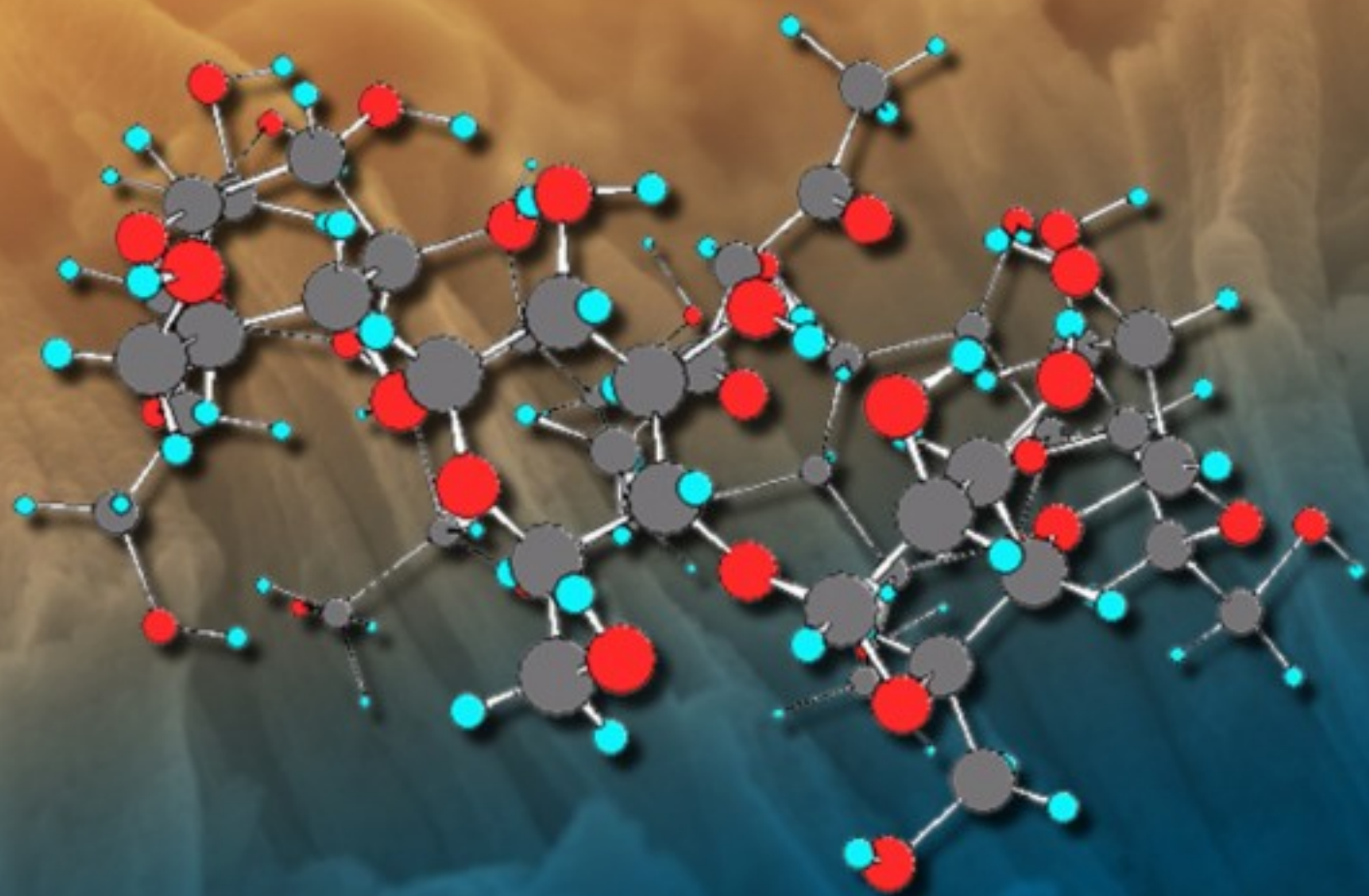


ISSN 1726-5479

SENSORS **11** vol. 146 & TRANSDUCERS **/12**



Nanosensors and Nanodevices

International Frequency Sensor Association Publishing





Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, 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

Editors for North America

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

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Africa

Maki K.Habib, American University in Cairo, Egypt

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, Vygtantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Azamimi, Azian binti Abdullah, Universiti Malaysia Perlis, Malaysia
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Motors 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, Universitè 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
Bouchikhi, Benachir, University Moulay Ismail, Morocco
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
Calvo-Gallego, Jaime, Universidad de Salamanca, Spain
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
Dieguez, Angel, University of Barcelona, Spain
Dighavkar, C. G., M.G. Vidyamandir's L. V.H. College, India
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevich, Alexander, 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
Driljaca, 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
Granell, 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
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
Kaniasas, 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
Khelfaoui, Rachid, Université de Bechar, Algeria
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South
Ko, Sang Choon, Electronics. and Telecom. Research Inst., Korea South
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kockar, Hakan, Balikesir University, Turkey
Kong, Ing, RMIT University, Australia
Kratz, Henrik, Uppsala University, Sweden

Krishnamoorthy, Ganesh, University of Texas at Austin, USA
Kumar, Arun, University of Delaware, Newark, 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, Fengyuan (Thomas), Purdue University, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Sihua, Agiltron, Inc., USA
Li, Xian-Fang, Central South University, China
Li, Yuefa, Wayne State University, USA
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
Malyshev, V.V., National Research Centre 'Kurchatov Institute', Russia
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
Mishra, Vivekanand, National Institute of Technology, India
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
Mrad, Nezh, Defence R&D, Canada
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Nabok, Aleksey, Sheffield Hallam University, UK
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
Passaro, Vittorio M. N., Politecnico di Bari, Italy
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Seteбал, 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
Pugno, Nicola M., Politecnico di Torino, Italy
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
Rastogi Shiva, K., University of Idaho, USA
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politècnica de Catalunya, Spain
Rodriguez, Angel, Universitat Politècnica de Catalunya, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Sandacci, Serghei, Sensor Technology Ltd., UK
Saxena, Vibha, Bbhba Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Shah, Kriyang, La Trobe University, Australia
Sankarraj, Anand, Detector Electronics Corp., USA
Silva Giraó, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleimanpour, Amir Masoud, University of Toledo, USA
Soleymanpour, Ahmad, University of Toledo, USA
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Sridharan, M., Sastra University, India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., NanoSonix Inc., USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Stefanescu, Dan Mihai, Romanian Measurement Society, Romania
Sumriddetchka, Sarun, National Electronics and Comp. Technol. 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, Industr. 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
Thirunavukkarasu, I., Manipal University Karnataka, India
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, Sen, Drexel University, USA
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Shuang-Hua, Loughborough University, UK
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

Contents

Volume 146
Issue 11
November 2012

www.sensorsportal.com

ISSN 1726-5479

Research Articles

- Diffusion in Carbon Nanotubes: Details, Characteristics, Comparisons at Nanolevel**
Paolo Di Sia 1
- Synthesis Characterization and Humidity Sensing Properties of Sol-gel Derived Novel Nanomaterials of $\text{LaSr}_x\text{Fe}_{1-x}\text{O}_{3-\delta}$**
Mary Teresita V., Jeseentharani V., Avila Josephine B., Jeyaraj B., Arul Antony S. 8
- Gas Sensing Characteristics of ZnO Nanowires Fabricated by Carbothermal Evaporation Method**
Roghayeh Imani and Mohammad Orvatinia 17
- In-Situ Decoration of Electrostatically Functionalized Multiwalled Carbon Nanotubes with $\beta\text{-Ni(OH)}_2$ Nanoparticles for Low Temperature NO_2 Detection**
Richa Saggar, Vasuda Bhatia, Prashant Shukla, Nitin Bhardwaj, Vinod K Jain 28
- Synthesis and Characterization of ZnO Nanoparticles as Prepared by Gel-combustion and ZnO Nanomorphologies by Sol-gel**
Mario F. Bianchetti, Marjeta Maček-Krzmanec, Ines Bracko, Sreco D. Skapin and Noemi E. Walsøe de Reca 36
- Multiwalled Carbon Nanotubes Reinforced Cement Composite Based Room Temperature Sensor for Smoke Detection**
Prashant Shukla, Vasuda Bhatia, Vikesh Gaur, Nitin Bhardwaj, Vinod Kumar Jain 48
- A Facile and Green Synthesis of Small Silver Nanoparticles in β -cyclodextrins Performing as Chemical Microreactors and Capping Agents**
Giorgio Ventimiglia and Alessandro Motta 59
- Electrostatically Functionalized Multi-Walled Carbon Nanotubes Based Flexible and Non-Enzymatic Biosensor for Glucose Detection**
Bhawana Singh, Vasuda Bhatia, V. K. Jain 69
- Amperometric Acetylcholinesterase Biosensor Based on Poly (Diallyldimethylammonium Chloride)/Gold Nanoparticles/Multi-walled Carbon Nanotubes-chitosans Composite Film-modified Electrode**
Xia Sun, Zhili Gong, Yaoyao Cao, Xiangyou Wang 78
- Structural, Morphological and Optical Properties of Spray Deposited Nano-crystalline CdO Thin Films**
Maqbul A. Barote, Elahipasha U. Masumdar 90
- A Novel Amperometric Immunosensor Based on $\{\text{MWCNTs-COOH-CHIT}\}_2/\text{GNPs}$ for Detection of Chlorpyrifos**
Xia Sun, Lu Qiao, Xiangyou Wang 96

Y³⁺ Added Nanocrystallite Mg-Cd Ferrite LPG, Cl₂ and C₂H₅OH Sensors <i>Ashok B. Gadkari, Tukaram J. Shinde, Pramod N. Vasambekar.....</i>	110
Immunosensor Based on Gold Nanoparticles-multi-walled Carbon Nanotubes-chitosans Composite and Prussian Blue for Detection of Chlorpyrifos <i>Xia Sun, Falan Li, Xiangyou Wang.....</i>	121
Nanostructured CdFe₂O₄ Thick Film Resistors as Ethonal Gas Sensors <i>S. V. Bangale, R. D. Prakshale, S. R. Bamane.....</i>	133
A Novel Combustion Route for the Preparation of Nanocrystalline LaAlO₃ Oxide Based Electronic Nose Sensitive to NH₃ at Room Temperature <i>K. A. Khamkar, S. V. Bangale, V. V. Dhapte, D. R. Patil, S. R. Bamane.....</i>	145
Gold Nanoparticle Amplification Combined with Quartz Crystal Microbalance DNA Based Biosensor for Detection of <i>Mycobacterium Tuberculosis</i> <i>Thongchai Kaewphinit, Somchai Santiwatanakul and Kosum Chansiri.....</i>	156
Structural, Morphological and Optical Properties of Spray Deposited Nanocrystalline ZnO Thin Films: Effect of Nozzle to Substrate Distance <i>Elahipasha U. Masumdar, Maqbul A. Barote.....</i>	164
Zinc and Pyrrole-added Akaganeite (β-FeOOH) Films by Ultrasonic Spray Pyrolysis Assessed as Propane Sensors <i>Carlos Torres Frausto, Alejandro Avila-Garcia.....</i>	170
Potentiometric Determination of Low Content of Water in Different Organic Solvents Using NASICON Based Probe <i>Parul Yadav and M. C. Bhatnagar.....</i>	182
Development of Electrochemical Sensors for the Detection of Mercury by CNT/Li⁺, C₆₀/Li⁺ and Activated Carbon Modified Glassy Carbon Electrode in Blood Medium <i>Muhammed M. Radhi, Dawood S. Dawood, Nawfal K. Al-Damlooji and Tan W. Tee.....</i>	191

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

International Frequency Sensor Association (IFSA).

Promoted by IFSA

Gyroscopes and IMUs for Defense, Aerospace & Industrial Report up to 2017

This report highlights market share analysis by application field and technology,
as well as global company shipments and technology breakdown

Order online:
http://www.sensorsportal.com/HTML/Gyroscopes_and_IMUs_markets.htm



The Fourth International Conference on Sensor Device Technologies and Applications

SENSORDEVICES 2013

25 - 31 August 2013 - Barcelona, Spain

Tracks: Sensor devices - Ultrasonic and Piezosensors - Photonics - Infrared - Gas Sensors - Geosensors - 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 - Sensors and Transducers for Non-Destructive Testing

Deadline for papers: 30 March 2013

<http://www.iaria.org/conferences2013/SENSORDEVICES13.html>



The Seventh International Conference on Sensor Technologies and Applications

**Deadline for papers:
30 March 2013**

SENSORCOMM 2013

25 - 31 August 2013 - Barcelona, Spain

Tracks: Architectures, protocols and algorithms of sensor networks - Energy, management and control of sensor networks - Resource allocation, services, QoS and fault tolerance in sensor networks - Performance, simulation and modelling of sensor networks - Security and monitoring of sensor networks - Sensor circuits and sensor devices - Radio issues in wireless sensor networks - Software, applications and programming of sensor networks - Data allocation and information in sensor networks - Deployments and implementations of sensor networks - Under water sensors and systems - Energy optimization in wireless sensor networks

<http://www.iaria.org/conferences2013/SENSORCOMM13.html>



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

CENICS 2013

25 - 31 August 2013 - Barcelona, Spain

Deadline for papers: 30 March 2013

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/conferences2013/CENICS13.html>

Immunosensor Based on Gold Nanoparticles-multi-walled Carbon Nanotubes-chitosans Composite and Prussian Blue for Detection of Chlorpyrifos

Xia SUN, Falan LI, Xiangyou WANG

School of Agriculture and Food Engineering, Shandong University of Technology,
No.12, Zhangzhou Road, Zibo 255049, Shandong Province, P.R. China
Tel.:+86-533-2786558, fax: +86-533-2786558
E-mail: sunxia2151@sina.com, wxy@sdut.edu.cn.

Received: 18 July 2012 /Accepted: 23 November 2012 /Published: 30 November 2012

Abstract: In this article, a simple and highly sensitive amperometric immunosensor was developed for the detection of chlorpyrifos. The immunosensor was prepared by sequentially electrodepositing prussian blue (PB), dripping composite membrane of chitosan (CTS), gold nanoparticles (GNPs) and multiwalled carbon nanotubes (MWCNTs) onto glassy carbon electrode (GCE). The electrochemical properties of the modified processes were characterized by electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV), respectively. Multi-walled carbon nanotubes-gold nanoparticles-chitosans composite modified electrode surface was characterized by scanning electron microscopy (SEM). The experimental conditions such as the concentration of antibodies, the incubation temperature, the incubation time and the pH were examined and optimized. Under the optimal conditions, the current response was proportional to the concentration of chlorpyrifos ranging from 0.1 ng/mL to 80 ng/mL and from 90 ng/mL to 200 ng/mL with the detection limit 0.224 ng/mL. The advantages of the immunosensor were exhibited in its wider linear range, better reproducibility, stability, selectivity and regeneration. Using cabbages and Chinese chives as model real samples, acceptable recoveries of 97.1 %-103.4 % was obtained. The proposed method was proven to be a feasible quantitative method for chlorpyrifos analysis, which exhibited high sensitivity, low cost and simplified procedures, for the detection of pesticides residues in food and environment. It may open a new door for ultrasensitive detection of chlorpyrifos residues in vegetables and fruits. *Copyright* © 2012 IFSA.

Keywords: Electrochemical immunosensor, Prussian blue, Chitosan, Gold nanoparticles, Multiwalled carbon nanotube, Chlorpyrifos.

1. Introduction

Chlorpyrifos is a broad-spectrum insecticide widely used in modern agriculture to control insects and nematodes through contact or after ingestion to enhance production and control of insect-borne diseases. Its highly toxicity and accumulation in living organisms has raised public concern regarding food safety and human health. Numerous analysis methods for chlorpyrifos such as gas chromatography, high-performance liquid chromatography, fluorimetry and enzyme-linked immunoassay (ELISA) are sensitive, reliable and precise. However, these methods require expensive instrumentation, complicated pretreatment procedure and professional operators, which limit their application for real-time detection. In this respect, biosensors are considered as suitable complementary tools for the real-time detection of chlorpyrifos in real samples. In addition immunosensors as the biosensors based on the highly sensitive and selective nature of the recognition between antigen (Ag) and antibody (Ab) have been used to detect or quantify specific substances, which is a reliable and promising alternative to classical methods because of their simple fabrication, easy operation, rapid response, high sensitivity and selectivity.

Many immunoassay methods, based on the measurement of antigen-antibody reactions, have been developed for the detection of CEA, such as radioimmunoassay (RIA), enzyme-linked immunosorbent assay (ELISA) and chemiluminescence immunoassay [1-3]. However, these methods exhibit radiation hazards, involve complicated and time-consuming procedures, have poor precision, require qualified personnel and sophisticated instrumentation. Among various immunoassay methods [4], electrochemical immunosensors have attracted considerable interest for its intrinsic advantages such as good portability, low cost, fast analytical time and high sensitivity [5-6]. To achieve a highly sensitive electrochemical immunoassay, various analytical signal amplification strategies have been developed. So far, electrochemical immunosensors, especially amperometric immunosensors, have been attracted a lot in the sides of clinical diagnosis [7], food analysis [8-9] and environmental inspection [10]. Compared to these conventional immunoassay methods, the electrochemical amperometric immunosensors showed great potential due to advantages such as simple pretreatment procedure, fast analytical time, highly sensitive current measurement, lower price and portability [11-13]. As for the construction of an electrochemical immunosensor, the crucial step is the immobilization of sensing biomolecules onto the electrode surface, which should be simple, fast and effective [14].

Nanomaterials have been found important applications in drug discovery and delivery, catalysis, information storage, environmental analysis, biodetections, and many other fields [15]. As one of the most popular tracer labels, enzymes, including glucose oxidase (GOD), horseradish peroxidase (HRP), alkaline phosphatase (ALP) have been immobilized on carbon nanotubes (CNTs) [16-18], bionanospheres [19], nanosilica particles [20-21] and gold nanoparticles (AuNPs) [22-24] for enhancing the enzymatically catalytical signal. In particular, AuNPs, as a class of nanomaterials with many unique properties such as colorimetric, conductivity, nonlinear optical properties, have been found many successful applications in biomolecular detection [25-26]. AuNPs which have good characteristics of easy preparation, good biocompatibility and highly conductivity with a high surface to volume ratio, are widely used in design of electrochemical sensors to provide a stable immobilization of biomolecules, such as DNA, cell and enzyme.

In the present work, the development of an amperometric immunosensor modified by PB and GNPs multilayer films for chlorpyrifos detection was described. The presence of GNPs could enhance electron transfer between Ab and electrode surface and provide a favorable microenvironment for immunoreaction. The PB could make the second GNPs layer immobilized onto the electrode surface firmly. Compared with other kinds of electrochemical immunosensor design, this method would be simple, rapid and more sensitive for pesticide determination with much lower detection limit [27-29]. As a result, the proposed biosensor was overall proofed with simple, selective, sensitive and high stable analysis feature by real cabbages, Chinese chives and spiked simple with known chlorpyrifos concentration. To develop more sensitive immunosensors, the incorporation of nanosized materials into

a sensing device has been extensively investigated [30-31]. Nanoparticles (NPs) can offer many advantages, such as large surface-to-volume ratio, high surface reaction activity and strong adsorption ability to immobilize the desired biomolecules [32-33]. Many metal and semiconductor NPs have been applied to prepare immunosensors [34]. Among these metal NPs, gold nanoparticles are not only better conductor but also offer good microenvironment for retaining the activity of antibody [35]. They can bind directly antibody without any biological properties disruption [36]. In addition, GNPs is able to reduce the insulating effect of the protein shell and thus enhance electron transfer in the reaction processes [37]. Shen et al. reported a label-free electrochemical immunosensor based on GNPs for the direct determination of pesticides [38].

2. Experimental

2.1. Materials and Apparatus

Alumina polishing powder was purchased from Tianjin Aida Heng Sheng Technology Development Co., Ltd. bovine serum albumin (BSA, 96-99 %), chlorpyrifos and chlorpyrifos antibody from Sigma Chemical Co. (St. Louis, MO, USA). ethanol, nitric acid, sulfuric acid, acetic acid, hydrochloric acid and $K_3Fe(CN)_6$ were purchased from Laiyang Economic Development Zone Fine chemical plant (China). Multi-wall carbon nanotubes (MWCNTs) and chitosan were purchased from Shenzhen. Sodium dihydrogen phosphate, sodium dihydrogen phosphate, potassium nitrate and ferric chloride were purchased from Tianjin Northern Tian Yi chemical reagent manufacturing Co., Ltd. Sodium citrate was purchased from the Tianjin Heng Xing chemical reagent manufacturing Co., Ltd. Potassium chloride was purchased from Tianjin Yong Sheng Fine Chemical Co., Ltd. All other reagents were of analytical grade. All aqueous solutions were prepared with distilled water.

Cyclic voltammetric experiment (CV) and electrochemical impedance spectroscopy (EIS) were performed using a CHI660D electrochemical work station (Shanghai CH Instruments Co., China). The working electrode was glassy carbon electrode (GCE, $d=3$ mm), an Ag/AgCl (saturated KCl) and platinum electrode were used as reference and auxiliary electrodes, respectively. If not mentioned, all potentials given below were relative to Ag/AgCl (saturated KCl) electrode. PH measurements were made with a pH meter (FE 20K, Shanghai Zhi Guang Instrument Co., Ltd.). Electronic analytical balance (AL-104) and digital display thermostat magnetic stirrer (GL-3250A) were purchased from Mettler-Toledo (Switzerland). The scanning electron micrographs were taken with a scanning electron microscope (SEM).

2.2. Experimental

2.2.1. Preparation of the PB

PB was mixed with aqueous solution containing 2.5 mM $FeCl_3$, 2.5 mM $K_3[Fe(CN)_6]$, 0.1 M KCl, and 0.1 M HCl.

2.2.2. Preparation of the Multi-walled Carbon-nano Gold-chitosan (GNPs-MWCNTs-CTS) Composite Membranes

All glasswares used in this experiment were cleaned in freshly prepared aqua regia (3:1 v/v HCl HNO_3), then thoroughly rinsed with distilled water and dried in an oven before use. Solutions were freshly prepared when needed. Colloidal Au was prepared by rapidly adding 2.5 mL trisodium citrate to 100 mL boiling aqueous $HAuCl_4$ solution with vigorous stirring. The color changed to burgundy. Boiling was continued for 15 min, and then stirring until the sample had cooled to room temperature. The

pretreatment MWCNTs (10 mg) was dissolved in 0.3 mL of ethanol solution sonicated 4 h and joined 10 mL 1.0% CTS solution sonicated thoroughly until a black homogeneous suspension (MWCNTs-CTS) was obtained. Then MWCNTs-CTS and nano-gold colloid were mixed at room temperatures with magnetic stirring. The solution was stored at 4 °C when not in use.

2.2.3. Preparation of the Immunosensor

First, a 7 μ L of the GNPs-MWCNTs-CTS composite film was cast onto pre-treated substrate and dried in two hours at room temperature. The glassy carbon electrode was immersed in PB solution for 300 s at 0.4 V to obtain electrodeposition of PB film modified electrode. After electrodeposition, the modified electrode was carefully washed with distilled water and placed into a solution containing 0.1 M KCl and 0.01 M HCl with cyclic voltammetry scans ranging from -0.2 to 0.5 V at a scan rate of 50 mV/s for five cycles until a stable voltammetric response was obtained. Afterwards, the substrate was rinsed with distilled water and dried under nitrogen. Following that, 7 μ L of the GNPs-MWCNTs-CTS composite film nanocomposite was cast onto the surface of the substrate for self-assembly for 2 h in a dry chamber at room temperature. These processes obtain the GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS composite film. Following that, the electrode was immersed in 10 μ g/mL chlorpyrifos antibody solutions and kept for at least 8 h at 4 °C. Finally, the electrode was incubated with 0.5 % BSA at room temperature for 0.5 h in order to block nonspecific binding sites. The resulted immunosensor was stored above the 0.1 M PBS (pH 7.5) at 4 °C when not in use. The schematic illustration of the fabrication process was shown in Fig. 1.

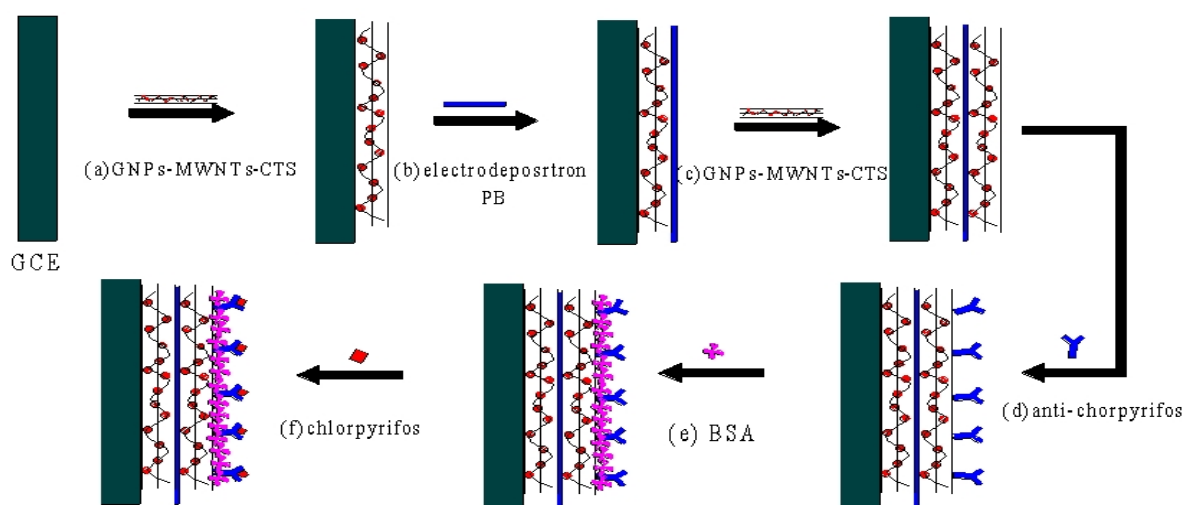


Fig. 1. Schematic illustration of the stepwise procedure of the immunosensor preparation: (a) drops coated with GNPs-MWCNTs-CTS; (b) electrodeposition of PB; (c) again drops coated with GNPs-MWCNTs-CTS; (d) immobilization of anti-chlorpyrifos; (e) BSA blocking.

2.2.4. Sample Preparation

The cabbages and Chinese chives were purchased from the supermarket and cleaned three times using distilled water. Different concentrations of chlorpyrifos solution were sprinkled on the surface of cabbages and Chinese chives. After 24 h, all the samples weighing 10 g were chopped and meshed. Then the samples were extracted with 11 mL of extraction solvent (10 mL 0.1 M PBS and 1 mL acetone) by ultrasonic treatment 20 min. Then the extract was separated from the insoluble materials by centrifugation for 10 min 10000 rpm and the supernatants were directly detected by CV without extraction or preconcentration.

2.2.5. Electrochemical Measurements

The electrochemical characteristics of the modified electrodes were characterized by cyclic voltammetry (CV). Electrochemical experiments were performed in a conventional electrochemical cell containing a three-electrode arrangement. Unless otherwise indicated, the CV scan was taken from -0.2 V to 0.6 V with a sweeping rate of 50 mV/s in 0.1 M PBS (pH 7.5) containing 0.1 M KCl at 37 °C. Meanwhile, the steps of the immunosensor fabrication procedures were characterized by EIS in the presence of a 5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$ and 0.1 M KCl mixture at room temperature. The chlorpyrifos detection was based on the variation of current response ($\Delta I = I_0 - I_1$) before and after immunoreaction, where I_0 and I_1 were the sensors before and after reaction to the chlorpyrifos, respectively.

3. Results and Discussion

3.1. SEM Characterization of GNPs-MWCNTs-CTS Modified GCE Interfaces

SEM was used to get the dynamic image of GNPs-MWCNTs-CTS modified GCE interfaces. As shown in Fig. 2, the SEM image revealed that MWCNTs were well distributed on the surface with the form of small bundles or double tubes. Such small bundles and double tubes assembled homogeneously on the substrate were believed to be very beneficial for the modified electrode performance because the well-dispersed MWCNTs were electrochemically accessible. This Figure displayed the typical SEM images of the nano-Au, which was in the form of many small, white global particles and their sizes were small. Therefore it could be concluded that nano-Au film had been dispersed on the surface of composite film successfully.

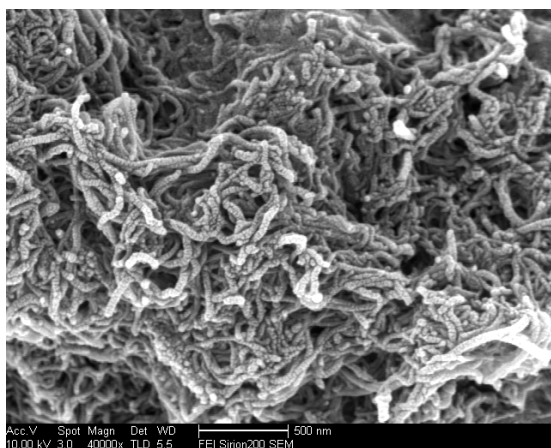


Fig. 2. SEM image map of fixed complexes of gold nanoparticles on the electrode.

3.2. Cyclic Voltammetry Characterization of the Electrode Modification Process

The cyclic voltammograms (CVs) of differently modified electrodes (0.1 M KCl, 0.1 M PBS pH 7.5) were presented in Fig. 3. Displays the CV of a bare GCE, it did not exhibit any waves in the working potential range (Fig 3 a). After plastic composite film of gold nanoparticles was formed on the electrode surface, no obvious cyclic voltammetric peak was found (Fig. 3 b). A pair of well-defined redox peaks was appeared (Fig. 3 c), indicating PB possessed excellent redox activity and MWCNTs improved the conductivity. Groups with a wealth of gold nanoparticles composite film could provide more amino and carboxyl groups, the conductivity of the solution increased, thereby enabling the current response curve peak further increase (Fig. 3 d). However, after the non-electrochemical activity material, SPA and

anti-chlorpyrifos antibody were immobilized on the GCE, a pair of typical reversible redox decreased (Fig. 3 e) in sequence, which could be attributed to the non-electrochemical activity material hindering the shuttle of electrons to the electrode surface. Subsequently, when BSA was used to block the non-specific sites, the current response significantly decreased (Fig. 3 f), which indicated that the BSA had been immobilized on the electrode successfully.

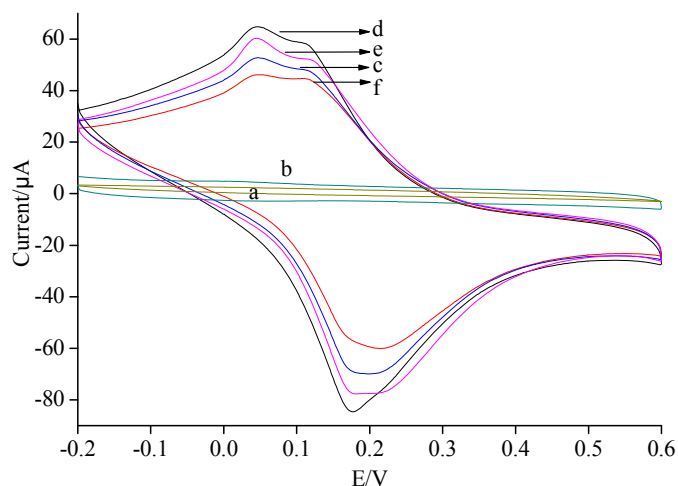


Fig. 3. Cyclic voltammograms of the different modified electrodes: (a) bare electrode; (b) GNPs-MWCNTs-CTS sensor; (c) GNPs-MWCNTs-CTS/PB sensor; (d) GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor; (e) Ab/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor; (f) BSA/Ab/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor.

3.3. Electrochemical Impedance Spectroscopy of the Electrode Modification Process

As shown in Fig. 4. the detailed electron-transfer behaviors of BSA/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS were also performed by EIS in the presence of 0.1 M PBS containing 5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$ and 0.1 M KCl. The results of current response were in agreement with the conclusion obtained from the CV.

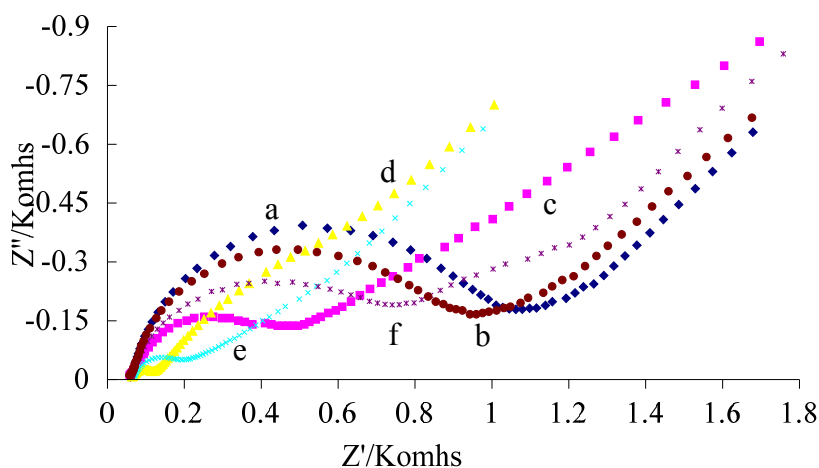


Fig. 4. Electrochemical impedance spectroscopy of the different modified electrodes in 0.1 M PBS containing 5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$ and 0.1 M KCl: (a) Bare electrode; (b) GNPs-MWCNTs-CTS sensor; (c) GNPs-MWCNTs-CTS/PB sensor; (d) GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor; (e) Ab/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor; (f) BSA/Ab/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor.

3.4. Electrochemical Characterization of the Immunosensor

Fig. 5 showed the CVs of the proposed immunosensor in PBS (pH 7.5) at scan rates ranging from 10 to 350 mV/s. With the scan rate increasing, the peak currents increased gradually. In addition, the peak current versus the square root of the sweep rate plot, shown in the inset, exhibited a linear relationship, indicating that the reaction was a diffusion-controlled process.

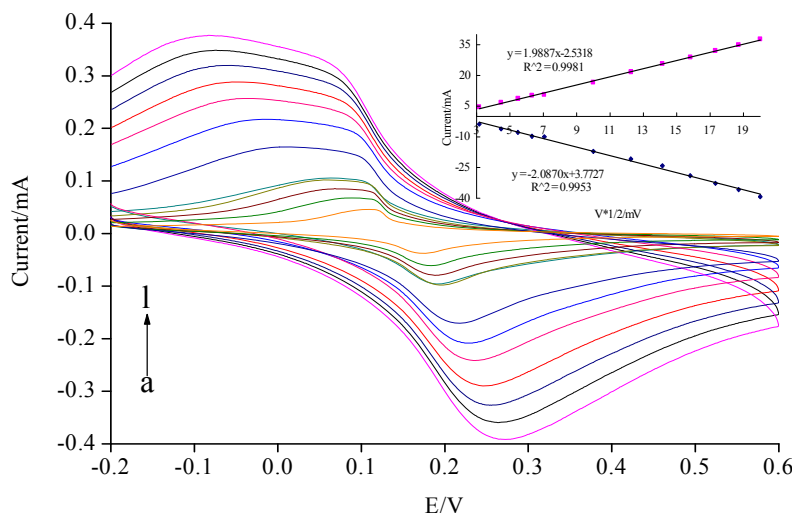
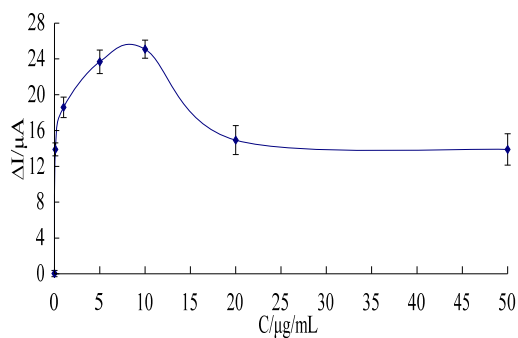


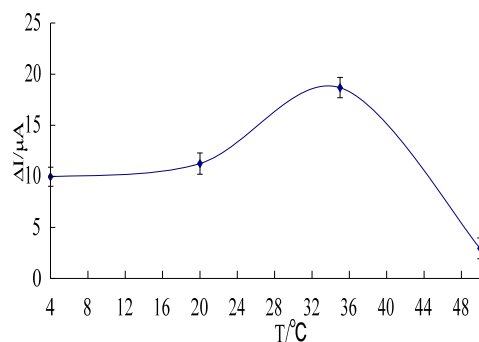
Fig. 5. CVs of the modified electrode at different scan rates (from inner to outer): from 10 to 350 mV/s in PBS (pH 7.5).

3.5. Optimization of Assay Conditions

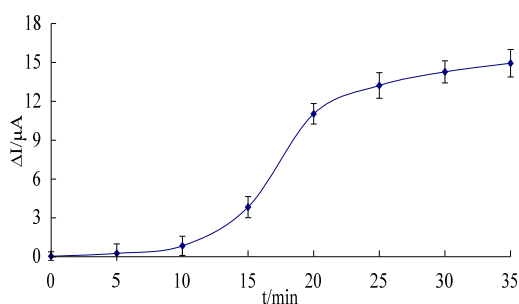
The operating pH, incubation temperature, incubation time and concentration of optimize analytical performance. The concentration of anti-chlorpyrifos antibody incubated onto the electrode bound to the immunosensor surface to bring about the change of impedance response. As shown in Fig. 6 a, the increase of the anti-chlorpyrifos antibody concentration seemed to be beneficial for obtaining an increased impedance response. When the concentration of the antibody was higher than 10 $\mu\text{g/mL}$, the impedance response became sluggish, which might be attributed to the interaction between the macromolecules and the limitation of the active binding sites for protein. Thus, in the experiment, an antibody concentration of 10 $\mu\text{g/mL}$ was used. The effect of incubation temperature was investigated in the range of 4 $^{\circ}\text{C}$ to 50 $^{\circ}\text{C}$. As shown in Fig. 6 b of the supplementary section, the response increased obviously with the temperatures increasing to 35 $^{\circ}\text{C}$. However, while temperatures were over 35 $^{\circ}\text{C}$, a deterioration of the response signals has been observed. The reason might be that the high temperature might decrease the activity of the biomolecules. Considering the lifetime and the response characteristics of the immunosensor, the temperature of 35 $^{\circ}\text{C}$ was chosen as a compromise. At this temperature, the influence of the immunochemical incubation time was also investigated. As shown in Fig. 6 c of the supplementary section, the current of the amperometric response decreased rapidly with the incubation time of up to 20 min. After that the variation slowed, indicating the saturated formation of the immunocomplex. Thus, the incubation time of 20 min was adopted as the optimal incubation condition. The pH of the working buffer had a great effect on the performance of the amperometric immunosensor. In order to evaluate the influence of the pH, immunosensors were tested in a series of PBS buffers at various pH values ranging from 4.5 to 8.5. In our test, it was found that the maximum response occurred at pH 7.5 (Fig. 6 d), and considering the activity of the protein and lifetime of the immunosensor, a PBS of pH 7.5 was selected for further experiment.



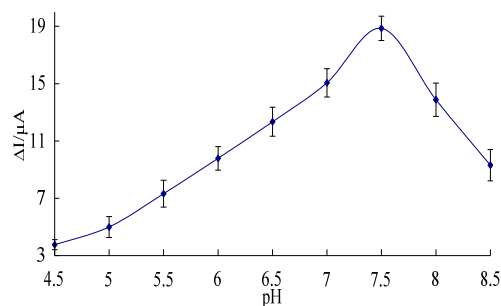
(a)



(b)



(c)



(d)

Fig. 6. The optimization of experimental parameter: (a) the influence of anti-chlorpyrifos antibody; (b) the influence of the incubation temperature; (c) the influence of the incubation time; (d) the influence of pH of working.

3.6. Performance of the Immunosensor

Fig 7 showed the calibration curve of immunosensor, illustrating that a linear response has been obtained within the range from 0.1 to 240 ng/mL. The results obtained from the methods showed a good correlation with the regression equation of $y=0.2276x+4.3801$ (x-axis, by concentration of chlorpyrifos; y-axis, by ΔI) and a correlation coefficient of 0.9927. The detection limit of this label-free impedance detection assay was about 0.224 ng/mL. Thus, the immunosensor has been satisfactorily applied to the determination of chlorpyrifos.

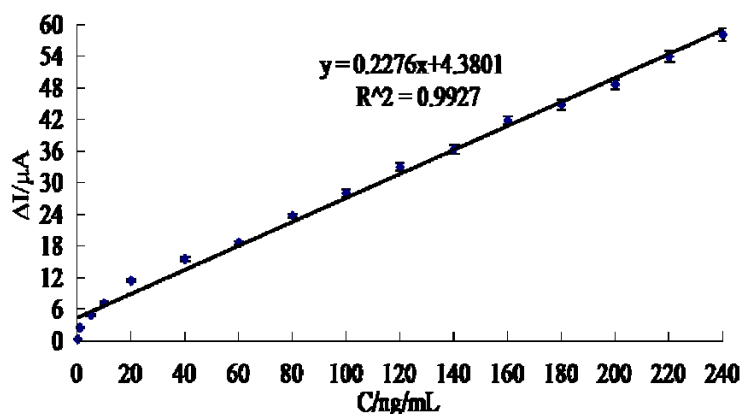


Fig. 7. The calibration curve of immunosensor.

3.7. Selectivity, Stability and Reproducibility of the Immunosensor

To test the selectivity of this sensing strategy, a few possible interferences, such as monocrotophos, carbaryl, malathion and carbofuran were used to evaluate the selectivity of the immunosensors. The immunosensor was incubated in interferences containing 1 $\mu\text{g}/\text{mL}$ monocrotophos, 1 $\mu\text{g}/\text{mL}$ carbaryl, 1 $\mu\text{g}/\text{mL}$ malathion, 1 $\mu\text{g}/\text{mL}$ carbofuran and the mixture of above four kinds of pesticides and 100 ng/mL chlorpyrifos, respectively. According to the experiments, the ΔI of CVs respectively showed in Fig. 8. The result indicated that the selectivity of the as-prepared immunosensor was acceptable within experimental error.

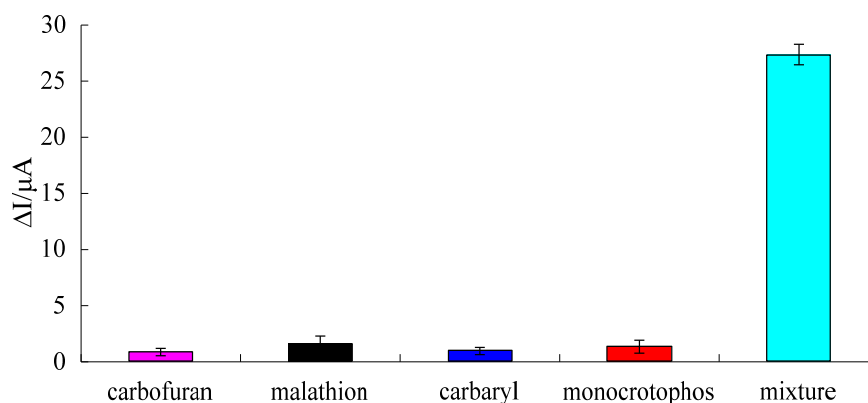


Fig. 8. Specificity of immunosensor in interferences included monocrotophos (1 $\mu\text{g}/\text{mL}$), carbaryl (1 $\mu\text{g}/\text{mL}$), malathion (1 $\mu\text{g}/\text{mL}$), carbofuran (1 $\mu\text{g}/\text{mL}$) and the mixture of chlorpyrifos (100 ng/mL) and the above four kinds of interferences stated above.

After the proposed immunosensor was incubated in 100 ng/mL chlorpyrifos for 20 min, it was dipped into a glycine-HCl buffer (pH 2.8) for about 5 min, removed and washed with distilled water. The relative standard deviation was 6.31 % for 5 independent determinations. The experimental results indicated good reproducibility of the immunosensor. The operational stability and storage stability were also examined as important parameters for the practical application of immunosensor. Under optimal conditions, the immunosensor was measured by CV for a 60-cycles successive scan, and a 3.03 % deviation of the initial response was observed. When the sensor was stored in a refrigerator at 4 $^{\circ}\text{C}$, the electrode retained more than 90.8 % of its original signal after 20 days of storage, showing good stability. These observations might be attributed to the fact that the antibody was attached firmly to the GCE via SPA molecules.

3.8. The Detection of the Real Samples

In order to investigate the ability of the immunosensor to detect chlorpyrifos accurately, the recovery test was carried out by detecting two different chlorpyrifos concentrations in real samples of cabbages and Chinese chives using BSA/GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS sensor. The recoveries (shown in the Table 1) were satisfactory with a range of 95.6 %-107.6 %, confirming that the prepared immunosensor was reliable to detect chlorpyrifos in the working buffer. Which indicated the present method might be applied for determination of chlorpyrifos.

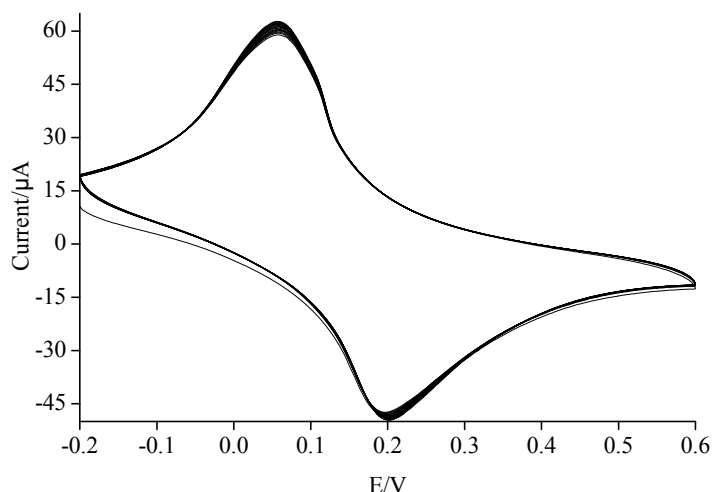


Fig. 9. The stability analysis of immunosensor.

Table 1. The detection of real samples of cabbages and Chinese chives by BSA/GNPs-MWCNTs-CTS /PB/GNPs-MWCNTs-CTS sensor.

Sample	The amount of chlorpyrifos sprinkled on the vegetables (ng/mL)	The amount of chlorpyrifos detected by the modified electrode (ng/mL)	RSD (% , n = 5)	Recovery (%)
Cabbages	0	0.056		
	10	10.76	3.2	107.6
	50	53.20	4.4	106.4
Chinese chives	0	0.039		
	10	9.56	4.7	95.6
	50	49.21	3.6	98.42

4. Conclusion

In this work, a new amperometric immunosensor was described for the determination of chlorpyrifos with good sensitivity and high stability based on the GNPs-MWCNTs-CTS/PB/GNPs-MWCNTs-CTS multilayer film. The nano-gold colloid complexes were easier dispensed on the electrode surface than electrodeposited gold nanoparticles complexes and it saved complexes and time. The films offered a larger surface area, allowed an increased immobilization amount of anti-chlorpyrifos on the electrode surface, which indicated that the resulting sensor offered relatively high sensitivity and a wide linear detection range for the determination of chlorpyrifos. The developed immunosensor had several attractive advantages such as high stability of this multilayer film, easily adsorptive immobilization of antibody on gold nanoparticle composite films. The results also indicated that it might be applied not only in the laboratory but also in the field for detecting the pesticide residues in food or environments. Further studies are in progress to improve the performance of the immunosensor.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 30972055, 31101286), Agricultural Science and Technology Achievements Transformation Fund Projects of the

Ministry of Science and Technology of China (No. 2011GB2C60020) and Shandong Provincial Natural Science Foundation, China (No.Q2008D03).

References

- [1]. J. H. Lin, H. X. Ju, Electrochemical and chemiluminescent immunosensors for tumor markers, *Biosensors and Bioelectronics*, Vol. 37, Issue 1, 2005, pp. 201-461.
- [2]. L. J. Hefta, M. Neumaier, J. E. Shively, Kinetic and affinity constants of epitope specific anti-carcinoembryonic antigen (CEA) monoclonal antibodies for CEA and engineered CEA domain constructs, *Immunotechnology*, Vol. 4, Issue 1, 1998, pp. 41-49.
- [3]. M. Tobi, D. O’Kieffe, N. Trujillo, L. E. Nochomovitz, W. M. Steinberg, Detection of carcinoembryonic antigen in colonic effluent by specific anti-CEA monoclonal antibodies, *Cancer Letters*, Vol. 67, Issue 1, 1992, pp. 47-67.
- [4]. T. Kawabata, M. Watanabe, K. Nakamura, S. Satomura, Liquid-phase binding assay of α -fetoprotein using DNA-coupled antibody and capillary chip electrophoresis, *Analytical Chemistry*, Vol. 77, Issue 17, 2005, pp. 5579-5582.
- [5]. Z. Aguilar, W. Vandaveer, I. Fritsch, Self-contained microelectrochemical immunoassay for small volumes using mouse IgG as a model system, *Analytical Chemistry*, Vol. 74, Issue 14, 2002, pp. 3321-3335.
- [6]. X. Li, X. Yang, S. Zhang, Electrochemical enzyme immunoassay using model labels, *TrAC Trends in Analytical Chemistry*, Vol. 27, Issue 6, 2008, pp. 543-553.
- [7]. D. Du, F. Yan, S. L. Liu, H. X. Ju, Immunological assay for carbohydrate antigen 19-9 using an electrochemical immunosensor and antigen immobilization in titania sol-gel matrix, *Journal of Immunological Methods*, Vol. 283, Issue 1-2, 2003, pp. 26-27.
- [8]. P. B. Lippa, L. J. Sokoll, D. W. Chan, Immunosensors-principles and applications to clinical chemistry, *Clinica Chimica Acta*, Vol. 314, Issue 1-2, 2001, pp. 31-41.
- [9]. C. A. Marquette, L. J. Blum, State of the art and recent advances in immunoanalytical systems, *Biosensors and Bioelectronics*, Vol. 21, Issue 8, 2006, pp. 211-424.
- [10]. S. Singh, Sensors - an effective approach for detection of explosives, *Journal of Hazardous Materials*, Vol. 114, Issue 1-2, 2007, pp. 144-151.
- [11]. T. T. Zhang, R. Yuan, Y. Q. Chai, K. G. Liu, S. J. Ling, Study on an immunosensor based on gold nanoparticles and a nano-calcium carbonate/Prussian blue modified glassy carbon electrode, *Microchimica Acta*, Vol. 165, Issue 1-2, 2009, pp. 165-253.
- [12]. X. H. Fu, J. Y. Wang, N. Li, L. Wang, L. Pu, Label-free electrochemical immunoassay of carcinoembryonic antigen in human serum using magnetic nanorods as sensing probes, *Microchimica Acta*, Vol. 165, Issue 3-4, 2009, pp. 437-442.
- [13]. D. Y. Tang, B. Y. Xia, Electrochemical immunosensor and biochemical analysis for carcinoembryonic antigen in clinical diagnosis, *Microchimica Acta*, Vol. 163, Issue 1-2, 2008, pp. 41-48.
- [14]. C. F. Ou, R. Yuan, Y. Q. Chai, M. Y. Tang, R. Chai, X. L. He, A novel amperometric immunosensor based on layer-by-layer assembly of gold nanoparticles-multi-walled carbon nanotubes/thionine multilayer films on polyelectrolyte surface, *Analytica Chimica Acta*, Vol. 603, Issue 2, 2007, pp. 205-213.
- [15]. Y. Xiang, Y. Zhang, Y. Chang, Y. Chai, J. Wang, R. Yuan, Reverse-Micelle synthesis of electrochemically encoded quantum dot barcodes: application to electronic coding of a cancer marker, *Analytical Chemistry*, Vol. 82, Issue 3, 2010, pp. 1138-1141.
- [16]. R. Malhotra, V. Patel, J. Vaque, J. Gutkind, J. Rusling, Ultrasensitive electrochemical immunosensor for oral cancer biomarker IL-6 using carbon nanotube forest electrodes and multilabel amplification, *Analytical Chemistry*, Vol. 82, Issue 8, 2010, pp. 3118-3123.
- [17]. G. Lai, F. Yan, H. Ju, Dual signal amplification of glucose oxidase functionalized nanocomposites as a trace label for ultrasensitive simultaneous multiplexed electrochemical detection of tumor markers, *Analytical Chemistry*, Vol. 81, Issue 23, 2009, pp. 9730-9736.
- [18]. T. Tsai, G. Heckert, L. Neves, Y. Tan, D. Kao, R. Harrison, D. Resasco, D. Schmidtke, Adsorption of glucose oxidase onto single-walled carbon nanotubes and its application in layer-by-layer biosensors, *Analytical Chemistry*, Vol. 81, Issue 19, 2009, pp. 7917-7925.
- [19]. D. Tang, R. Yuan, Y. Chai, Ultrasensitive electrochemical immunosensor for clinical immunoassay using thionine-doped magnetic gold nanospheres as labels and horseradish peroxidase as enhancer, *Analytical Chemistry*, Vol. 80, Issue 5, 2008, pp. 1582-1588.

- [20].Z. Zhong, M. Li, D. Xiang, N. Dai, Y. Qing, D. Wang, D. Tang, Signal amplification of electrochemical immunosensor for the detection of human serum IgG using double-codified nanosilica particles as labels, *Biosensors and Bioelectronics*, Vol. 24, Issue 7, 2009, pp. 2246-2249.
- [21].J. Wang, G. Liu, Y. Lin, Electroactive silica nanoparticles for biological labeling, *Small*, Vol. 2, Issue 10, 2006, pp. 1134-1138.
- [22].C. Ding, Y. Ge, J. Lin, Aptamer based electrochemical assay for the determination of thrombin by using the amplification of the nanoparticles, *Biosensors and Bioelectronics*, Vol. 25, Issue 6, 2010, pp. 1290-1294.
- [23].J. Ho, H. Chang, N. Shih, L. Wu, Y. Chang, C. Chen, C. Chou, Diagnostic detection of human lung cancer-associated antigen using a gold nanoparticle-based electrochemical immunosensor, *Analytical Chemistry*, Vol. 82, Issue 14, 2010, pp. 5944-5950.
- [24].Z. Zhong, W. Wu, D. Wang, D. Wang, J. Shan, Y. Qing, Z. Zhang, Nanogold-enwrapped graphene nanocomposites as trace labels for sensitivity enhancement of electrochemical immunosensors in clinical immunoassays: carcinoembryonic antigen as a model, *Biosensors and Bioelectronics*, Vol. 25, Issue 10, 2010, pp. 2379-2383.
- [25].S. Bi, Y. Yan, X. Yang, S. Zhang, Gold nanolabels for new enhanced chemiluminescence immunoassay of alpha-fetoprotein based on magnetic beads, *Chemistry A European Journal*, Vol. 15, Issue 18, 2009, pp. 4704-4709.
- [26].A. Ambrosi, M. Castañeda, A. Killard, M. Alegret, A. Merkoçi, Doublecodified gold nanolabels for enhanced immunoanalysis, *Analytical Chemistry*, Vol. 79, Issue 14, 2007, pp. 523-524.
- [27].T. Hianika, M. Šnejdárková, L. Sokolíková, E. Meszára, R. Krivánka, V. Tvarožek, I. Novotný, J. Wang, Immunosensors based on supported lipid membranes, protein films and liposomes modified by antibodies, *Sensors and Actuators B: Chemical*, Vol. 57, Issue 1-3, 1999, pp. 201-212.
- [28].X. Sun, X. Y. Wang, S. Y. Du, W. P. Zhao, Q. Q. Li, X. B. Han, Label-free amperometric immunosensor for the detection of carbofuran pesticide, *Sensors Letter*, Vol. 9, Issue 3, 2011, pp. 958-963.
- [29].X. Sun, X. Y. Wang, Acetylcholinesterase biosensor based on Prussian blue-modified electrode for detecting organophosphorous pesticides, *Biosensors and Bioelectronics*, Vol. 25, Issue 12, 2010, pp. 2611-2614.
- [30].C. Shan, H. Yang, J. Song, D. Han, A. Ivaska, L. Niu, Direct electrochemistry of glucose oxidase and biosensing for glucose based on graphene, *Analytical Chemistry*, Vol. 81, Issue 6, 2009, pp. 2378-2382.
- [31].R. Nenkova, D. Ivanova, J. Vladimirova, T. Godjevargova, New amperometric glucose biosensor based on cross-linking of glucose oxidase on silica gel/multiwalled carbon nanotubes/polyacrylonitrile nanocomposite film, *Sensors Actuators. B*, Vol. 148, Issue 1, 2010, pp. 59-65.
- [32].L. Q. Yang, X. L. Ren, F. Q. Tang, L. Zhang, A practical glucose biosensor based on Fe₃O₄ nanoparticles and chitosan/naion composite film, *Biosensors and Bioelectronics*, Vol. 25, Issue 4, 2009, pp. 889-895.
- [33].W. Y. Cai, Q. Xu, X. N. Zhao, J. J. Zhu, H. Y. Chen, Porous gold-nanoparticle-CaCO₃ hybrid material: Preparation, characterization, and application for horseradish peroxidase assembly and direct electrochemistry, *Chemistry of Materials*, Vol. 18, Issue 2, 2006, pp. 279-284.
- [34].R. Baron, B. Willner, I. Willner, Biomolecule-nanoparticle hybrids as functional units for nanobiotechnology, *Chemical Communications*, Vol. 4, Issue 4, 2007, pp. 323-332.
- [35].D. X. Li, Q. He, Y. Cui, L. Duan, J. B. Li, Immobilization of glucose oxidase onto gold nanoparticles with enhanced thermostability, *Biochemical and Biophysical Research Communications*, Vol. 355, Issue 2, 2007, pp. 488-493.
- [36].A. A. Vertegel, R. W. Siegel, J. S. Dordick, Silica nanoparticle size influences the structure and enzymatic activity of adsorbed lysozyme, *Langmuir*, Vol. 20, Issue 16, 2004, pp. 6800-6807.
- [37].M. D. Hughes, Y. J. Xu, P. Jenkins, P. McMorn, P. Landon, D. I. Enache, A. F. Carley, G. A. Attard, G. J. Hutchings, F. King, E. H. Stitt, P. Johnston, K. Griffin, C. J. Kiely, Tunable gold catalysts for selective hydrocarbon oxidation under mild conditions, *Nature*, Vol. 437, Issue 10, 2005, pp. 1132-1135.
- [38].S. Q. Hu, J. W. Xie, Q. H. Xu, K. T. Rong, G. L. Shen, R. Q. Yu, A label-free electrochemical immunosensor based on gold nanoparticles for detection of paraoxon, *Talanta*, Vol. 61, Issue 6, 2003, pp. 769-777.



International Frequency Sensor Association Publishing Call for Books Proposals

Sensors, MEMS, Measuring instrumentation, etc.



Benefits and rewards of being an IFSA author:

1

Royalties

Today IFSA offers most high royalty in the world: you will receive 50 % of each book sold in comparison with 8-11 % from other publishers, and get payment on monthly basis compared with other publishers' yearly basis.

2

Quick Publication

IFSA recognizes the value to our customers of timely information, so we produce your book quickly: 2 months publishing schedule compared with other publishers' 5-18-month schedule.

3

The Best Targeted Marketing and Promotion

As a leading online publisher in sensors related fields, IFSA and its Sensors Web Portal has a great expertise and experience to market and promote your book worldwide. An extensive marketing plan will be developed for each new book, including intensive promotions in IFSA's media: journal, magazine, newsletter and online bookstore at Sensors Web Portal.

4

Published Format: printable pdf (Acrobat).

When you publish with IFSA your book will never go out of print and can be delivered to customers in a few minutes.

You are invited kindly to share in the benefits of being an IFSA author and to submit your book proposal or/and a sample chapter for review by e-mail to editor@sensorsportal.com. These proposals may include technical references, application engineering handbooks, monographs, guides and textbooks. Also edited survey books, state-of-the-art or state-of-the-technology, are of interest to us. For more detail please visit: http://www.sensorsportal.com/HTML/IFSA_Publishing.htm



International Frequency Sensor Association (IFSA) Publishing

Digital Sensors and Sensor Systems: Practical Design

Sergey Y. Yurish



Formats: printable pdf (Acrobat) and print (hardcover), 419 pages

ISBN: 978-84-616-0652-8,
e-ISBN: 978-84-615-6957-1

The goal of this book is to help the practitioners achieve the best metrological and technical performances of digital sensors and sensor systems at low cost, and significantly to reduce time-to-market. It should be also useful for students, lectures and professors to provide a solid background of the novel concepts and design approach.

Book features include:

- Each of chapter can be used independently and contains its own detailed list of references
- Easy-to-repeat experiments
- Practical orientation
- Dozens examples of various complete sensors and sensor systems for physical and chemical, electrical and non-electrical values
- Detailed description of technology driven and coming alternative to the ADC a frequency (time)-to-digital conversion

Digital Sensors and Sensor Systems: Practical Design will greatly benefit undergraduate and at PhD students, engineers, scientists and researchers in both industry and academia. It is especially suited as a reference guide for practitioners, working for Original Equipment Manufacturers (OEM) electronics market (electronics/hardware), sensor industry, and using commercial-off-the-shelf components

http://sensorsportal.com/HTML/BOOKSTORE/Digital_Sensors.htm

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 of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor 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. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

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

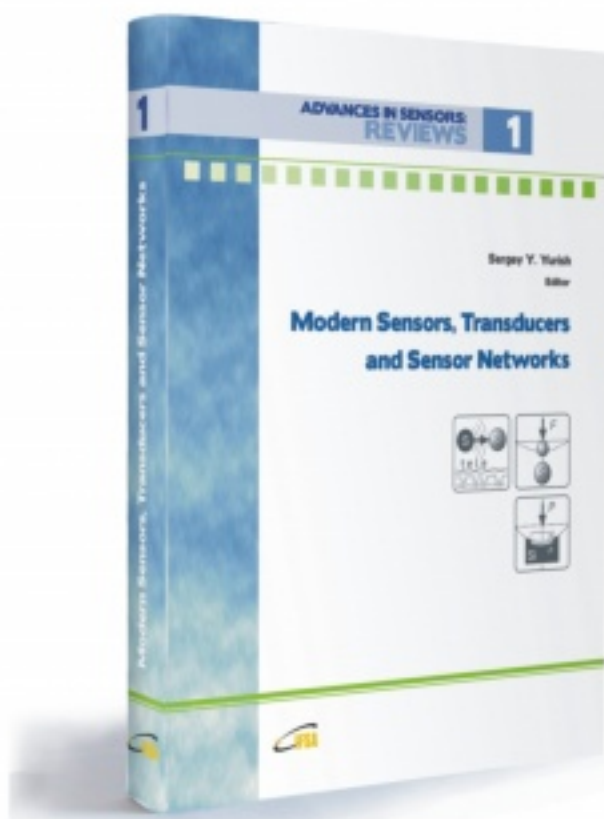
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example 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_2012.pdf

Sergey Y. Yurish
Editor

Modern Sensors, Transducers and Sensor Networks



Modern Sensors, Transducers and Sensor Networks is the first book from the Advances in Sensors: Reviews book Series contains dozen collected sensor related state-of-the-art reviews written by 31 internationally recognized experts from academia and industry.

Built upon the series Advances in Sensors: Reviews - a premier sensor review source, the *Modern Sensors, Transducers and Sensor Networks* presents an overview of highlights in the field. Coverage includes current developments in sensing nanomaterials, technologies, MEMS sensor design, synthesis, modeling and applications of sensors, transducers and wireless sensor networks, signal detection and advanced signal processing, as well as new sensing principles and methods of measurements.

Modern Sensors, Transducers and Sensor Networks is intended for anyone who wants to cover a comprehensive range of topics in the field of sensors paradigms and developments. It provides guidance for technology solution developers from academia, research institutions, and industry, providing them with a broader perspective of sensor science and industry.

Order online:

http://sensorsportal.com/HTML/BOOKSTORE/Advance_in_Sensors.htm



www.sensorsportal.com