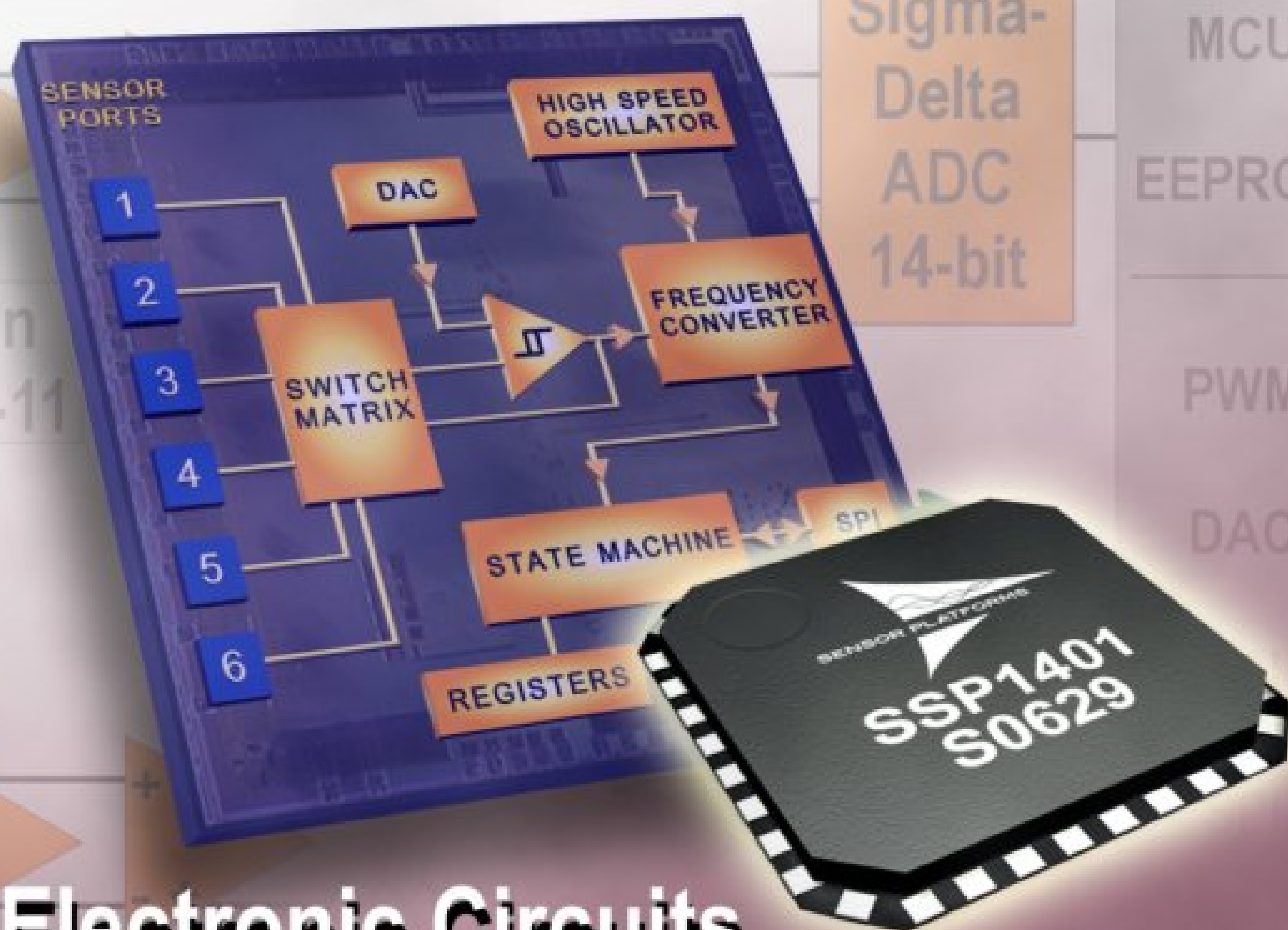
ISSN 1726-5479

SENSORS & TRANSDUCERS

6 vol. 117 /10



Electronic Circuits, Signal Conditioning and ASIC

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 117, Issue 6, June 2010 | www.sensorsportal.com | ISSN 1726-5479

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, Universitá 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, Nothern 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, 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
Dieguez, 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 Alcala, 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, Bhbha 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
Raoof, 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
Soleymanpour, 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, Qintao, 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

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD. Copyright © 2010 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

Volume 117
Issue 6
June 2010

www.sensorsportal.com

ISSN 1726-5479

Research Articles

A Holistic Approach to Automated Synthesis of Mixed-technology Digital MEMS Sensors Part 1: Layout Synthesis of MEMS Component with Distributed Mechanical Dynamics
Chenxu Zhao and Tom J. Kazmierski 1

A Holistic Approach to Automated Synthesis of Mixed-technology Digital MEMS Sensors Part 2: Synthesis of a MEMS System with Associated Control Loop
Chenxu Zhao and Tom J. Kazmierski 16

Realization of a Solid-Propellant based Microthruster Using Low Temperature Co-fired Ceramics
Jaya Thakur, Rudra Pratap, Yannick Fournier, Thomas Maeder, Peter Ryser 29

A Numerical Approach to Investigate of Pull-In Phenomenon of Circular Micro Plate Subjected to Nonlinear Electrostatic Pressure
Farzad Choobdar Rahim 41

Surface Electromyographic Sensor for Human Motion Estimation Based on Arm Wrestling Robot
Zhen Gao and Dan Zhang. 50

Study of Microstructural Parameters of Screen Printed ZnO Thick Film Sensors
A. V. Patil, C. G. Dighavkar, S. K. Sonawane, U. P. Shinde, S. J. Patil and R. Y. Borse 62

Development of Analytical Results for the Fluidic Self-alignment Torque on a Silicon Die
R. C. Woods. 71

Metrology of Temperature Transducer based on Raman Effect
Bogdan Stadnyk, Sviatoslav Yatsyshyn, Oleh Seheda 78

Compensation of a Primary Transducer Resistance Alteration by Changing the Amplitude-Frequency Characteristics of a Noise-Thermometer Input Circle
Bogdan Stadnyk, Ihor Mykytyn 85

Effect of Different Post Deposition Annealing Treatments on Properties of Zinc Oxide Thin Films
Arti Arora, Anil Arora, P. J. George, V. K. Dwivedi, Vinay Gupta 92

Development of Ultrasonic Transmission-Mode Tomography for Water-Particles Flow
Mohd Hafiz Fazalul Rahiman, Ruzairi Abdul Rahim 99

Influence of Temperature on Current-Voltage Characteristics and Noise of Hydrogen Sensors
Z. H. Mkhitaryan, V. M. Aroutiounian, A. A. Durgaryan 106

Thermo-oxidation in Arauco and Arbequina Extra-virgin Olive Oil. Changes in Odour using and Electronic Nose and SPME-GC-FID
Valeria Messina, Andrea Biolatto, Adriana Descalzo, Ana Sancho, Noemí E. Walsöe de Reca 112

Effect of SiO_2 Overlayer on WO_3 Sensitivity to Ammonia
Vibha Srivastava and Kiran Jain 120

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/Submition.htm

International Frequency Sensor Association (IFSA).

IMU Market 2007-2012

Yole's IMU market report

IFSA offers a SPECIAL PRICE

Competitive market analysis of the RLG – FOG – DTG - Quartz and MEMS based Inertial Measurement Units

This report not only describes the market at the player and application level, but it provides a global view of the IMU market allowing the report user to build diversification strategies taking into account technical requirements.

http://www.sensorsportal.com/HTML/IMU_Markets.htm

IFSA SENSORS WEB PORTAL

Primary Internet Resource for SENSORS, 100% Target Audience

Sensors Web Portal

SENSORS

TURN OUR VISITORS INTO YOUR CUSTOMERS BY THE SHORTEST WAY

MEDIA KIT 2010

http://www.sensorsportal.com/HTML/Sensor.htm

sales@sensorsportal.com

Sensors & Transducers Journal, Vol. 117, Issue 6, June 2010, pp. 62-70

Sensors & Transducers

www.sensorsportal.com

ISSN 1726-5479
© 2010 by IFSA
http://www.sensorsportal.com

Study of Microstructural Parameters of Screen Printed ZnO Thick Film Sensors

***[1]A. V. PATIL, [1]C. G. DIGHAVKAR, [1]S. K. SONAWANE, [1]U. P. Shinde, [2]S. J. PATIL and [2]R. Y. BORSE**

[1] L. V. H. College, Panchavati, Nashik 422003, Maharashtra, India
[2] Thin and Thick film Laboratory, Dept. of Electronics M. S. G.College, Malegaon Camp 423105, Dist. Nashik, Maharashtra, India
*E-mail: aruptl@gmail.com, ratanborse@yahoo.co.in

Received: 8 March 2010 /Accepted: 21 June 2010 /Published: 25 June 2010

Abstract: This paper explores the compositional, morphological and structural properties of ZnO thick films prepared by a standard screen printing method and fired between 650 ^{o}C to 900 ^{o}C for 2 hours in an air atmosphere. The material characterization was done using X-ray energy dispersive analysis (EDX), X-ray diffraction (XRD) and a scanning electron microscope (SEM). The deposited films were polycrystalline in nature having the wurtzite (hexagonal) structure with a preferred orientation along the (101) plane. The result shows that the wt. % of Zn was found to be 80.39, 82.66 and 83.47 % for firing temperatures of 700, 800 and 900 ^{0}C respectively may be due to the release of excess oxygen. The effect of the firing temperature on structural parameters such as the crystallite size, specific surface area, texture coefficient, RMSmicrostrain, dislocation density and stacking fault probability have been studied. The results indicate that grain growth can be increased by increasing the firing temperature which is responsible for decreasing the RMSmicrostrain, stacking fault probability and dislocation density in ZnO thick films. The crystallite size changes from 18.58 nm to 37.23 nm with respect to the increase in the firing temperature. *Copyright © 2010 IFSA.*

Keywords: ZnO, Thick films, SEM, XRD, EDX.

1. Introduction

ZnO is an n-type semiconductor. It is attracting tremendous attention due to its interesting properties like a wide band gap of 3.37 eV at room temperature with excitation binding energy (60 meV), high

chemical stability, low dielectric constant, large electrochemical coupling coefficient and high luminous transmittance [1]. It is widely used in photovoltaics, gas sensors, varistors, surface acoustic wave devices, electric transducers, as a piezoelectric material and for room temperature ultraviolet lasing [2, 3]. Therefore it can be applied extensively in IT (Information tech.), BT (Bio-tech.) and ET (Environmental tech.) [4]. Several deposition methods have been used to grow undoped and doped ZnO films such as spray pyrolysis, evaporation, chemical vapour deposition, magnetron sputtering, pulsed laser deposition, a sol-gel technique and a screen printing technique [5]. The Screen printing technique was introduced in the later part of the 1950's to produce compact, robust and relatively inexpensive hybrid circuits for many purposes. Later on a thick film technique has attracted attention for the sensor field [6]. Screen printing is a viable and economical method to produce thick films of various materials [7-12]. The main aim of the present study is to focus on the structural and surface morphological properties of ZnO thick films. We report studies on the structural parameters of ZnO thick films produced at different firing temperatures. Such a detailed understanding of film properties are necessary if ZnO is to be developed to a degree which will enable its use in gas sensing devices.

2. Experimental

Analar grade ZnO powder was calcined at 400 ºC for 2 h in a muffle furnace. Then this powder was crushed and thoroughly mixed with a glass frit (PbO-70 %, SiO_2-18 %, Al_2O_3-9 % and B_2O_3-3 %) as a permanent binder. Organic vehicles such as butyl carbitol acetate (BCA) and ethyl cellulose (EC) were added to this mixture to achieve proper thixotropic properties of the paste. The ratio of inorganic to organic parts was maintained at 70:30 (the ratio of active powder to permanent binder was kept at 95:5 in 70 % and the ratio of EC to BCA was 98:2 in 30 %). ZnO thick films were prepared on alumina substrates using a standard screen-printing technique. The screen of nylon (40s, mesh no.355) was selected for screen-printing. The required mask (2 x 1.25 cm) was developed on the screen using a standard photolithography process. The paste was printed on clean alumina substrates (5 x 2 cm) with the help of a mask. The pattern was allowed to settle for 15 to 20 minutes in air. The films were dried under infrared radiation for 45 minutes and fired at temperatures of 650, 700, 800 and 900°C for1.5 to 2 h (which includes the time required to achieve the peak firing temperature and then constant firing for 30 minutes at the peak temperature) in a muffle furnace. The structural properties of ZnO films were investigated using X-ray diffraction analysis from 20-80^{0} [Rigaku diffractometer (Miniflex Model, Rigaku, Japan) with CuKα, λ=0.1542 *nm* radiation] with a 0.1^{o}/step (2θ) at the rate of 2 s/step. A scanning electron microscopy (SEM- JOEL JED-2300) was employed to characterize the surface morphology. The composition of ZnO thick film samples were analyzed by an energy dispersive X ray spectrometer (EDX) (JOEL-JED 6360 LA). The thickness of the ZnO thick films was measured using a Taylor-Hobson (Taly-step UK) system. The thickness of the films was observed to be uniform in the range of 20μm to 22μm. The effect of the firing temperature on the orientation of the films was investigated by calculating the texture coefficient using the following equation:

$$T_C(hkl) = \frac{I(hkl)/I_O(hkl)}{\left(1/N\right)\Sigma I(hkl)/I_O(hkl)}, \quad (1)$$

where
T_C (hkl) is the texture coefficient of the (hkl) plane;
I (hkl) is the measured intensity from the (hkl) plane;
I_O (hkl) is the JCPDS standard intensity of (hkl) plane;
N is the number of diffraction peaks.

The crystallite size was determined using Scherrer's formula:

$$D = \frac{0.94\lambda}{\beta_{20}\cos\theta}, \quad (2)$$

where D is the crystallite size, λ is the wavelength of the X-ray radiation (1.542 Å), β is the peak full width half maxima of the (101) peak of the XRD pattern and θ is the diffraction angle.

Root mean square (RMS) microstrain (e) can be determined using a Williamson and Hall plot. The slope of the plot of (βcosθ/λ) versus (2sinθ/λ) gives the value of the RMS microstrain.

The dislocation density was calculated using the following equation:

$$\rho = \sqrt{12}\,(e^2)^{1/2}/dD, \quad (3)$$

where *e* is the RMS microstrain, *d* is the interplanar spacing and *D* is the crystallite size.

The stacking fault probability was calculated using the following equation:

$$\alpha = \frac{2\pi^2\Delta(2\theta)}{45\sqrt{3}\tan\theta_{101}} \quad (4)$$

The specific surface area of ZnO thick films was calculated using BET method using the following equation:

$$S_w = \frac{6}{\rho d} \quad (5)$$

where d is the diameter of the particles, ρ is the density of the particles.

3. Result and Discussion

3.1. Calcination, Drying and Firing of the Films

The calcination of the powder before the paste preparation and the firing process of the printed film can determine the sensitivity of the active layer of the film if it is used as a gas sensor. With calcination, grain boundaries are developed and the powder sinters to bigger agglomerates. This powder was milled after calcination. This causes a higher surface area after firing and therefore a higher sensitivity of layer .The calcination took from 1 h to 10 h [13].

A drying stage is required to remove the organic solvents, make the printed film adhere to the substrate and be relatively immune to smudging. After printing, the film was allowed to settle in air for a few minutes so that some of the volatile solvents were evaporated slowly at room temperature. The organic agent was still present in the paste at this stage. Drying took place at temperatures between 70-180 ^{o}C either in a conventional oven or by placing films under infrared radiation [13].

The high temperature firing cycle is designed to remove the remaining organic binders, to develop the structural and electrical properties of the film and to bond the film to the substrate. Temperatures up to 1000°C are required to achieve these objectives. During this firing process the glass frit melts and grains of the functional materials are held together and also the film becomes bonded firmly to the

substrate. There are three distinct regions in this firing cycle. Firstly the temperature slowly was increased towards the peak firing temperature. During this time the remaining organics were removed. This occurred at 350-400 °C. As the temperature reached 600-900 °C, the glass frit softens. Secondly the temperature remained constant for about 30 minutes. During this time the active material sintered and various reactions took place. The electrical properties of the film began to develop. Finally there was a cooling stage to room temperature that allows the glass frit to solidify [13].

3.2. Composition

Table 1 shows the composition of the films fired at different temperatures. The EDX spectrum showed the presence of only Zn and Oxygen. The mass percentage of Zn was found to increase with an increase of the firing temperature due to release of excess oxygen [14]. From the analysis it was found that the ZnO films are non- stoichiometric. The deficiency or excess of any type of atom in the crystal results in a distorted band structure, with a corresponding increase in conductivity. Zinc oxide looses oxygen on heating so that zinc is then in excess. The oxygen, of course, evolves as an electrically neutral substance so that it is associated with each excess zinc ions in the crystal; there will be two electrons that remain trapped in the solid material, thus leading to non-stoichiometricity in the solid. This leads to the formation of the n-type semiconductor [15].

Table 1. Composition of the films at different firing temperature.

Firing Temperature	Element	At.Wt. %	Mass%
700 °C	Zn O	80.39 19.61	94.37 5.63
800 °C	Zn O	82.66 17.34	95.12 4.88
900 °C	Zn O	83.47 16.53	95.38 4.62

3.3. Structural Parameters and their Analysis

Fig. 1 shows X-ray diffraction patterns of ZnO thick films deposited on alumina substrates and fired at 650 °C, 700 °C, 800 °C, 900 °C. XRD characterization demonstrates that all the structural variants correspond to the hexagonal wurtzite structure of ZnO. It has been observed that the XRD peak broadening decreases with an increase of the firing temperature. The intensity of reflections increases with a rise in the firing temperature. It has been observed that (101) reflections are of maximum intensity, which indicates that ZnO films have preferred orientation in the (101) plane. The observed 'd' values are found to be close to the JCPDS file for hexagonal ZnO [16].

Texture Coefficient (T_C)

From the values calculated using equation-1[17-18], it was observed that T_C approaches unity for randomly distributed samples whereas T_C is larger than unity for a preferentially oriented (hkl) plane. The lower values of T_C reveals that the films have poor crystallinity and this may be improved at a higher firing temperature. Fig. 2 shows the variation of the texture coefficient with firing temperatures for the (100), (002), (101) planes. From Fig. 2 it has been observed that the preferred orientation is the (101) plane for all firing temperatures. The increase in preferred orientation is attributed to an increased number of grains having this plane.

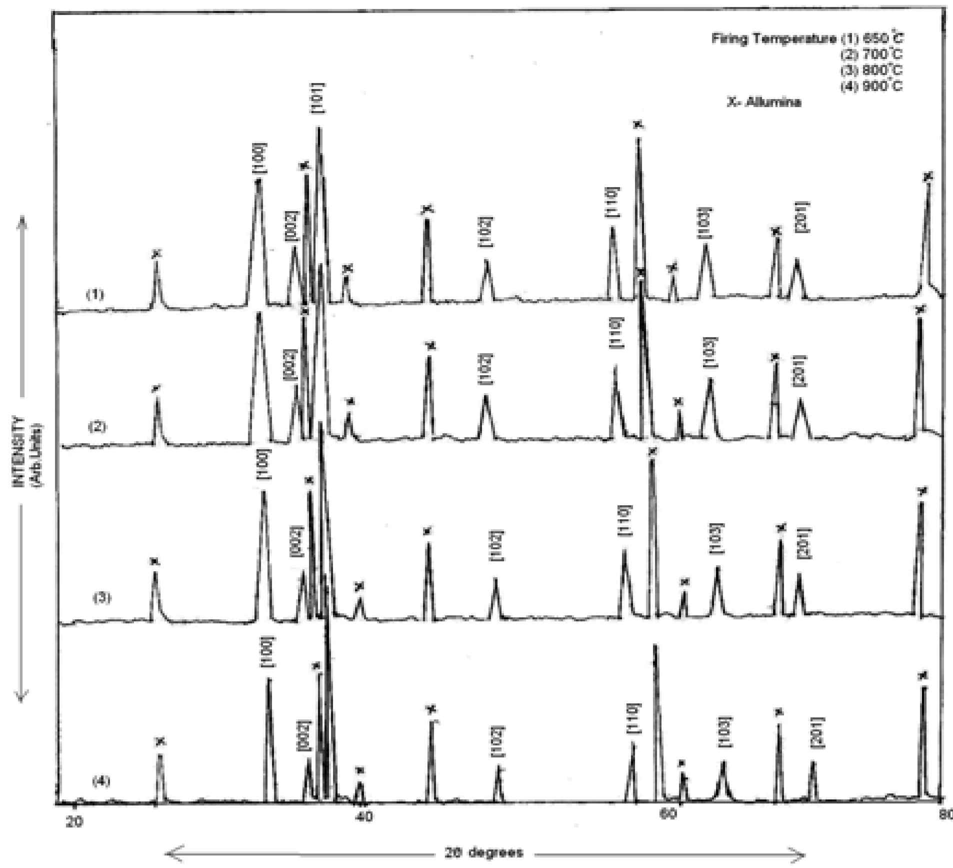


Fig. 1. XRD patterns of ZnO films fired at 650 °C, 700 °C, 800 °C, 900 °C.

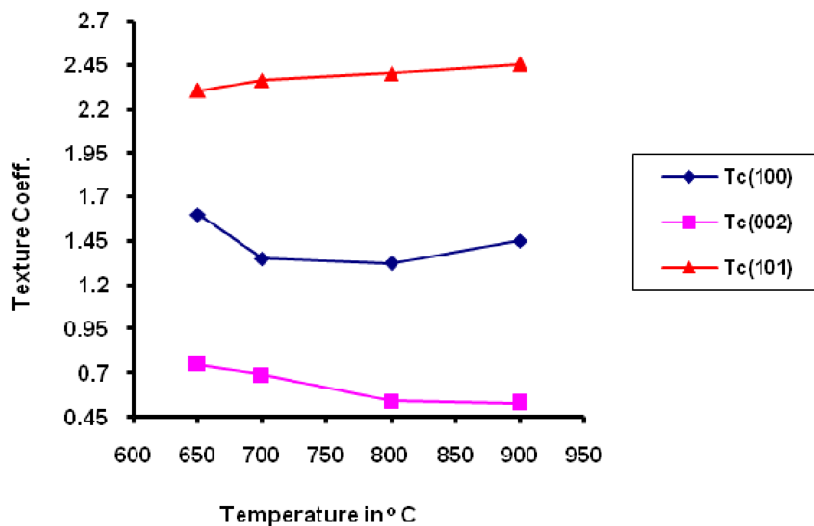


Fig. 2. Variation of the texture coefficient with firing temperature.

Crystallite Size (D)

The XRD pattern was used to calculate the crystallite size of ZnO by using equation-2 (Scherrer's formula) [19]. The crystallite size of ZnO films at different firing temperatures is given in Table 2.

Table 2. Variation of structural parameters with firing temperature.

Firing Temp. ^{o}C	Crystallite (grain)Size, D nm (XRD)	Particle Size, d nm (SEM)	Specific Surface Area in m^2/g	Micro Strain, e	Dislocation Density, ρ x10^{13} Lines/cm^2	Stacking Fault probability α
650	18.58	381	2.75	0.6926	5.1985	0.0092
700	18.637	381	2.75	0.6926	5.1811	0.0092
800	24.79	470	2.25	0.5205	2.925	0.00797
900	37.23	617	1.715	0.3476	1.298	0.0066

Microstrain (e)

Broadening of X-ray diffraction line profiles is mainly caused by non-ideal optics of the instrument, wavelength dispersion, and microstructural imperfections in the crystals. The microstructural line broadening can be subdivided into size broadening and strain broadening. Size broadening is due to the finite size of domains surrounded by stacking faults, by twins or other imperfections, which diffract incoherently with respect to one another. Strain broadening is caused by a varying displacement of the atoms with respect to their reference-lattice positions. A uniform compressive or tensile strain (macrostrain) results in a peak shift of the X-ray diffraction lines, whereas a uniform statistical distribution of tensile and compressive strain results in a broadening of the diffraction lines (microstrain). A method to determine the microstrain by analyzing X-ray diffraction lines is described by Williamson and Hall [20]. A Williamson and Hall (W-H) plot is a classical method to obtain qualitative information of the anisotropy in broadening. The slope of the plot of ($\beta\cos\theta/\lambda$) versus ($2\sin\theta/\lambda$) gives the value of the RMS microstrain. Fig. 3 shows the Williamson-Hall plots for ZnO thick films with different deformations from planes (100) to (201) at different firing temperatures. The points in the W-H plot are scattered. Therefore microstrain is RMS. If the points in the WH plot are scattered, i.e., if ($\beta\cos\theta/\lambda$) is not a monotonic function of ($2\sin\theta/\lambda$), the broadening is termed anisotropic. The RMS microstrains calculated at different firing temperatures indicate a decreasing trend with firing temperature is given in Table 2.

Dislocation Density (ρ)

Dislocation density is defined as the length of dislocation lines per unit volume of the crystal [21]. A dislocation is an imperfection in a crystal associated with the misregistry of the lattice in one part of the crystal with an other part [21]. The dislocation density calculated using equation-3 [21] at different firing temperatures indicates a decreasing trend with firing temperature and is given in Table 2.

Stacking Fault Probability (α)

A stacking fault is a planar imperfection that arises from the stacking of one atomic plane out of sequence with another while the lattice on either side of the fault is perfect. The presence of a stacking fault gives rise to a shift in the peak positions of observed reflections with respect to the ideal JCPDS positions of the sample [22]. From the XRD patterns of ZnO films, the peak shift $\Delta(2\theta)$ for the oriented (101) plane was measured with a change in firing temperature. The stacking fault probability was calculated using equation-4 [21] at different firing temperatures indicating a decreasing trend with firing temperature and is given in Table 2.

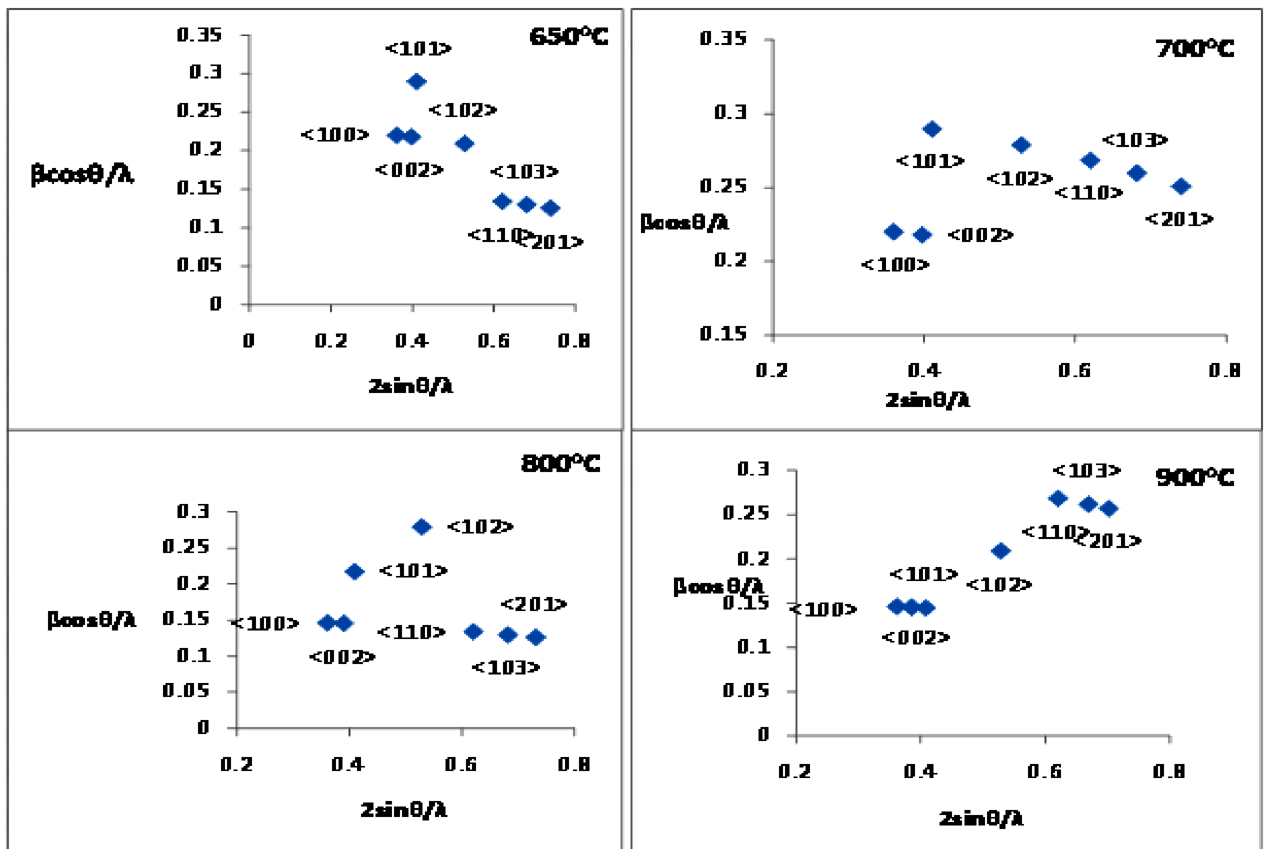


Fig. 3. Williamson-Hall plots for ZnO thick films with different deformations at different firing temperatures.

Fig. 4(a) shows the variation of RMS microstrain and dislocation density as function of firing temperature. Fig. 4(b) shows the variation of stacking fault probability as function of firing temperature. It was observed that the microstrain, dislocation density and stacking fault probability decrease with an increase in the firing temperature. This leads to a reduction in the concentration of lattice imperfections [23-24]. A similar trend has been reported by Mahalingam et al. [21] for electrodeposited ZnO thin films.

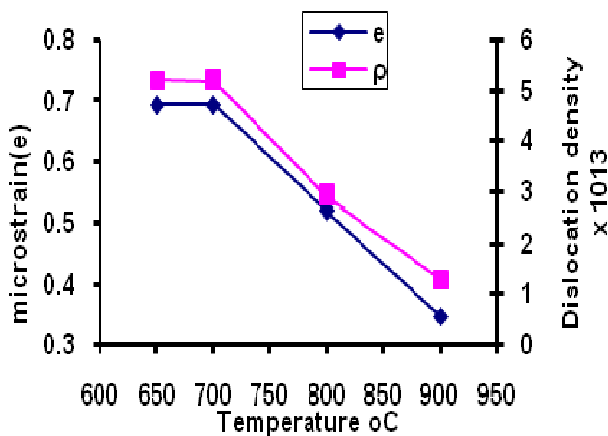


Fig. 4(a). Variation of microstrain e and dislocation density ρ with firing temp.

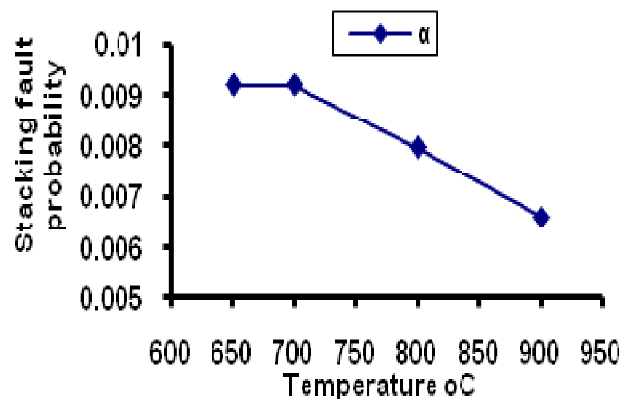
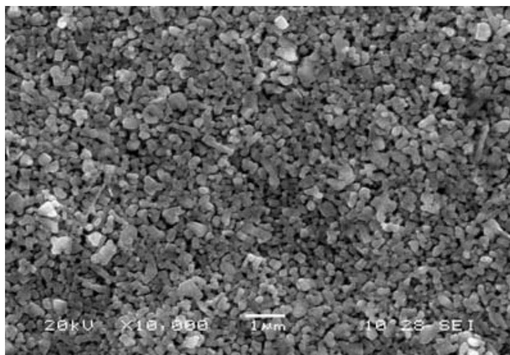


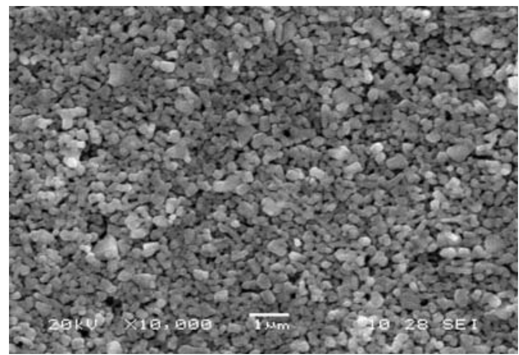
Fig. 4(b). Variation of stacking fault probability with firing temp.

3.4. Surface Morphology Analysis

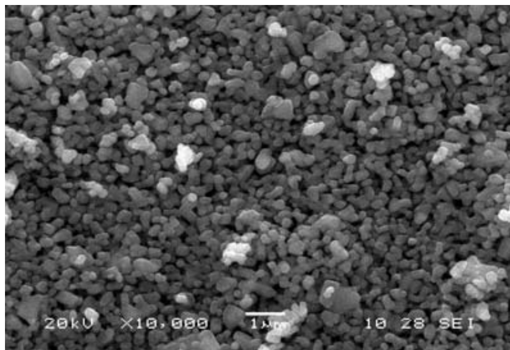
Fig. 5-(a), (b), (c) and (d) show SEM images of ZnO thick films at firing temperatures of 650 ^oC, 700 ^oC, 800 ^oC, 900 ^oC respectively. Fig. 5 (a) and (b) shows that the film structure is uniform and consists of a large number of spherical grains leading to a high porosity and large effective area available for the adsorption of oxygen species. Fig. 5 (c) shows that some necks are formed within the structure. Fig. 5 (d) shows the strongly agglomerated structure with neck growth. Due to this strong agglomeration, the effective surface- to- volume ratio would be decreased and oxygen adsorption-desorption capability of the film structure would be decreased. It has been observed that an increase in the firing temperature leads to an increase in the crystallite size. It is thought that the increase in crystallite size was affected by the promotion of the crystalline phase in the film and neck growth between particles as the firing temperature was increased. From the SEM images the average particle size has been measured and the specific surface area was calculated using equation 5 [25]. As the firing temperature increases, the grain and particle size increases and the specific surface area decreases.



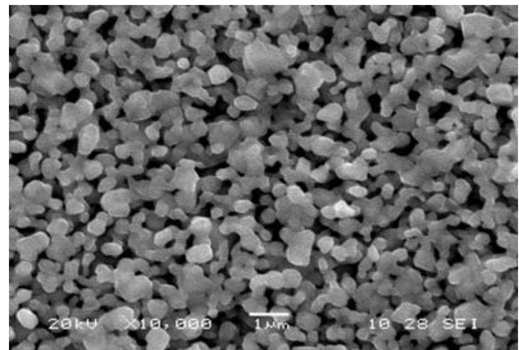
(a) SEM of ZnO film at 650 ^oC.



(b) SEM of ZnO film at 700 ^oC.



(c) SEM of ZnO film at 800 ^oC.



(d) SEM of ZnO film at 900 ^oC.

Fig. 5. SEM images for ZnO thick films fired at different firing temperatures.

4. Conclusion

ZnO thick films were prepared on alumina substrates by a standard screen printing technique which is a simple and in expensive method. From EDX and SEM it was confirmed that ZnO films were non-stoichiometric, which are suitable for gas sensing applications. XRD analysis reveals the hexagonal structure having improved crystnallity with an increase in the firing temperature. SEM indicates an

increase in crystallite size and particle size with an increase in the firing temperature. We have also studied various structural parameters of ZnO films. The microstrain, dislocation density and stacking fault probability, specific surface area decrease with an increase in the firing temperature.

Acknowledgment

The authors thank Management authorities of M. G. Vidyamandir Malegaon camp Dist:-Nasik, The Principal, M.S.G. College, Malegaon and The Principal, L.V.H.College,Nashik for providing all the required infrastructural facilities for doing this work.

References

[1]. M. S. Wagh, G. H. Jain, D. R. Patil, S. A. Patil, L. A. Patil, *Sensors and Actuators B*, 115, 2006, pp. 128-133.
[2]. Xu Haiyan, Hao Wang, YongCai Zhang Shu Wang, ManKang Zhu, Hui Yan, *Cryst. Res. Technol.*, 38, 6, 2003, pp. 429-432.
[3]. K. Hiruma, M. Yazawa, T. Katsuyama, K. Ogawa, K. Haraguchi, M. Koguchi, *Appl. Phys.*, 77, 1995, pp. 447-451.
[4]. Yong Jae Kwon, Kyoung Hun Kim, Chang Sung Lim, Kwang BO Shim, *Ceramic Processing Research*, 3, 3, 2002, pp. 146-149.
[5]. Benny Joseph, K. G., Gopchandran, P. K. Manoj, Peter Koshy, V. K. Vaidyan, *Bull. Mater. Sci.*, 22, 5, 1999, pp. 921-926.
[6]. N. Jayadev Dayan, S. R. Sainkar, R. N. Karekar, R. C. Aiyer, *Thin Solid Films*, 325, 1998, pp. 254-258.
[7]. Bindu Krishnan, V. N. Nampoori, *Bul. Mater. Sci.*, 28, 3, 2005, pp. 239-242.
[8]. S. G. Ansari, P. Boroojerdian, S. K. Kulkarni, S. R. Sainkar, R. N. Karekar, R. C. Aiyer, *Materials Science: Materials in Electronics*, 7, 1996, pp. 267-270.
[9]. Maria Prudenziati, Bruno Morten, *Sensors and Actuators*, 10, 1986, pp. 65-82.
[10].Kiran Jain, R. B. Pant, S. T. Lakshmikumar, *Sensors and Actuators B*, 113, 2006, pp. 823- 829.
[11].A. T. Nimal, Vijay Kumar, A. K. Gupta Indian, *Pure and Applied Physics*, 42, 2004, pp. 275-278.
[12].L. A. Patil, P. A. Wani, S. R. Sainkar, A. Mitra, G. J. Pathak and D. P. Amalnerakar, *Materials Chemistry and Physics*, 55, 1998, pp. 79-83.
[13].Peter Tsolovivanov, Design, Fabrication and Characterization of Thick film sensors, Ph.D. Thesis, *Universitat Rovira Virgili*, Spain, 10 June 2004.
[14].E. San Andress, M. Toledano Luque, A. Del Prado, M. A. Navacerrada, G. Martill I. and Gonzalez Diaz, *Vac. Sci. Tech. A*, 23, 6, 2005, pp. 1523-1530.
[15].Devidas Ramrao Patil Lalchand Avachit Patil, *IEEE Sensors Journal*, 7, 3, 2007, pp. 434- 439.
[16].JCPDS ZnO 1992, 5 – 0664.
[17].T. Schuler, M. A. Aegerter, *Thin Solid Films*, 351, 1999, pp. 125-131.
[18].K. H. Kim, J. S. Chun, *Thin Solid Films*, 141, 1986, pp. 287-295.
[19].B. D. Cullity, in Elements of X-ray diffraction, 2nd Edition, *Addison Wesley*, 1978.
[20].Vorgelegt Von Benjamin, Louis Kniep, Dessertation Tag der wissenschaftlichen Aussprache, 2005, Berlin D 83.
[21].T Mahalingam, V. S. John, L. S. Hsu, *New Materials for Electrochemical Systems*, 10, 2007, pp. 9- 14.
[22].B. E. Warren, E. P. Warekois, *Acta Metallurgica*, 3, 1955, pp. 473-479.
[23].B. Karunagarn, R. T. Rajendra Kumar, D. Mangalraj, Sa. K. Narandas, Mohanrao G, *Crystal Reasearch Technology*, 37, 2002, pp. 1285-1292.
[24].K. R. Pradip Kalita, B. K. Sarma, H. L. Das, *Bulletein of Material Science*, 23, 2000, pp. 313-317.
[25].L. Gao, Li. Q., Song Z. Wang, *Sens. Actuators B*, 71, 2000, pp. 179-183.

2010 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(http://www.sensorsportal.com)

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 additional, 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:

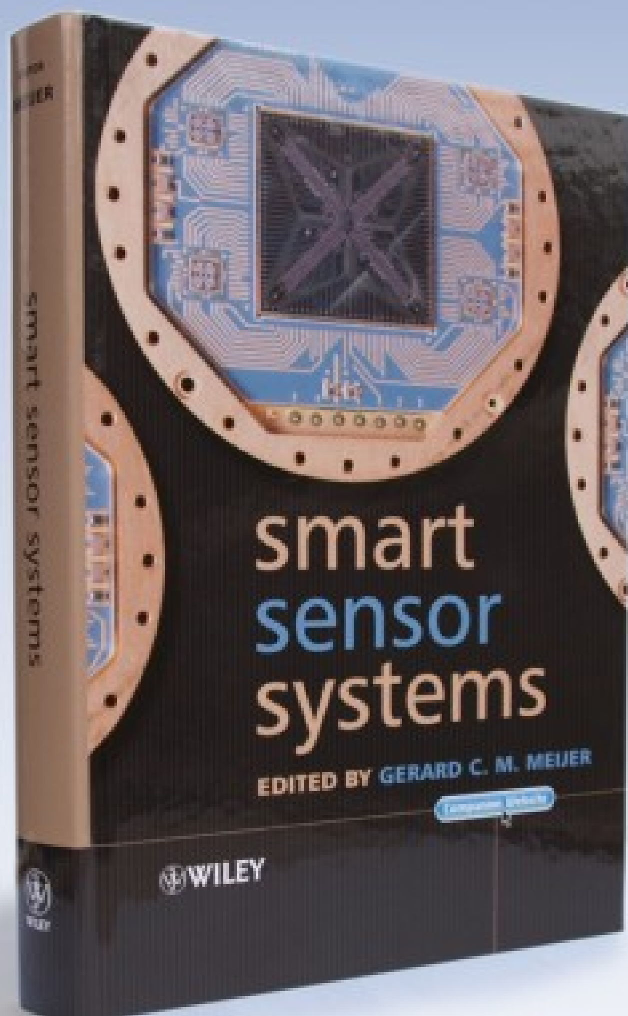
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors 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/Submition.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



'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 semsor systems, their building blocks and methods of signal processing.'

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

www.sensorsportal.com