

ISSN 1726-5479

SENSORS & TRANSDUCERS

9^{vol. 120}
/10



TEDS Sensors, IEEE 1451 Standards

International Frequency Sensor Association Publishing





Editors-in-Chief: professor Sergey Y. Yurish, tel.: +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, N.I. Center for Higher Education, (N.I. University), 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, Universite 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
Diegues, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Kim, Min Young, Kyungpook National University, Korea South
Djordjevich, 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
Granel, 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
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India

Ko, Sang Choon, Electronics. and Telecom. Research Inst., 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 Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica de Cataluna, 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
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shah, Kriyang, La Trobe University, Australia
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
Sumriddetchka, 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
Vanga, Raghav Rao, Summit Technology Services, Inc., USA
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, Pacific Northwest National Laboratory, 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
Zakaria, Zulkarnay, University Malaysia Perlis, Malaysia
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 120
Issue 9
September 2010

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Design of a Modular Signal Conditioning Circuit for Biopotential Sensors <i>Winncy Y. Du, Winston Jose, Jake Askeland</i>	1
MEMS Accelerometers Sensors: an Application in Virtual Reality <i>Daniel Corrêa, Douglas Santos, Leonardo Contini, Alexandre Balbinot</i>	13
Contactless Quality Monitoring Sensor Based on Electrical Conductivity Measurements <i>Armin Satz, W. Granig, D. Tumpold and F. Reininger</i>	27
Gas Sensing Properties of Pure and Cr Activated WO₃ Thick Film Resistors <i>V. B. Gaikwad, R. L. Patil, M. K. Deore, R. M. Chaudhari, P. D. Hire, S. D. Shinde, G. H. Jain</i>	38
Ellipsometric Immunosensor for Detection of Amyloid Precursor Protein with a View of Alzheimer's Disease Diagnostics <i>Alexei Nabok, Mohd Kamarulzaki Mustafa, David Parkinson, Anna Tsargorodskaya</i>	53
Optical Tomography System: Charge-coupled Device Linear Image Sensors <i>M. Idroas, R. Abdul Rahim, M. H. Fazalul Rahiman, R. G. Green, M. N. Ibrahim</i>	62
Spray Pyrolyzed Polycrystalline Tin Oxide Thin Film as Hydrogen Sensor <i>Ganesh E. Patil, D. D. Kajale, D. N. Chavan, N.K. Pawar, V. B. Gaikwad, G. H. Jain</i>	70
Research of a Novel Three-dimensional Force Flexible Tactile Sensor Based on Conductive Rubber <i>Fei Xu, Yunjian Ge</i>	80
Induction Magnetometers – Design Peculiarities <i>Valeriy Korepanov, Vira Pronenko</i>	92
Noise Feature Analysis in Pulse Temperature Modulated MOS Gas Sensors <i>Nimisha Dutta and Manabendra Bhuyan</i>	107
Drowsy Driver Detection via Steering Wheel <i>Herlina Abdul Rahim, Zulkifli Yusop and Ruzairi Abdul Rahim</i>	119
Microwave Detection of Soil Moisture Using C-Band Rectangular Waveguide <i>Jayesh Pabari, Shrutisingh Yadav and Rajani Singh</i>	134
Performance Characterization of a Long-Stroke Direct-Drive Electromagnetic Linear Actuator <i>Mohammad I. Kilani</i>	142
Sensitivity Enhancement of Biochemical Sensors Based on Er⁺³ Doped Microsphere Coupled to an External Mirror <i>Alireza Bahrampour, Azam Gholampour Azhir, Razie Taghiabadi, Kazem Rahimi Yazdi</i>	152

The Sixth International Conference on Systems



ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles



Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

<http://www.iaria.org/conferences2011/ICONS11.html>

Tracks:

- Systems' theory and practice
- System engineering
- System instrumentation
- Embedded systems and systems-on-the-chip
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

The Seventh International Conference on Networking and Services



ICNS 2011

May 22-27, 2011 - Venice, Italy



Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/ICNS11.html>

Tracks:

- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks

The Third International Conference on Bioinformatics, Biocomputational Systems and Biotechnologies



BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy



Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications

- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems

- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing

- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.iaria.org/conferences2011/BIOTECHNO11.html>

Spray Pyrolyzed Polycrystalline Tin Oxide Thin Film as Hydrogen Sensor

^aGanesh E. Patil, ^aD. D. Kajale, ^bD. N. Chavan, ^cN. K. Pawar,
^dV. B. Gaikwad, ^{a,*}G. H. Jain

^aMaterials Research Lab., Arts, Commerce and Science College, Nandgaon -423 106, MS, India

^bDepartment of Chemistry, Arts, Commerce and Science College, Lasalgaon-422 306, India

^cDepartment of Physics, Arts, Commerce and Science College, Satana-423 105, MS, India

^dMaterials Research Lab., K. T. H. M. College, Nashik -422 005, MS, India

*E-mail: gotanjain@rediffmail.com

Received: 20 July 2010 / Accepted: 14 September 2010 / Published: 27 September 2010

Abstract: Polycrystalline tin oxide (SnO₂) thin film was prepared by using simple and inexpensive spray pyrolysis technique (SPT). The film was characterized for their phase and morphology by X-ray diffraction (XRD) and scanning electron microscopy (SEM), respectively. The crystallite size calculated from the XRD pattern is 84 nm. Conductance responses of the polycrystalline SnO₂ were measured towards gases like hydrogen (H₂), liquefied petroleum gas (LPG), ethanol vapors (C₂H₅OH), NH₃, CO, CO₂, Cl₂ and O₂. The gas sensing characteristics were obtained by measuring the sensor response as a function of various controlling factors like operating temperature, operating voltages (1 V, 5 V, 10 V, 15 V, 20 V and 25 V) and concentration of gases. The sensor response measurement showed that the SnO₂ has maximum response to hydrogen. Furthermore; the SnO₂ based sensor exhibited fast response and good recovery towards hydrogen at temperature 150 °C. The result of response towards H₂ reveals that SnO₂ thin film prepared by SPT would be a suitable material for the fabrication of the hydrogen sensor. *Copyright © 2010 IFSA.*

Keywords: SnO₂ thin film, Gas sensor, Operating voltages, Selectivity, Response and recovery time.

1. Introduction

In last two decades there exists a worldwide strong interest in realizing inexpensive oxide thin films to be used, for example, in solar cells, as gas sensor devices or as coating to heat glass windows. Gas sensor have a great influence in many areas such as environmental monitoring, domestic safety, public

security, automotive applications, space crafts, houses and sensor networks. It has some advantages over other possible materials such as SnO₂, In₂O₃, ZnO or Cd₂SnO₄ due to its unique combination of interesting properties: non-toxicity, good electrical, optical and piezoelectric behaviour and its low price. Tin oxide (SnO₂) is a versatile material having applications in the areas like transparent electrodes in photoelectric conversion devices namely amorphous silicon solar cells, liquid crystal display, gas sensor and many more [1-3], mainly due to their outstanding properties.

Hydrogen is mainly used for energy generations in the near future due to the fact that fuel cell electricity generators are clean, quiet and more efficient than any other known technology. It is therefore straightforward that in all these applications safety measures should be of highest concern due to the explosive properties of hydrogen. To this end, there is an emerging scientific interest in developing solid state hydrogen sensors based on different operation principles [4], as catalytic-type chemiresistive [5], thermoelectric [6] and micromechanical gas sensors [7]. Recent works have shown that SnO₂ is a promising material for applications as sensors towards various gases. Moon et al [8] reported SnO₂ exhibiting good response towards CO. Patil and co-workers [9] synthesized SnO₂ which gives sensitivity towards H₂ gas. While Jain [10] reported Ni doped to be sensitive towards LPG. Most of the researchers have focused on detection of LPG, H₂S, H₂ and NH₃ because of their toxicity, their relation with atmospheric composition or to their high levels in some environments.

Spray pyrolysis technique (SPT) is useful alternative to the traditional methods for obtaining thin films of pure SnO₂. It is of particular interest because of its simplicity, low cost and minimal waste production. In this technique, a solution consists of the ions of required compound is sprayed on a heated substrate and their pyrolysis results in deposition of the compound in thin film form. The chemical reactants are selected such that the products other than the desired compound are volatile at the temperature of deposition [11].

In the present work, we report polycrystalline thin SnO₂ thin film prepared by spray pyrolysis technique. The prepared film has been studied for their gas sensing properties under different conditions.

2. Experimental

SnO₂ thin film was deposited by spray pyrolysis technique (SPT) onto ultrasonically cleaned glass substrate using tin dichloride pentahydrate as precursor solution. The solution of SnCl₄.5H₂O (0.075 M) was prepared in de-ionized water and methanol in a volume ratio of 1:1. The solution was sprayed continuously through a glass nozzle of 0.1 mm inner diameter onto substrate kept at 350 °C. The deposition parameters like spray rate 5 mL/min. was adjusted using air as a carrier gas, nozzle to substrate distance (25 cm) were kept constant, and to and fro frequency of the nozzle (18 cycles min⁻¹) were kept constant at the optimized values indicated in brackets. Due to the air pressure of the carrier gas, a vacuum is created at the tip of the nozzle to suck the solution from the tube after which the spray starts. The precursor solution was sprayed on to the substrate in the air as small drops and around a high temperature zone where thermal decomposition and possible reaction between solutions occur, through compressed air, which is used as carrier gas with a flow rate controlled through air compressor regulator. To achieve uniform deposition the moving arrangement has been used. For this substrate is kept stationary, while the nozzle is free for to and fro motion with microcontroller based moving arrangement as stepper motor has been advantageous, so we don't have to spend energy moving the table with the hot plate and all electrical connections. As prepared SnO₂ thin film was annealed at 550 °C for 30 min.

3. Characterization

3.1. Phase Identification

X-ray diffraction pattern was recorded on diffractometer (Miniflex Model, Rigaku, Japan) using $\text{CuK}\alpha$ radiation with a wavelength $\lambda = 1.5418 \text{ \AA}$ at 2θ values between 20° and 80° . The average crystallite size (D) was estimated using the Scherrer equation [12] as follows:

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

where λ , β and θ are the X-ray wavelength, the full width at half maximum (FWHM) of the diffraction peak, and Bragg's diffraction angle, respectively.

3.2. Surface Morphology

A JEOL 2300 model (Japan) was used to examine the surface morphology of the sample by scanning electron microscopy (SEM) and the percentage of constituent elements was evaluated by the energy dispersive X-rays analysis (EDAX) technique.

3.2. Gas Sensing Characterization

Sensor response (S) is defined as the ratio of change in conductance of the sample on exposure to a test gas to the conductance in air [13, 14].

$$S = \frac{(R_a - R_g)}{R_a} = \frac{\Delta R}{R_a} \quad (2)$$

where R_a and R_g are the resistance of a sensor in air and the test gas, respectively. The sensor was examined under different gases such as LPG, H_2 , CO, CO_2 , NH_3 , O_2 , Cl_2 and ethanol.

4. Result and Discussion

4.1. Structural Analysis

The X-ray diffraction pattern of the SnO_2 thin film is shown in Fig. 1. It shows well defined diffraction peaks, indicating formation of polycrystalline phases. The diffraction peak indexing, done by matching with the Joint Committee on Powder Diffraction Standard (JCPDS) (no. 72-1147), clearly revealed formation of the SnO_2 phases with tetragonal structure. The average crystallite size was determined using Scherrer equation which was observed to be 84 nm.

4.2. Scanning Electron Microscopy (SEM) and Energy Dispersive X-rays Analysis (EDAX)

Fig. 2 shows SEM images of the SnO_2 thin film on glass substrates at three different magnifications. It exhibits uniform and granular morphology, covering the entire substrate area. The average particle size is found to be ~115 nm.

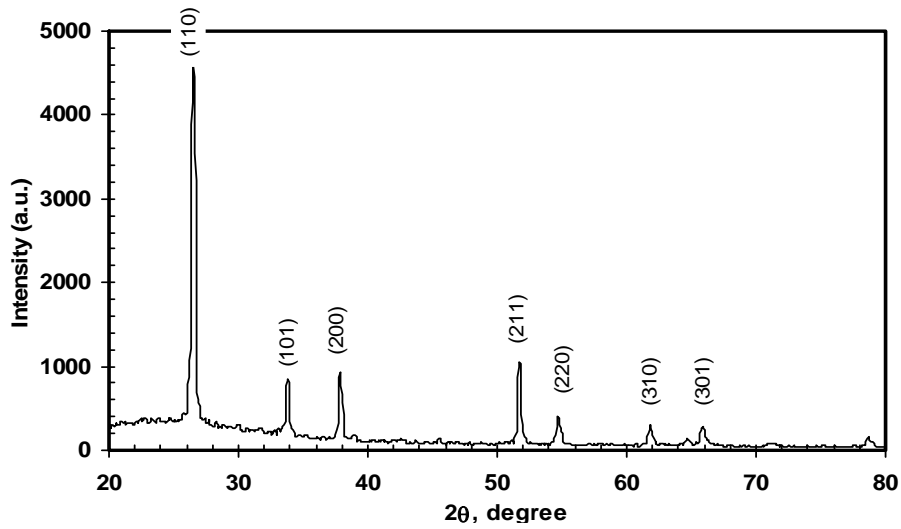
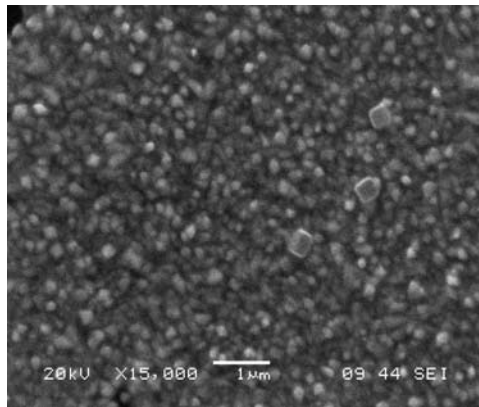
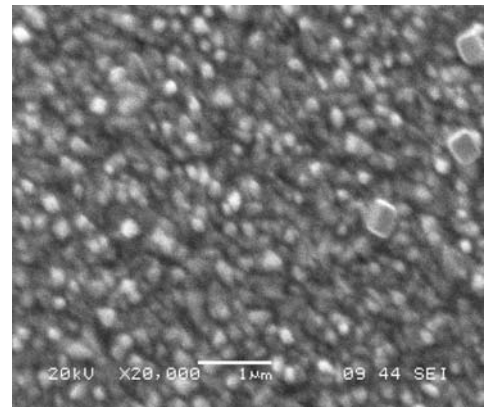


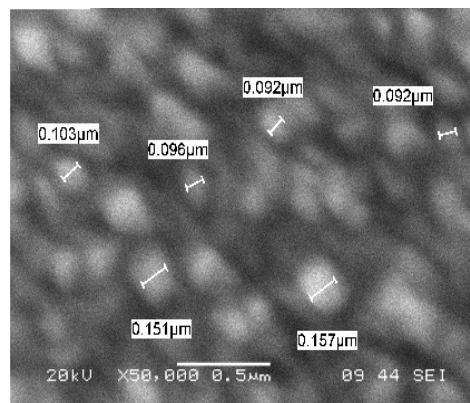
Fig. 1. X-ray diffraction pattern of SnO₂ thin film.



(a)



(b)



(c)

Fig. 2. SEM images of SnO₂ thin film at three different magnifications of (a) 15,000×; (b) 20,000×; and (c) 50,000×.

The EDAX analysis was used to examine the composition of the deposited materials. Fig. 3 shows the EDAX spectra for SnO₂ thin film composition. It is seen that the major peaks are of tin and oxygen

and no other impurity. Stoichiometric mass % of Sn and O in SnO₂ are 78.77 and 21.23, respectively. The mass % of Sn and O in our sample are 83.64 and 16.36 which is not as per the stoichiometric proportion and observed to be the oxygen deficient, leading to the semiconducting nature of SnO₂.

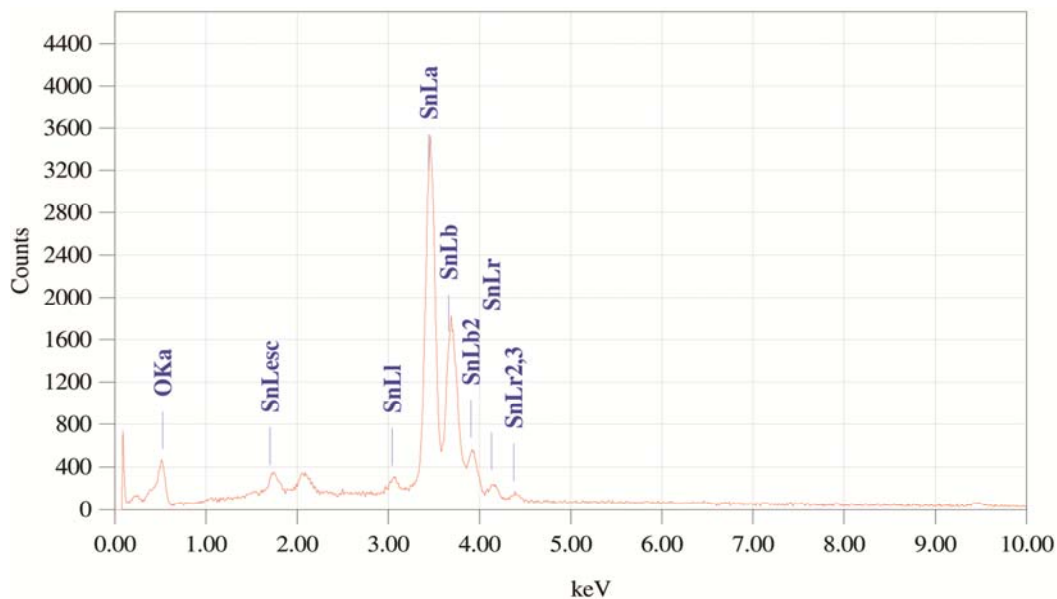


Fig. 3. EDAX spectra of SnO₂ thin film.

4.3. I-V Characteristics

Fig. 4 represents I-V characteristics of the SnO₂ thin film at room temperature. It was clear from the I-V characteristics that the contacts fabricated on the film were ohmic in nature [15]. The non-linear I-V characteristics may be due to semiconducting nature of the films. The voltage was applied in the range 1 V-25 V.

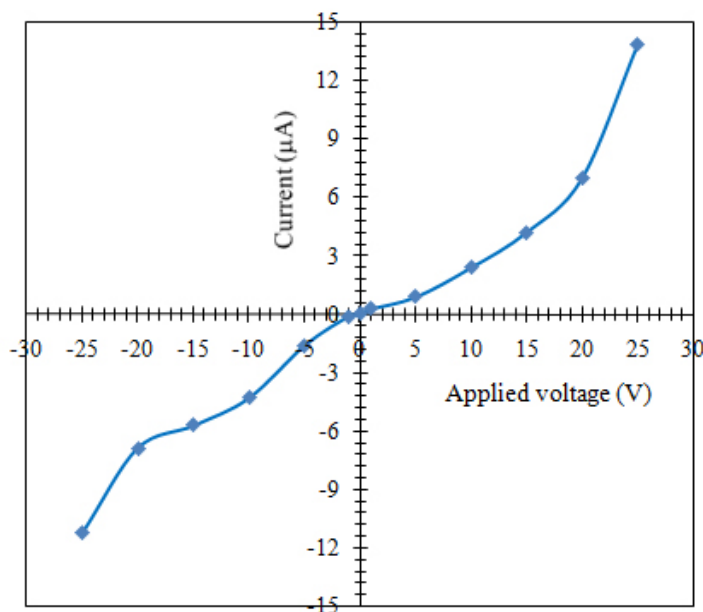


Fig. 4. I-V characteristics of the SnO₂ thin film.

4.4. Gas Sensing Properties

4.4.1. Variation of Sensor Response with Operating Temperature

Fig. 5 shows the variation of response of SnO₂ thin film sensor to 300 ppm H₂ gas with operating temperature. It is seen that for temperatures lower and higher than 150 °C, the sensor response is less indicating 150 °C to be an optimum temperature to have high sensing response at different operating voltages (1 V, 5 V, 10 V, 15 V, 20 V, 25 V). The response for our sample is found to be better than that reported in literature [16, 17]. Also the operating voltage is one of the main factors that influence the sensor response to H₂ gas. The operating voltage is necessary for driving electrons in gas sensing film. However, when the operating voltage is too high, the response to H₂ gas will be decreased. The decrease of the sensor response can be explained as follows: An increase in operating voltage results in increase in electron concentration in the film and at grain boundaries. I-V characteristic (Fig. 4) shows the current in the sensor is a non-linear increase with an increasing operating voltage. The increase of current indicates increasing electric charge in the film. Since there is electrostatic repulsion between electronic excess negative charges in the film and gaseous H₂ molecules, the H₂ adsorption quantities amount in the film decreases. As a consequence, a decrease in response to H₂ of the gas sensing film is observed and shows higher response at 150 °C for all operating voltages.

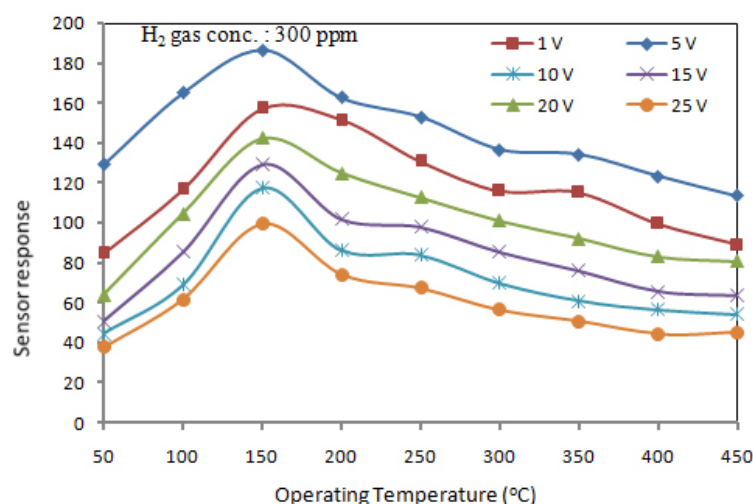


Fig. 5. Variation of sensor response to H₂ with operating temperature.

4.4.2. Sensor Response with H₂ Gas Concentration

To test the H₂ gas concentration characteristics, the sensor was exposed to H₂ gas of ten different concentrations at a constant operating temperature. The sensor responses to H₂ in concentration range (100-1000 ppm) are shown in Fig. 6 at 150 °C operating temperature and six operating voltages (1 V, 5 V, 10 V, 15 V, 20 V, 25 V). It indicates that the sensor has good response to H₂ at the operating voltage 5V. For all the operating voltages, the response values were observed to increase continuously with increasing the gas concentration up to 1000 ppm at 150 °C. The rate increase of response was relatively larger up to 300 ppm, smaller during 300-1000 ppm and then saturates after 300 ppm. Thus the active region of the sensor would be between 100-300 ppm. At lower gas concentration, the monolayer of gas molecules would be expected to be formed on the surface which would interact with the surface more actively giving larger responses [18]. There would be multilayer of gas molecules on the sensor surface at the higher gas concentration resulting in saturation in response.

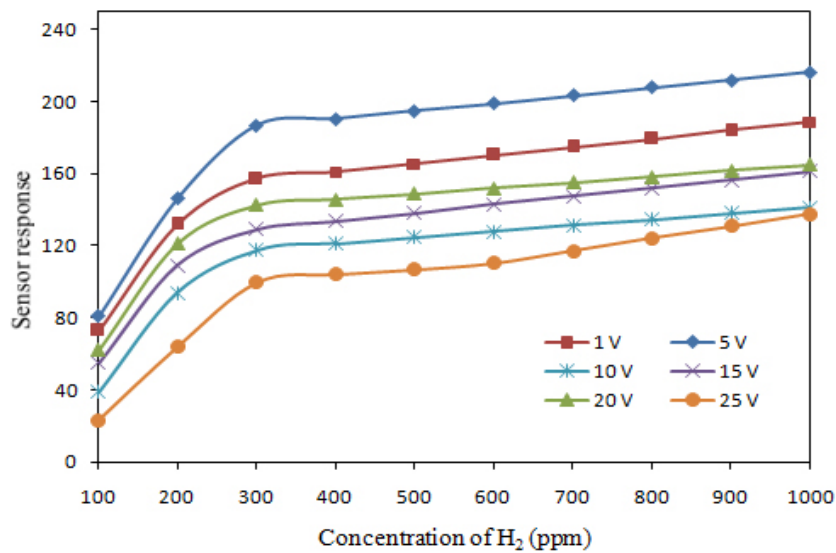


Fig. 6. Sensor response with H₂ gas concentration at 150 °C.

4.4.3. Selectivity of Sensor against Different Gases

Selectivity can be defined as the ability of a sensor to respond to a certain gas in the presence of different gases [19]. Fig. 7 depicts the selectivity of SnO₂ thin film sensor for H₂ (300 ppm) at 150 °C and at the operating voltage 5 V. The sensor showed the high selectivity for H₂ among the following gases: LPG, NH₃, CO, CO₂, C₂H₅OH, H₂S, O₂ and Cl₂.

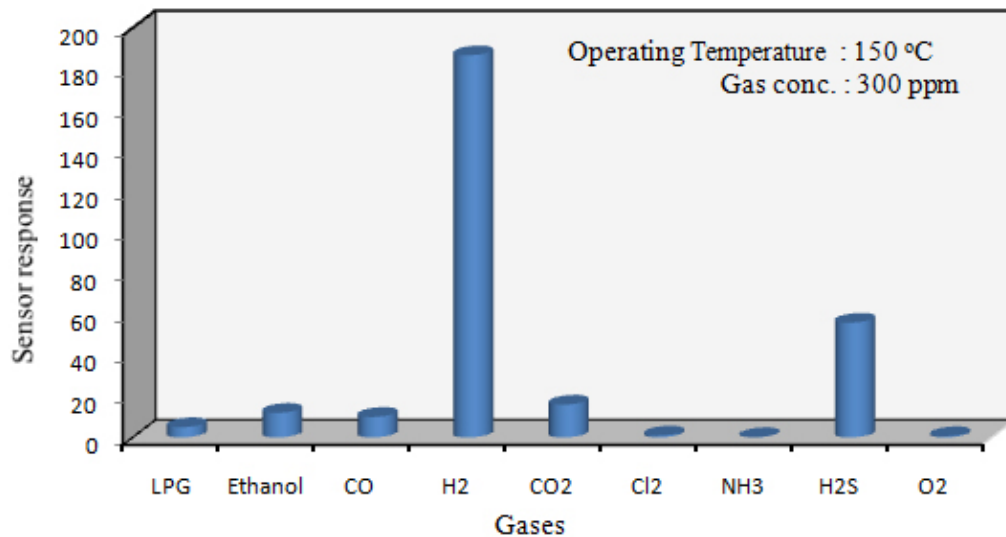


Fig. 7. Selectivity of sensor for various gases.

4.4.4. Response Time and Recovery Time

The response/ recovery time is an important parameter used for characterizing a sensor. It is defined as the time required to reach 90 % of the final change in current, when the gas is turned on and off respectively. The sensor response vs. time is shown in Fig. 8 for 300 ppm of H₂. From the plot, it is seen that the response time is 90 sec and the recovery time is 130 sec.

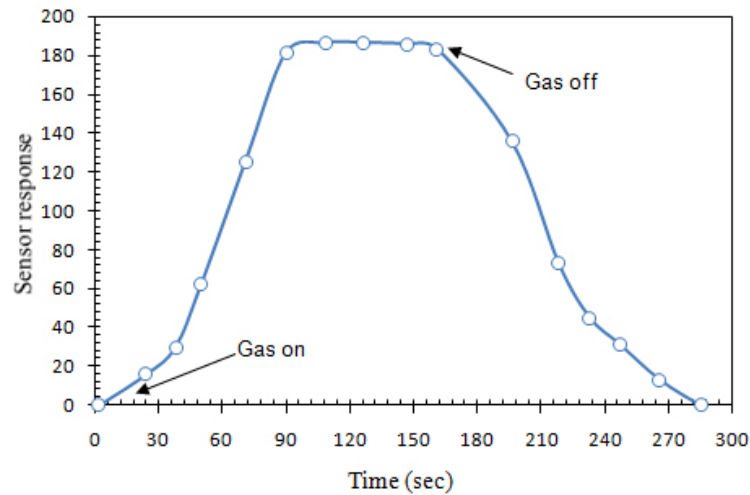


Fig. 8. A dynamic response of SnO₂ thin film sensor.

Fig. 9 shows the response and recovery time vs. concentration of H₂. It is revealed that response time decreased from 160 sec to 56 sec when H₂ concentration is increased from 100 ppm to 1000 ppm. This may be due to the presence of sufficient gas molecules at the interface for reaction to occur. From the same graph, it is found that for higher concentrations of H₂, the recovery time was long. This may be due to the reaction products are not leaving from the interface immediately after the reaction.

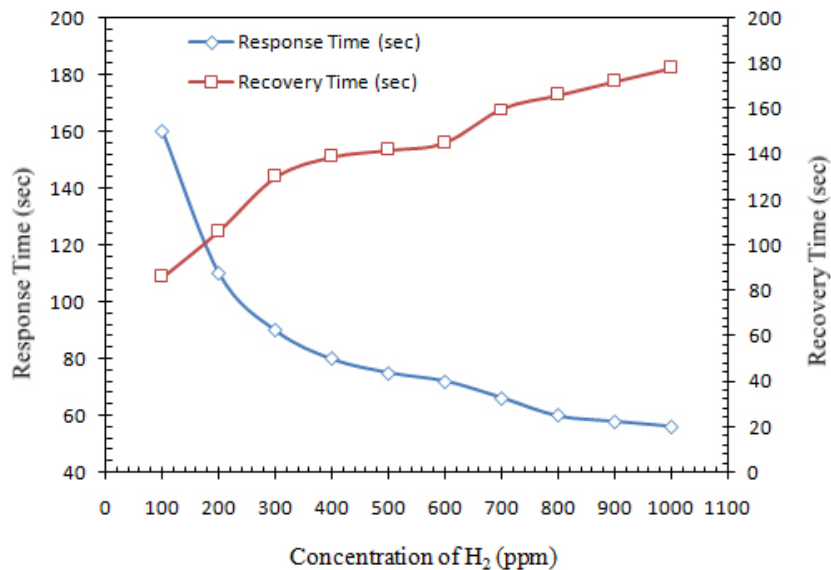
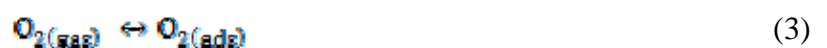


Fig. 9. Variation of response and recovery time with concentration of H₂.

4.4.5. Gas Sensing Mechanism

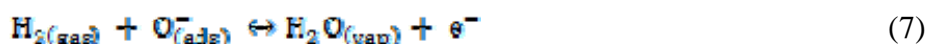
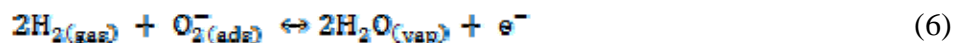
The gas sensing mechanism of an n-type tin oxide is based on electrical conduction results from point defects, such as oxygen vacancies and interstitial tin atoms (i.e. non-stoichiometric composition), that acts as donor [20-22]. When exposed to air, freshly prepared tin oxide particles adsorb oxygen atoms on the surface [23]:





Thus the oxygen atoms pick up the electrons from the conduction band of the tin oxide and are adsorbed on the particle surface as O^- and also other oxygen adsorbates such as O^{2-} and O_2^- are also to cover the surface.

Under H_2 exposure, a surface reaction reduces the coverage of oxygen, causing returning electrons to SnO_2 [9] by the following reactions:



The extra electrons released in this process enhance the surface conductance of the thin film. The model proposed above, explains the gas sensing mechanism of the SnO_2 thin film sensor qualitatively. But it does not explain the increase in gas sensitivity with rise in operating temperature (Fig. 5). In this connection, the microstructure, particularly the size and distribution of surface porosity may also have a significant role. This is so because the surface SnO_2 thin film may provide suitable chemisorption sites, and hence can influence the extent as well as the kinetics of the oxidation reaction (Eq. 7) between the sensor surface and the surrounding gas ambient. The minimum operating temperature found in the present work is only 150°C . At such a low temperature, the reaction region is mostly limited to the sensor surface (Fig. 5) or at the most up to the gas-solid interface. Therefore, it is suggested that uniform granular distribution would cause high response at such a low temperature as has been observed in the present work.

5. Conclusions

From the results, following statements can be made for the sensing performance of the SnO_2 thin film sensor.

1. Polycrystalline SnO_2 thin film could be prepared by simple and inexpensive spray pyrolysis technique (SPT).
2. SnO_2 thin film sensor shows a high response to H_2 gas in a wide concentration range at operating temperature 150°C and at an operating voltage 5V.
3. The sensor showed good selectivity to H_2 gas against LPG, NH_3 , $\text{C}_2\text{H}_5\text{OH}$, CO , CO_2 and Cl_2 gases.
4. The polycrystalline SnO_2 thin film exhibits rapid response–recovery which is one of the main features of this sensor.
5. The results obtained by SPT are promising for the preparation of sensitive and low cost hydrogen sensor operating at low temperatures.

Acknowledgement

The authors are thankful to University Grants Commission, New Delhi and BCUD, University of Pune, Pune for providing financial support. Thanks to Principal, Arts, Commerce and Science College, Nandgaon for providing laboratory facilities for this work. Authors are grateful to Dr L.A. Patil, Head, Nanomaterials Research Lab., Pratap College, Amalner and Dr D.P. Amalnerkar, Director, C-MET, Pune for their valuable cooperation rendered for characterizations of the material.

References

- [1]. J. Isidorsson, C. G. Granquist, Electrochromism of Li-intercalated Sn oxide films made by sputtering, *Solar Cells*, 44, 1996, pp. 375.
- [2]. K. L. Chopra, S. Major, D. K. Pandya, Transparent Conductors - A Status Review, *Thin Solid Films*, 102, 1983, pp. 1.
- [3]. B. Stjerna, E. Olsson, C. G. Granquist, Optical and electrical properties of radio frequency sputtered tin oxide films doped with oxygen vacancies, F, Sb, or Mo, *J. Appl. Phys.*, 76, 1994, pp. 3797-3817.
- [4]. D. Kohl, Function and applications of gas sensors, *J. Phys. D: Appl. Phys.*, 34, 2001, R 125.
- [5]. V. R. Katti, A. K. Debnath, S. C. Gadkari, S. K. Gupta, V. K. Sahni, Passivated thick film catalytic type H₂ sensor operating at low temperature, *Sens. Actuators, B, Chem.*, 84, 2002, pp. 219-225.
- [6]. M. Matsumiya, W. Shin, N. Izu, N. Murayama, Nano Structured Thin-Film Pt Catalyst for Thermoelectric Hydrogen Gas Sensor, *Sens. Actuators, B, Chem.*, 93, 2003, pp. 309-315.
- [7]. D. R. Baselt, B. Fruhberger, E. Klaassen, S. Cemalovic, C. L. Britton Jr., S. V. Patel, T. E. Mlsna, D. McCorkle, B. Warmack, Design and performance of microcantilever-based hydrogen sensor, *Sens. Actuators, B, Chem.*, 88, 2003, pp. 120-131.
- [8]. Chang Sup Moon, Hae-Ryong Kim, Graeme Auchterlonie, John Drennan, Jong-Heun Lee, Highly sensitive and fast responding CO sensor using SnO₂ nanosheets, *Sens. Actuators, B, Chem.*, 131, 2008, pp. 556-564.
- [9]. L. A. Patil, M. D. Shinde, A. R. Bari, V. V. Deo, Highly sensitive and quickly responding ultrasonically sprayed nanostructured SnO₂ thin films for hydrogen gas sensing, *Sens. Actuator B, Chem.*, 143, 2009, pp. 270-277.
- [10]. Kiran Jain, R. P. Pant, S. T. Lakshmikummar, Effect of Ni doping on thick film SnO₂ gas sensor, *Sensors and Actuators B*, 113, 2006, pp. 823-829.
- [11]. P. S. Patil, Versatility of chemical spray pyrolysis technique, *Materials Chemistry and Physics*, 59, 1999, pp. 185-198.
- [12]. B. D. Cullity, Elements of X-ray diffraction, *Addison-Wesley Publishing Co.*, 1956.
- [13]. G. H. Jain, L. A. Patil, M. S. Wagh, D. R. Patil, S. A. Patil, D. P. Amalnerkar, Surface modified BaTiO₃ thick film resistors as H₂S gas sensors, *Sens. Actuators, B, Chem.*, 117, 2006, pp. 159-165.
- [14]. G. H. Jain, V. B. Gaikwad, D. D. Kajale, R. M. Chaudhari, R. L. Patil, N. K. Pawar, L. A. Patil, Gas Sensing Performance of pure and modified Barium Strontium Titanate Thick Film Resistors, *Sensors & Transducers*, 90, 2008, pp. 160-173.
- [15]. G. H. Jain, L. A. Patil, CuO-doped BSST thick film resistors for ppb level H₂S gas sensing at room temperature, *Sens. Actuators, B, Chem.*, 123, 2007, pp. 246-253.
- [16]. Kwang Soo Yoo, Sang Hyoun Park, Ju Hyun Kang, Nano-grained thin-film indium tin oxide gas sensors for H₂ detection, *Sensors and Actuators B*, 108, 2005, pp. 159-164.
- [17]. Yun-Hyuk Choi, Seong-Hyeon Hong, H₂ sensing properties in highly oriented SnO₂ thin films, *Sensors and Actuators B*, 125, 2007, pp. 504-509.
- [18]. G. H. Jain, L. A. Patil, P. P. Patil, U. P. Mulik, K. R. Patil, Studies on gas sensing performance of pure and modified Barium Strontium Titanate thick film resistors, *Bull. of Mate. Sci.*, 30, 2007, pp. 9-17.
- [19]. V. B. Gaikwad, D. D. Kajale, Y. R. Baste, S. D. Shinde, P. K. Khanna, N. K. Pawar, D. N. Chavan, M. K. Deore, G. H. Jain, Studies on Gas Sensing Performance of Pure and Surface Modified SrTiO₃ Thick Film Resistors, *Sensors and Transducers*, *Sensors & Transducers*, 6, 2009, pp. 57-68.
- [20]. Y. Shimazu, M. Egashira, Basic Aspects and challenges of semiconductor Gas sensors, *MRS Bulletin*, 1998, pp. 18-24.
- [21]. V. B. Gaikwad, M. K. Deore, P. K. Khanna, D. D. Kajale, S. D. Shinde, D. N. Chavan, G. H. Jain, Studies on gas sensing performance of pure and nano-Ag doped ZnO thick film resistors, *Recent Advances in Sensing Technology, LNEE*, 49, 2009, pp. 293-308.
- [22]. V. B. Gaikwad, A. V. Borade, Y. R. Baste, D. D. Kajale, G. H. Jain, Electrical and gas sensing performance of coppergermanate, *Recent Advances in Sensing Technology, LNEE*, 49, 2009, pp. 283-292.
- [23]. G. Faglia, P. Nelli, G. Sbrveglein, Frequency effect on highly sensitive NO₂ sensors based on RGTO SnO₂(Al) thin films, *Sens. Actuators, B, Chem.*, 18, 1994, pp. 497-499.



The Second International Conference
on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- 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

<http://www.iaria.org/conferences2011/SENSORDEVICES11.html>



The Fifth International Conference on Sensor
Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

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

<http://www.iaria.org/conferences2011/SENSORCOMM11.html>



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

CENICS 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

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

<http://www.iaria.org/conferences2011/CENICS11.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

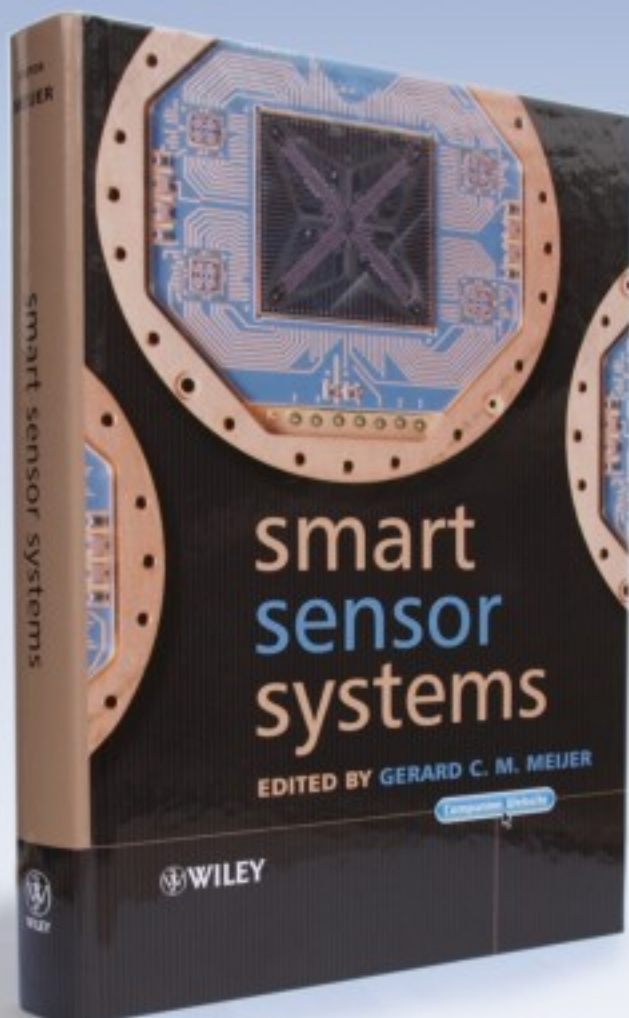
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example 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