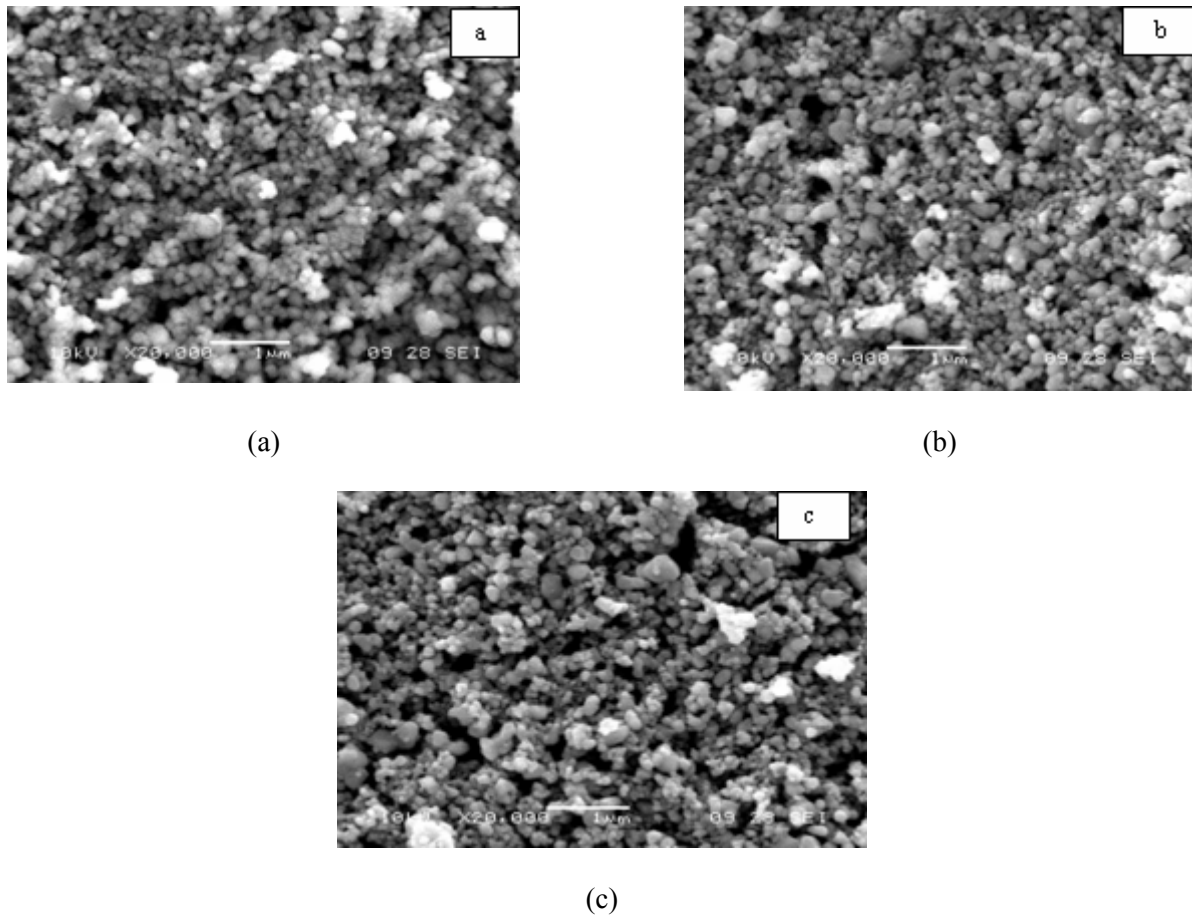


Fig. 3. Scanning Electron Micrograms of SnO₂ thick film samples fired at (a) 580 (b) 680 and (c) 780°C.

3.3. Humidity Response

3.3.1. Sensitivity

Fig. 4. shows the humidity sensing response curves for SnO₂ films fired at different temperatures. The response of SnO₂ film resistor fired at temperature 580 °C shows that as RH increases, resistance decreases linearly up to 50 %RH and then decreases slightly up to 80 %RH and show average sensitivity of 0.85. Curve for thick film fired at 680 °C shows that as %RH increases fast decrease in resistance up to 30 % RH and slowly up to 52 % RH and finally saturates with average sensitivity of 1.40. Curve for SnO₂ film sample fired at 780 °C shows rapid decrease in resistance with increase in relative humidity up to 55 % RH and then decreases slightly up to 60 %RH, then finally saturates with average sensitivity of 5.85.

3.3.2. Response Time

The response time is the time taken by sensor to sense a humidity change from lower RH (20%) to higher RH (80 %) and the reverse response time is the time taken by the sensor to sense a humidity change from higher RH (80 %) to lower RH (20 %). Fig. 5. shows a plot of $[(R_{rh}-R_a)/R_a]$ % versus time for the SnO₂ thick films fired at 580, 680 and 780°C. From Fig. 5 (a). it is observed that the response time from lower RH (20 %) to higher RH (80 %) is 140 sec for the thick film fired at 580 °C, 80 sec for 680 °C and 75 sec for 780 °C. For the reverse change (80 %RH-20 %RH) in Fig. 5(b), the response time is 2 min for films fired at 580 °C, for 10 min for 680 °C and 3 min for 780 °C.

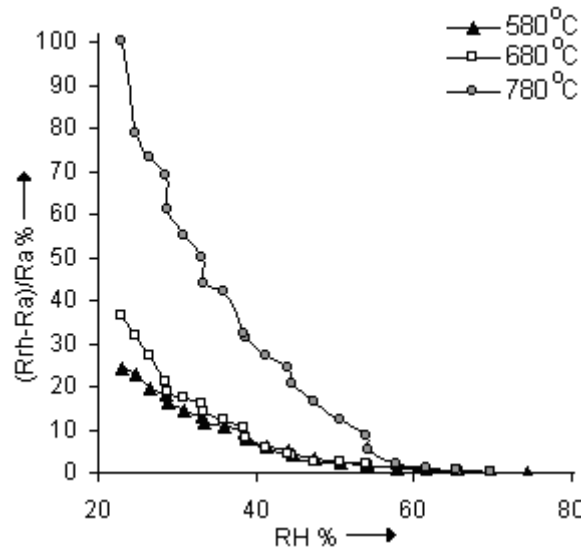
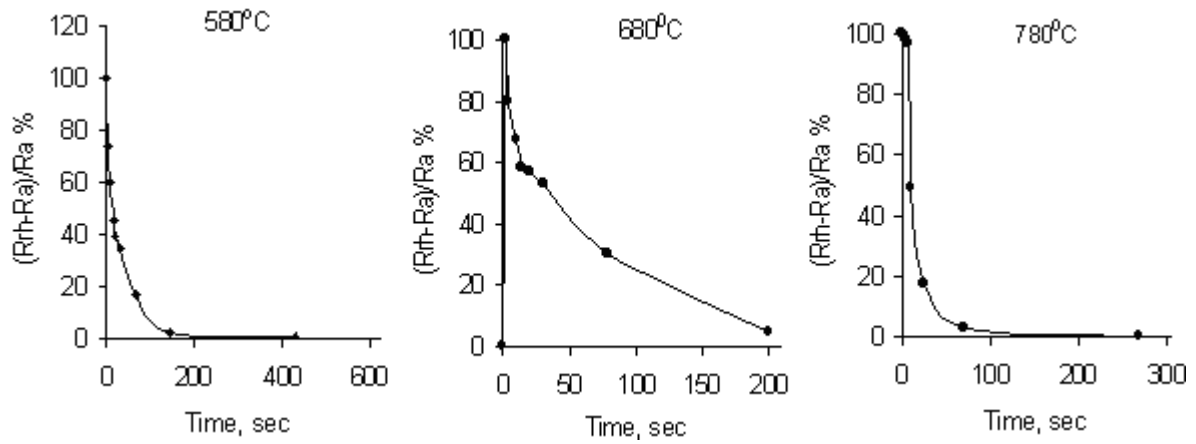
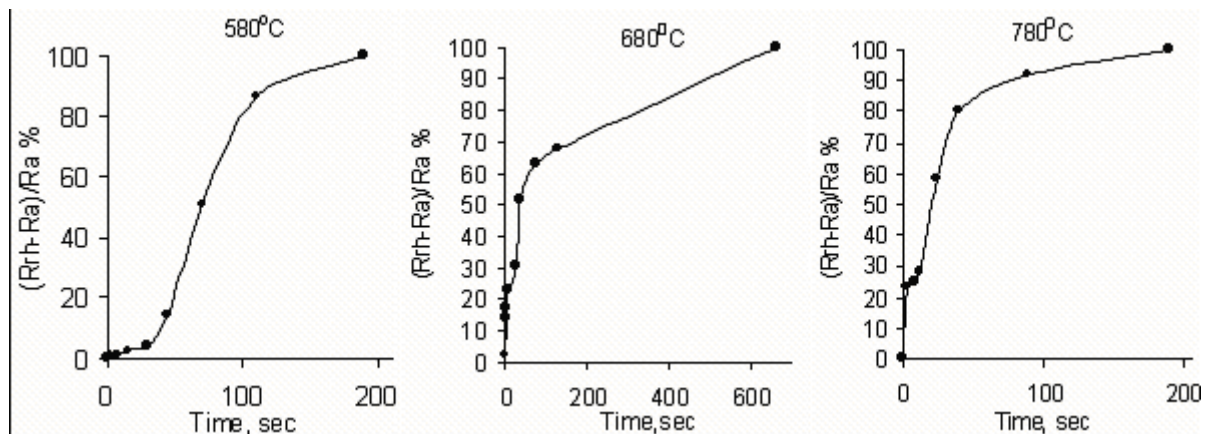


Fig. 4. Plot of $[(R_{rh}-R_a)/R_a]$ % versus %RH for SnO₂ thick film samples fired at 580, 680 and 780 °C.



(a) Response time (Low to High transition)



(b) Response time (High to Low transition).

Fig. 5. Plots of $[(R_{rh}-R_a)/R_a]$ % vs time for the SnO₂ thick films fired at 580, 680 and 780°C.

3.3.3. Hysteresis

It is defined as the maximum percentage difference in the two curves at any RH%, when the sample is exposed to decreasing and increasing humidity cycle successively, with respect to RH%. Fig. 6. gives typical cycling hysteresis response of SnO₂ thick film samples. In this case, the film samples fired at 580, 680 and 780 °C gives maximum percentage deviation 0.125, 0.244 and 0.335 in two curves particularly for 36 %, 46 % and 46 % RH respectively.

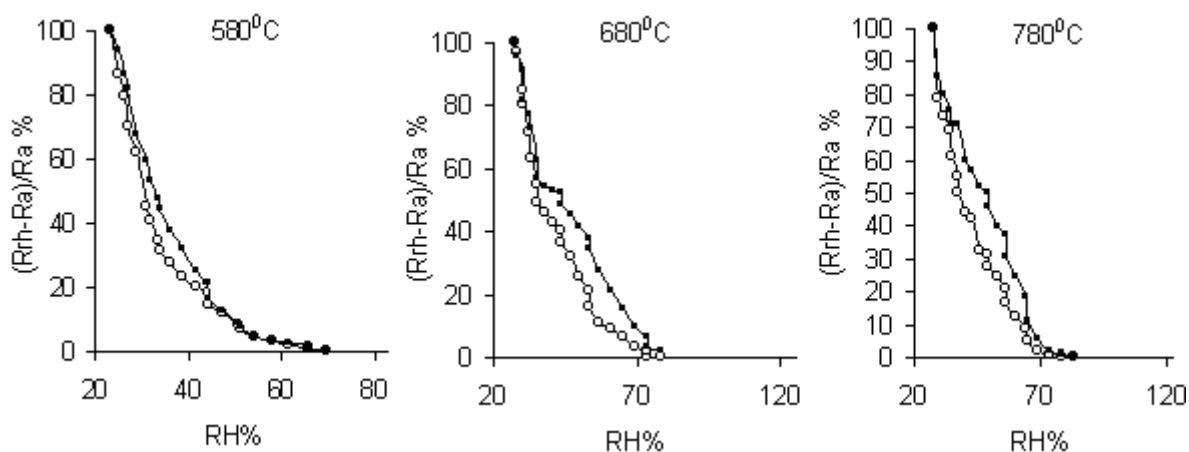


Fig. 6. Hysteresis curves for three samples fired at 580, 680 and 780 °C.

4. Discussions

In Order to understand the phases in SnO₂ film samples, the X-ray diffraction study was undertaken. Fig. 2. shows an XRD patterns of SnO₂ film samples fired at 580, 680 and 780 °C, plotted in the range 20-80° (2θ) versus intensity. The XRD pattern consists of several peaks of tin oxide phases indicating polycrystalline nature. The tetragonal, orthorhombic and triclinic phases were observed. The observed peaks match well with the reported ASTM data of tin-oxide, confirming the polycrystalline nature. The higher peak intensities of an XRD pattern is due to the better crystallinity and bigger grain size can be attributed to the agglomeration of particles. The average crystallite size is increasing with increase of firing temperature. The total number of peaks increases with increase in firing temperature. Fig. 3 shows the surface morphology of SnO₂ films observed by Scanning Electron microscope (SEM). The micrograph of these samples shows voids between the particles are basically due to evaporation of the organic solvent during the firing of the films. It can be seen from Fig. 3 (a) to (c) that the grain size increased with increase in firing temperature. Another fact observed is of some segregation in film fired at higher temperature. The micrograph also shows the presence of more agglomeration in the film samples. The EDS spectrum indicates that the wt.% and at.% are nearly matched from EDS spectra it is seen that the major peaks are for tin and oxygen and no other impurity elements are present in the film sample.

The Fig. 4. shows decrease in relative resistance of SnO₂ film with increase in RH% is due to the increase thickness of the absorbed H₂O film on the surface of SnO₂ film resistor [4, 9, 23, 26]. The decrease in resistance with increase in humidity is also due to the dissociation of H₂O molecules [27], into proton (or another H₃O⁺) and hydroxyl groups (OH⁻). H₃O⁺ is responsible for the reversible reaction. These hydroxyl groups combine with surface oxygen ions forming water and releases back an electron to the material. Thus the conductance of n-type semiconductor increases (resistance decreases) with increase in humidity [4, 28].

The physisorbed water dissociates because of high electrostatic field in the chemisorbed layer. The possible reaction can be written as



The response of SnO₂ film resistor fired at temperature 580 °C shows that as RH increases, resistance decreases linearly 50 %RH, then decreases slightly up to 80 %RH. Response of SnO₂ thick film fired at 680 °C shows that as %RH increases resistance decreases rapidly up to 30 %RH and slowly up to 52% RH and saturates at constant value. Curve for SnO₂ film Sample fired at 780 °C shows that as %RH increases, the resistance decreases rapidly up to 55% RH and then decreases slightly up to 60 %RH, and finally saturates. The maximum sensitivity of 5.85 for the film sample fired at 780 °C is due to presence of large number of pores in the film. The nonlinearity in response at lower RH level is probably due to single layer coverage of the water molecules (chemisorbed water) on the surface of the film [9, 23, 29]. This result in smaller change in resistance with RH, as shown by the lower end of the response curves. Similarly at high RH, the capillary condensation effects are expected to play a significant role in getting non-linearity by saturation. [9, 29]. However, this effect of such type of interaction is observed in case of film sample fired at 780 °C.

Response times of typical SnO₂ thick film resistors are given in Fig. 5. (a) and (b). The film resistor gives response to rising humidity from 20 to 80 %RH (Low to High). It is observed that the response time to a transition from low to high RH is of the order of 140 sec for the thick film fired at 580 °C, 80 sec for 680 °C and 75 sec for 780 °C. For the reverse change (80-20) %RH, it is 2 min for films fired at 580 °C, for 680 °C 10 min and for 780 °C 3 min. This may be due to the closed humidity system used. Desorption via evaporation is a ventilation dependent process. The response time can be decreased by reducing the size of film sample. The thermal mass of the samples is very small with as compared to that of the humidity chamber.

Typical cycling hysteresis response of the three SnO₂ thick film resistors fired at temperatures of 580,680 and 780 °C is given in Fig. 6. The adsorption-desorption cycles of thick film resistors show hysteresis. The hysteresis in humidity sensors is due to the slow desorption of chemisorbed water molecules (at lower RH) and capillary condensation (at higher RH). The hysteresis in humidity sensors can be explained with the help of Kelvin effect [14], which prevents or retards the desorption of water, condensed in the pores of SnO₂ during adsorption process as it forms a concave meniscus. The vapour pressure of water over the concave meniscus is much lower than that in surrounding atmosphere, hence desorption can take place only when external vapour pressure becomes less than vapour pressure above the meniscus which mainly occurs in the range of 85 to 50 % RH [9].

5. Conclusion

Following conclusions can be drawn from the experimental results.

1. The D.C. resistance of SnO₂ thick films decreases with increasing relative humidity.
2. The SnO₂ films showed extremely high sensitivity to humidity at higher firing temperatures.
3. The sensing mechanism of the SnO₂ thick film resistors was the surface controlled mechanism (adsorption/desorption).
4. The present SnO₂ thick film device has advantages of ease of fabrication, small size, high sensitivity, low hysteresis and response time.

Acknowledgment

The authors thank Management authorities of M.G. Vidyamandir's Malegaon-camp Dist. Nasik and Principal Dr. B. S. Jagdale for providing all the required infrastructural facilities for doing this work.

References

- [1]. H. N. Norton, Humidity Moisture, Sensors and Analyzer Hand book, *Prentice-Hall, Englewood Cliffs, NJ*, [Chapter:2], 1982, p. 204.
- [2]. B. Chachulski, J. Gebicki, *J. Measurement Science and Technology*, 17, 2006, pp. 12-16.
- [3]. B. C. Yadav, N. K. Pandey, Amit K. Srivastav, Preeti Sharma, *J. Measurement Science and Technology*, 18, 2007, pp. 260-264.
- [4]. N. Yamazoe, and Y. Shinizu, *Sensors and Actuators*, 10, 1986, pp. 379.
- [5]. H. N. Norton, Handbook of Transducers, *Prentice Hall*, Englewood, Cliff, NJ, 1989, p. 251.
- [6]. Kalyan Kumar Mastery, Debdujal Saha, Sen Gupta Kamalendu, *Sensors and Actuators*, B, 106, 2005, pp. 258-262.
- [7]. Kummer Adrian M., Hierlemann Andreas, *IEEE Sensors Journal*, 6, 2006, pp. 3-10.
- [8]. H. Arai, *J. Surface Sci. Soc. Jpn.*, 5, 1984, pp. 165.
- [9]. M. L. Jadhav, S. A. Gangal and R. N. Karekar, *Sensors and Actuators*, 8, 1985, pp. 149.
- [10]. Maria Prudenziati and Bruno Morten, *An Overview Sensors and Actuators*, 10, 1986, pp. 65.
- [11]. S. Mukode, and H. Futata, *Sensors and Actuators*, 16, 1989, pp. 1.
- [12]. T. Seiyama, and H. Arai, Semiconductor type humidity sensors, *Japanese patent Application*, 1982, filed Nr. 57-186035 (laid open to public inspection, Nr. S59-75602 (in Japanese)).
- [13]. F. Fukushima, R. Makimoto, J. Terada, and T. Nitta, *Neo-Humi-Ceram, Nat. Tech. Rep.*, (in Japanese), 29, 1983, pp. 450.
- [14]. Y. Shimizu, H. Arai and T. Seiyama, *Sensors and Actuators*, 7, 1985, pp. 1.
- [15]. Kiran Jain, R. B. Pant, S. T. Lakshikumar, *Sensors and Actuators*, B, 113, 2006, pp. 823-829.
- [16]. N. K. Pandey, Anupam Tripathi, Karunesh Tiwari, Akash Roy, Amit Rai, Priyanka Awasti, Aradhana Mishra, Alok Kumar, *Sensors & Transducers Journal*, 96, 9, pp. 2008, pp. 42-46.
- [17]. B. C. Yadav, N. K. Pandey, *Sensors & Transducers Journal*, 78, 4, pp. 2007, pp. 1127-1133.
- [18]. S. G. Ansari, P. Boiroojerdian, S. K. Kulkarni, S. R. Sainkar, R. N. Karekar and R. C. Aiyer, *Materials Science: Materials in Electronics* 7, 1996, pp. 267.
- [19]. S. G. Ansari, R. N. Karekar and R. C. Aiyer, *National seminar on Physics and Technology of Sensors*, Pune, P-C 32-1, February 1-3, 1996.
- [20]. A. T. Nimal, Vijay Kumar and A. K Gupta, *Indian J. Physics*, 42, 2004, p. 275.
- [21]. B. D Cullity, Elements of X-ray diffraction, *Addison-Wesley Publishing Co.*, 1956.
- [22]. C. L Cutting, A simple apparatuses for hygrometer calibration, *J. Sci. Instrum.*, 30, 1953, pp. 338.
- [23]. S. G. Ansari, Z. A. Ansari, M. R. Kadam, R. N. Karekar, R. C. Aiyer, *Sensors and Actuators*, B, 21, 1994, pp. 159.
- [24]. R. C. Weast (ed), CRC Handbook of Chemistry and Physics, *CRC Press Boca Raton, FL*, 59th edition, 1978-1979, p. B92, E253.
- [25]. G. Sarala Devi, S. Manorama and V. J. Rao, *J. Electrochem. Soc.*, 42, 1995, pp. 2754.
- [26]. H. Grange, C. Bieth, H. Boucher, and D. Delapierra, *Sensors and Actuators*, 12, 1987, pp. 291.
- [27]. G. Huyberegts., M. Honore, J. Roggem, *Sensors and Actuators*, B, 15-16, 1993, pp. 281.
- [28]. Bernard M. Kulwicki, *J. Am. Ceram. Soc.* 74, 4, 1991, pp. 697.
- [29]. G. Gualtiero, Giampiero Montesperelli, Enrico Ttaversa, Andrea Bearzotti, *Sensors and Actuators*, B, 13-14, 1993, pp. 525.

SENSORCOMM 2010:

The Fourth International Conference on Sensor Technologies and Applications

July 18 - 25, 2010 - Venice, Italy



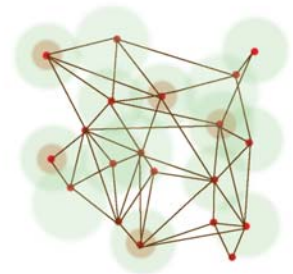
SENSORCOMM 2010 (The Fourth International Conference on Sensor Technologies and Applications) is a multi-track event covering related topics on theory and practice on wired and wireless sensors and sensor networks. The topics suggested can be discussed in term of concepts, state of the art, research, standards, implementations, running experiments, applications, and industrial case studies.

Conference tracks

- APASN** Architectures, protocols and algorithms of sensor networks
- MECSN** Energy, management and control of sensor networks
- RASQOFT** Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN** Performance, simulation and modelling of sensor networks
- SEMOSN** Security and monitoring of sensor networks
- SECSN** Sensor circuits and sensor devices
- RIWISN** Radio issues in wireless sensor networks
- SAPSN** Software, applications and programming of sensor networks
- DAIPSN** Data allocation and information in sensor networks
- DISN** Deployments and implementations of sensor networks
- UNWAT** Under water sensors and systems
- ENOPT** Energy optimization in wireless sensor networks

Important dates

- Submission (full paper):** February 20, 2010
- Notification:** March 25, 2010
- Registration:** April 15, 2010
- Camera ready:** April 20, 2010



<http://www.iaaria.org/conferences2010/SENSORCOMM10.html>

CENICS 2010:

The Third International Conference on Advances in Circuits, Electronics and Micro-electronics

July 18 - 25, 2010 - Venice, Italy



CENICS 2010 continues a series of events initiated in 2008, capturing the advances on special circuits, electronics, and micro-electronics on both theory and practice, from fabrication to applications using these special circuits and systems. The tracks cover fundamentals of design and implementation, techniques for deployment in various applications, and advances in signal processing. The topics suggested can be discussed in term of concepts, state of the art, research, standards, implementations, running experiments, applications, and industrial case studies.

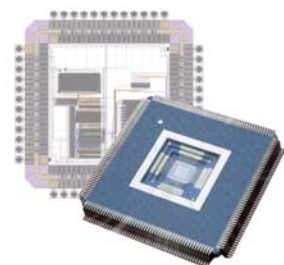
Conference tracks

- Semiconductors and applications
- Design, models and languages
- Signal processing circuits
- Arithmetic computational circuits
- Microelectronics
- Electronics technologies
- Special circuits
- Consumer electronics
- Application-oriented electronics

Important dates

- Submission (full paper):** February 20, 2010
- Notification:** March 25, 2010
- Registration:** April 15, 2010
- Camera ready:** April 20, 2010

<http://www.iaaria.org/conferences2010/CENICS10.html>



Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

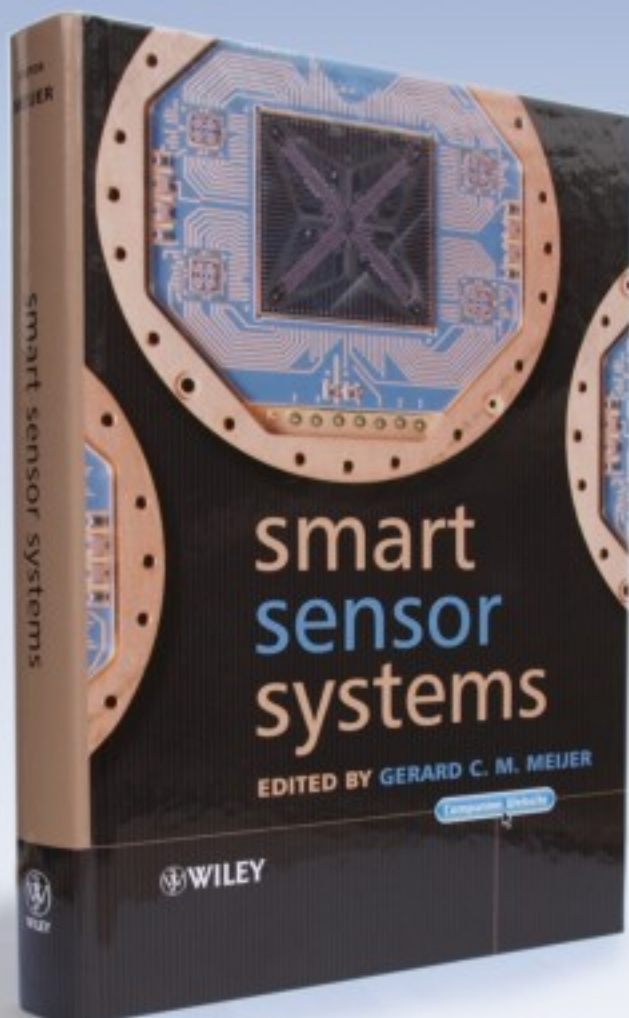
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.pdf

 **WILEY**
1807-2007

KNOWLEDGE FOR GENERATIONS



'Written by an internationally-recognized team of experts, this book reviews recent developments in the field of smart sensors systems, providing complete coverage of all important systems aspects. It takes a multidisciplinary approach to the understanding, design and use of smart sensor systems, their building blocks and methods of signal processing.'



Order online:

http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm

www.sensorsportal.com