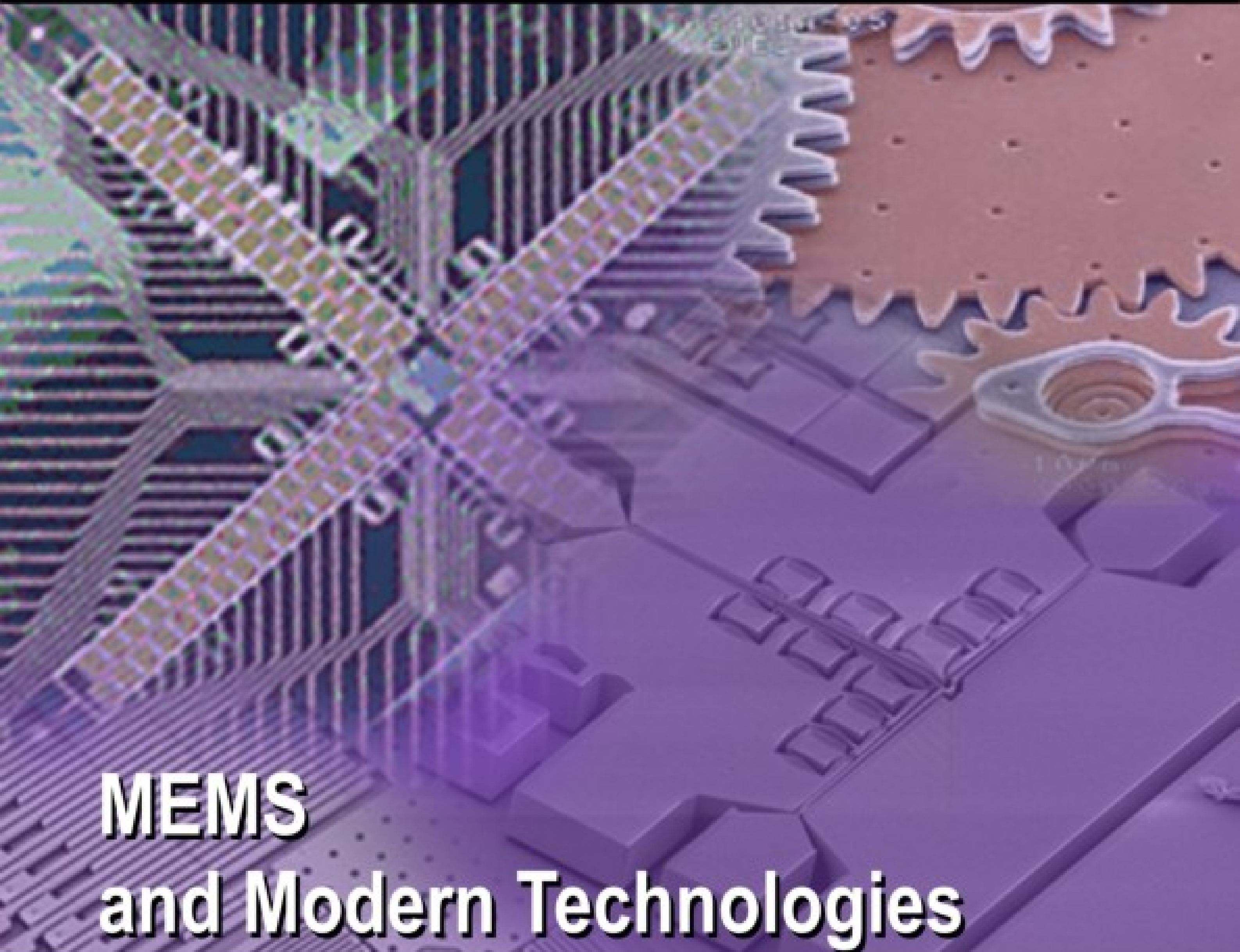
ISSN 1726-5749

SENSORS & TRANSDUCERS

vol. 91
4/08



MEMS
and Modern Technologies

International Frequency Sensor Association Publishing
IFSA

Sensors & Transducers

Volume 91
Issue 4
April 2008

www.sensorsportal.com

ISSN 1726-5479

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

Editors for Western Europe
Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vitorio, Universitá 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

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
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
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
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, 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 Jian, Ning, Jiangsu University, China
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, University 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
Hashsham, Syed, Michigan State University, USA
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
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
Kim, Min Young, Koh Young Technology, Inc., Korea South

Ko, Sang Choon, Electronics and Telecommunications Research Institute, Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, Universidade NOVA de Lisboa, Portugal
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, DIMET, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mukhopadhyay, Subhas, Massey University, New Zealand
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucin, 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
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhbha Atomic Research Centre, Mumbai, India
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
Shearwood, Christopher, Nanyang Technological University, Singapore
Shin, Kyuho, Samsung Advanced Institute of Technology, Korea
Shmaliy, Yuriy, Kharkiv National University 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 Institute for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vaseashta, Ashok, Marshall University, USA
Vazques, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Advanced Micro Devices, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung University 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
Ymeti, Aurel, University of Twente, Netherland
Yu, Haihu, Wuhan University of Technology, China
Yufera Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zeni, Luigi, Second University of Naples, Italy
Zhong, Haoxiang, Henan Normal University, China
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
Zhou, Zhi-Gang, Tsinghua University, China
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 CD-ROM. Copyright © 2007 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

Volume 91
Issue 4
April 2008

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Active Sensing in Ambient Conditions Using an Electrostatically Driven Silicon Microcantilever
G. Keskar, B. Elliott, M. J. Skove, J. Gaillard, S. M. Serkiz and A. M. Rao 1

MEMS Tunneling Wide Range Micro Thermometer Based on Bimetallic Cantilever Beam
Samrand K. Nezhadian, Shahram Khalilariya, Ghader Rezazadeh.. 14

Cantilever Embedded MOSFET Characteristics for Detection of Photosystem I Reaction Centers
Sazia A. Eliza, Ida Lee, Syed K. Islam and Elias Greenbaum.. 24

Design and Analysis of Wet Etching Based Comb Type Capacitive Accelerometer
Shankar Dutta, Shaveta, R. Pal, D. K. Bhattacharya, P. Datta and R. Chatterjee 31

Flexible Membrane LRC Strain Sensor Fabricated Using MEMS Method
Hee C. Lim, James Zunino III and John F. Federici.. 39

Influence of Pd Layer on the Sensitivity of CHx/PS/Si as Structure for Oxygen Sensing
N. Ghellai, S. Belhousse, N. Ababou, Y. Ouadah, N. Gabouze... 47

Design of MEMS Cantilever - Hand Calculation
Abhijeet V. Kshirsagar, S. P. Duttagupta, S. A. Gangal... 55

Piezoelectric Zinc Oxide Based MEMS Acoustic Sensor
Aarti Arora, P. J. George, Anil Arora, V. K. Dwivedi, Vinay Gupta... 70

Design and Fabrication of High Sensitive Piezoresistive MEMS Accelerometer
Joshi A. B., Joshi B. P., Sam Baskar S., K. Natarajan, S. A. Gangal 76

Gaseous Fluidics Control Device
Brahim Dennai, Rachid Khelfaoui, Boumedienne Benyoucef, Belkacem Draoui, Abdelkader Slimani.. 84

A Sensor for Gas Detection Fabricated by a Circular Single-wall Carbon Nanotube
Lun-Wei Changa, Yi-Chen Yeha and Juh-Tzeng Lueb.. 91

Role of Cu^{2+} Concentration on the Microstructure and Gas Sensing Properties of $Ni_{1-x}Cu_xFe_2O_4$ ($0 \leq x \leq 0.8$) Ferrite
Elena Rezlescu, Florin Tudorache, Paul Dorin Popa and Nicolae Rezlescu.................................... 100

Sr(II)-added $ZnAl_2O_4$ Spinel Composites as an Ammonia Sensor
J. Judith Vijaya, L. John Kennedy, G. Sekaran and K. S. Nagaraja 109

Odor Sensing with Indium Tin Oxide Thin Films on Quartz Crystal Microbalance
Nirmal Patel, Jay Huebner, Jason Saredy and Brian Stadelmaier.. 116

Cobalt Chloride Doped Polymer Film for Relative Humidity Measurement
Pabitra Nath, Hidam Kumarjit Singh, Pranayee Datta, Kanak. Ch. Sarmah...................................... 127

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).

Sensors & Transducers Journal, Vol. 91, Issue 4, April 2008, pp. 24-30

Sensors & Transducers

ISSN 1726-5479
© 2008 by IFSA
http://www.sensorsportal.com

Cantilever Embedded MOSFET Characteristics for Detection of Photosystem I Reaction Centers

[1]Sazia A. Eliza, [2]Ida Lee, [1]Syed K. Islam and [2]Elias Greenbaum
[1]Department of Electrical and Computer Engineering, The University of Tennessee, Knoxville,
TN 37996-2100, USA
[2]Oak Ridge National Laboratory, Oak Ridge,
TN 37831-6194, USA
E-mail: seliza@utk.edu, leei@ornl.gov

Received: 11 December 2007 /Accepted: 21 April 2008 /Published: 30 April 2008

Abstract: This paper presents a micro sensor for detection and characterization of biomolecular photodiodes - Photosystem I (PS I) reaction centers. In oxygenic plants, photons are captured with high quantum efficiency by two specialized reaction centers, Photosystems I and II (PS I and PS II). Photon capture triggers rapid charge separation and the conversion of light energy into an electric voltage across the nanometer-scale (~6 nm) reaction centers. In this work, MOSFET embedded micro cantilevers have been used to detect the energy harvesting biomolecules. The bending of cantilevers due to immobilization of reaction centers induces stress on MOSFET gate and hence modulates the MOSFET current voltage characteristics. Again, the optoelectrical property of PS I alter the electrostatic properties of the MOS gate, which reflects in the transport characteristics of the transistor. *Copyright © 2008 IFSA.*

Keywords: Cantilever embedded MOS, Photosystem I, Biomolecular, Photodiode

---

1. Introduction

Using the technique of Kelvin force probe microscopy (KFM), the first measurement of exogenous photovoltages generated from single PS I reaction centers immobilized on atomically flat gold surfaces has been reported [1]. However, no two-terminal device or sensor has been developed for these biomolecular photodiodes. Imprinting biomolecules for construction of electrical devices has been a significant challenge due to temperature and resolution constraints of the growth processes. Recently three-terminal devices for detection and characterization of molecules have become very popular due to the simpler imprint technique and amplification advantages. Detection of PS I reaction centers has been reported using high electron mobility transistors (HEMT) [2-3]. This technique exploited the photo-electrical characteristics of reaction centers to modulate the channel charge and hence the output current-voltage characteristics of the HEMTs. FET-based stress sensors are widely reported for micromechanical devices such as accelerometers, resonators, and parallel cantilevers for scanning probe microscopy, as well as for residual stress measurements [4–6]. When a microcantilever bends as a result of adsorption-induced surface stress, modulation of the channel current underneath the gate region results from altered channel mobility of the transistor due to increased channel resistance. As fixed biased voltages are applied on the gate and source-drain region of the transistor, any change in channel mobility will result in change in the drain current of the transistor. In this work, we used the 2D microcantilever arrays with geometrically configured metal-oxide semiconductor field-effect transistors (MOSFETs) embedded in the high-stress region of the microcantilevers [7] to detect PS I reaction centers through immobilization on the microcantilevers.

2. Immobilization of PS I Reaction Centers

PS I reaction centers can be isolated efficiently from thylakoids of plant leaves (such as spinach) using the technique of detergent solubilization and hydroxylapatite column purification [8]. The reaction center/core antenna complexes contain about 40 chlorophylls per photoactive reaction center pigment (P700)The isolated PS I complexes are elliptical in shape with major and minor axes of about 6 and 5 nm, respectively [8].

The structure and function of PSI reaction centers are schematically illustrated in Fig. 1. The chlorophylls serve as an antenna to capture photons and transfer photon energy to P700, where the light energy triggers photochemical charge separation. An isolated PS I complex contains electron acceptors (A_0, A_1, F_X and F_{AB}) in addition to P700 and the antenna chlorophylls.

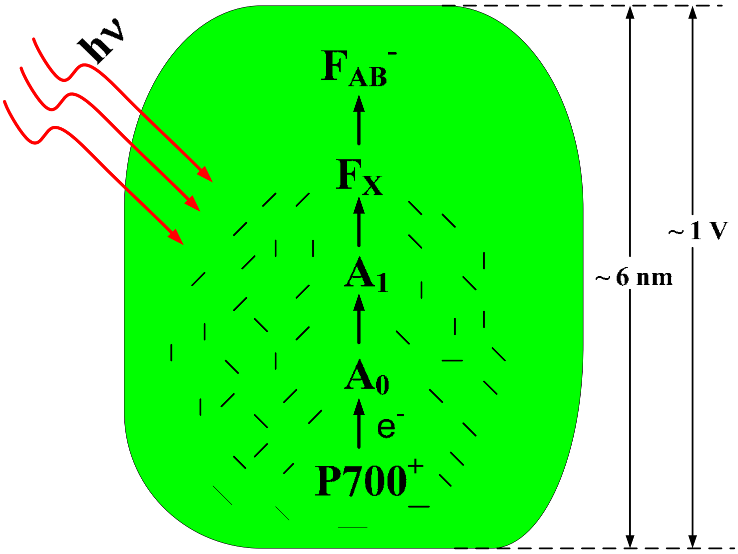


Fig. 1. Schematic illustration of the structure and function of an isolated PS I reaction center core antenna complex.

The primary events in photosynthesis are absorption of light and creation of a singlet excited state, transfer of the excitation between pigment molecules, and photochemical charge separation in the reaction center. The photochemistry of P700 generates a primary charge separation ($P700^{+} A_0^{-}$) within about 1.5 ps [8]. Due to efficient excitation transfer and trapping, the entire photophysical chemistry can be completed in 10-30 ps. The electron released from P700 by charge separation is transferred to the terminal acceptor F_{AB} at the reducing side of PS I, through intermediate acceptors A_0, A_1 and F_X. The quantum yield of PS I photochemistry is very close to 100%. Charge separation in this natural photovoltaic device generates a potential difference of about 1 volt across about 6 nm between the reduced (F_{AB}^{-}) and oxidized ($P700^{+}$) sides of the PS I complex, resulting in a very strong electric field (~- 10^8 volts per meter).

The photoactive energy elements (PS I) can be immobilized on Au by chemical modification of the surface. Also, the orientation of PS I can be selectively made as shown in Fig. 2. For mercaptoacetic acid, 83% of the electron transport vectors were parallel to the surface (Fig. 2A), whereas with 2-mercaptoethanol 70% were oriented perpendicularly in the "up" position (with P700 facing the Au surface) (Fig. 2B) and only 2% were in the "down" position (Fig. 2C). No preferential orientation was observed with 2-dimethylaminoethanethiol.

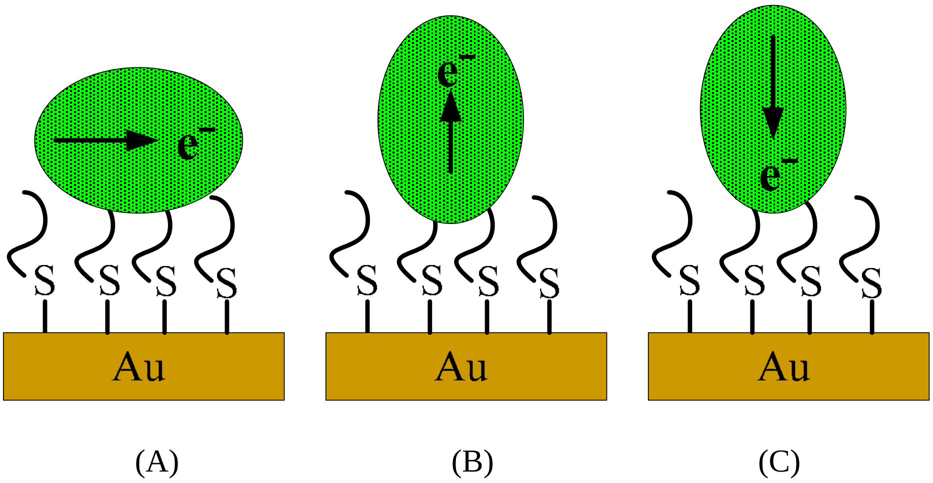
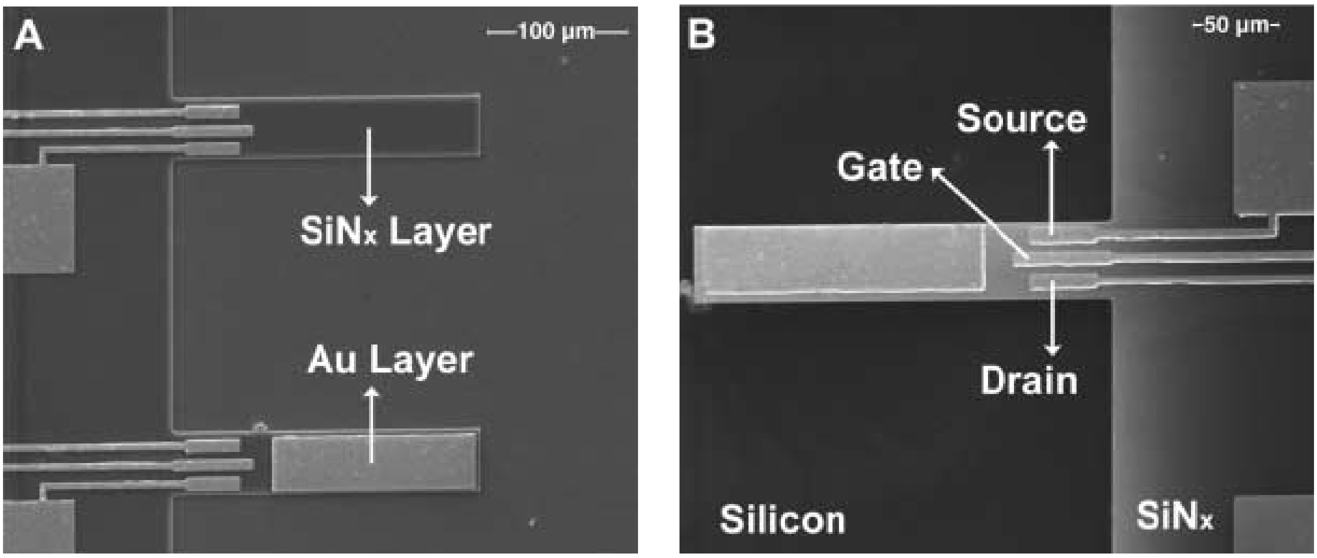


Fig. 2. The orientation of individual PSI reaction center.

3. Experiment

Each MOS pair consists of one microcantilever coated with a thin film of gold for immobilization of probe molecules, and the other is uncoated and acts as the reference (Fig. 3(A)). The differential drain current between the sensing and the reference microcantilevers, which further minimizes systematic noise and environmental perturbations, forms the basis for the MOSFET electronic detection. For the experiments, the MOSFET-embedded microcantilevers were cleaned with isopropyl alcohol and then immersed with 2-mercaptoethanol for 30 sec. Then, 0.25µm filtered PS I solution was put over the sensing and reference cantilevers and was waited for 2 minutes for I-V measurement of the cantilever embedded transistors. The dark and white light measurements of the characteristics of both the reference MOS and sensing MOS were done after immobilization of PS I reaction centers so that both the binding effects of PS I on Au coated cantilever and the effects of photochemical charge transfer within PS I could be estimated.



(A) (B)

Fig. 3. (A) SEM image of two identical cantilevers displaying embedded MOSFET and geometry of the gold-coated and SiNx cantilever beam pair; (B) Details of MOSFET location on cantilever beam, which is released by etching a 2.5-mm sacrificial oxide layer [7].

4. Experimental Results and Discussions

The deposition of Au layer on sensing MOS cantilever create slight difference in drain current as seen from Fig. 4. The drain current changes due to the self assembled monolayer (SAM) of 2-mercaptoethanol on sensing cantilever coated with Au as seen from Fig. 5. The change in drain current results from the modulation of channel mobility because of surface stress. The mobility change may also arise from the changes in the interface charge densities, generation of trap states, band structure alteration, and generation of shallow defects due to localized bending stress. Immobilization of PS I reaction centers on thiol derivatized Au cantilever further changes the drain current of the embedded MOS. On the other hand, with absorption of light electron transfer initiates from the bottom end (P700) to the upper end (F_{AB}) of the vertically oriented PS I resulting positive charges on the gate and therefore increasing the drain current with turn on of light (Fig. 6). However, MOS itself is light sensitive and hence shows changes in current level between light and dark. This difference has been subtracted to calculate the photoresponse of MOS due to PS I in Fig. 6.

5. Conclusion

This paper demonstrates a micro sensor for detection and characterization of PS I reaction centers. The cantilever embedded MOS sensor experiences changes in current due to immobilization of PS I reaction centers. The loading of PS I reaction centers on the cantilever results in surface stress, which modulates the channel current. Also, the photogeneration characteristics of PS I changes the electrostatic properties of the gate and hence the output current of sensor as visible from the difference of light and dark characteristics of the sensor MOS.

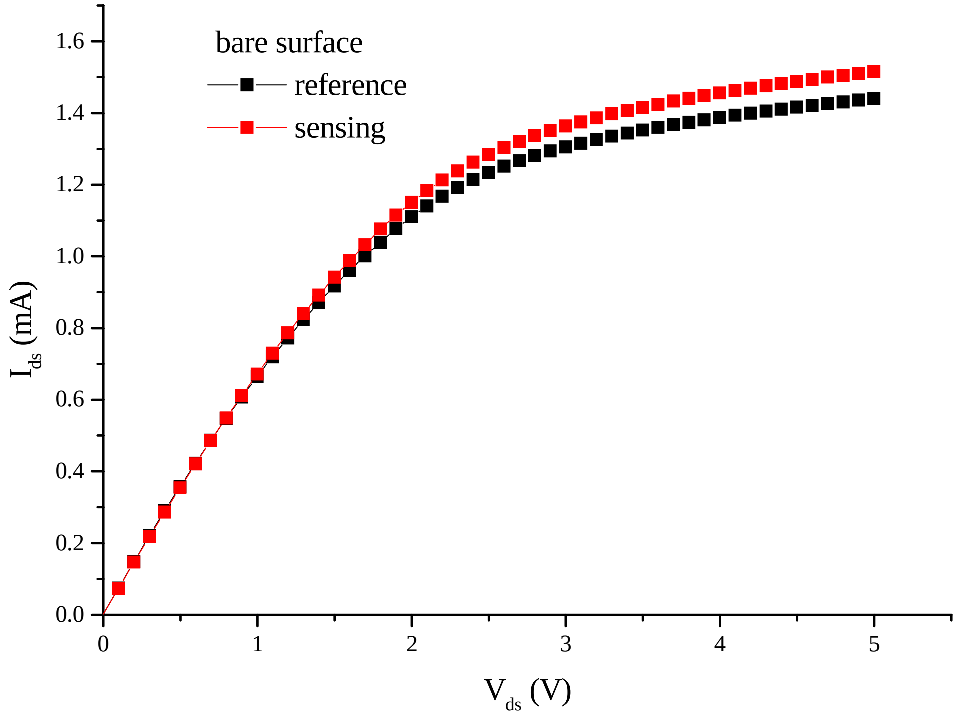


Fig. 4. Output characteristics of reference and sensing MOS transistors.

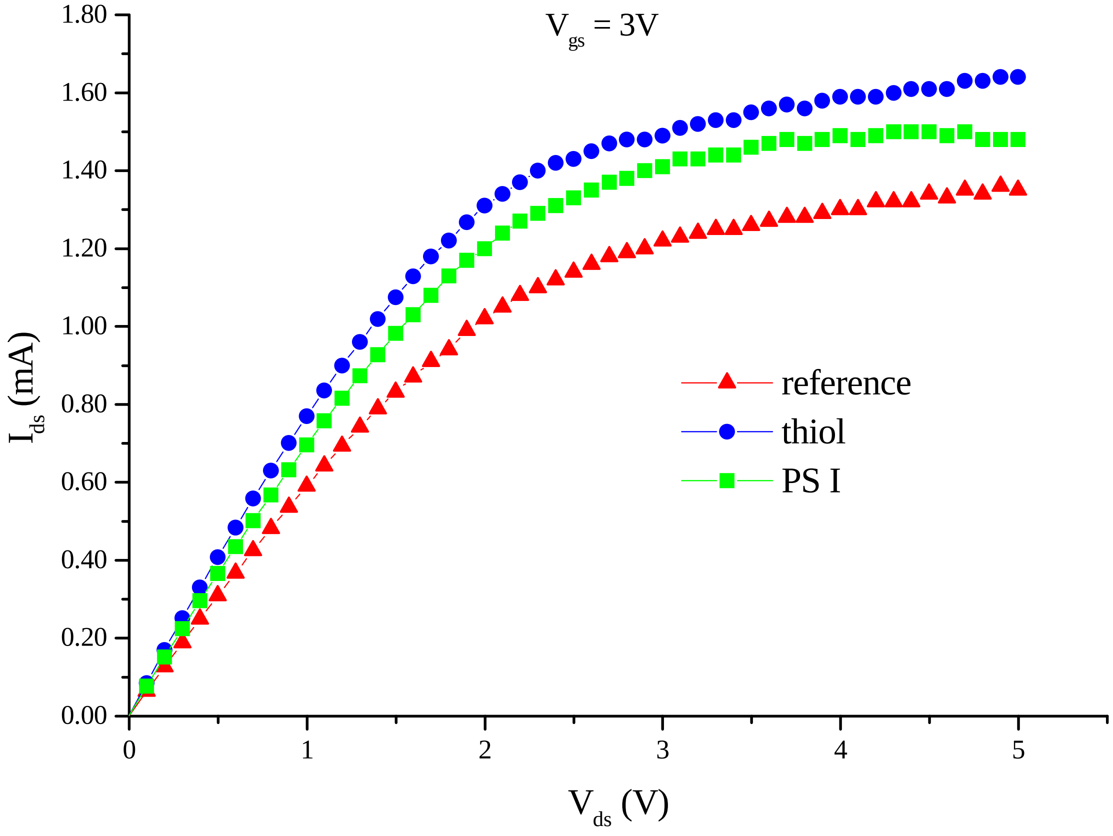


Fig. 5. Change in drain current due to SAM of thiol molecules and immobilization of PS I reaction centers.

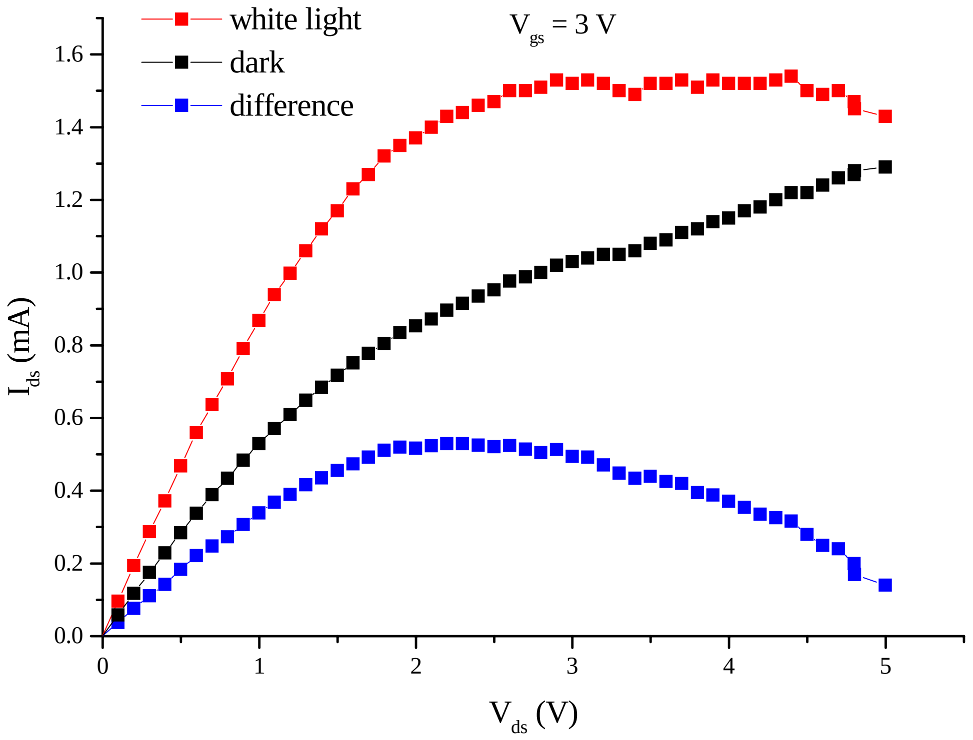


Fig. 6. Difference of MOS characteristics in white light and dark environment due to photochemical activity of immobilized PS I reaction centers .

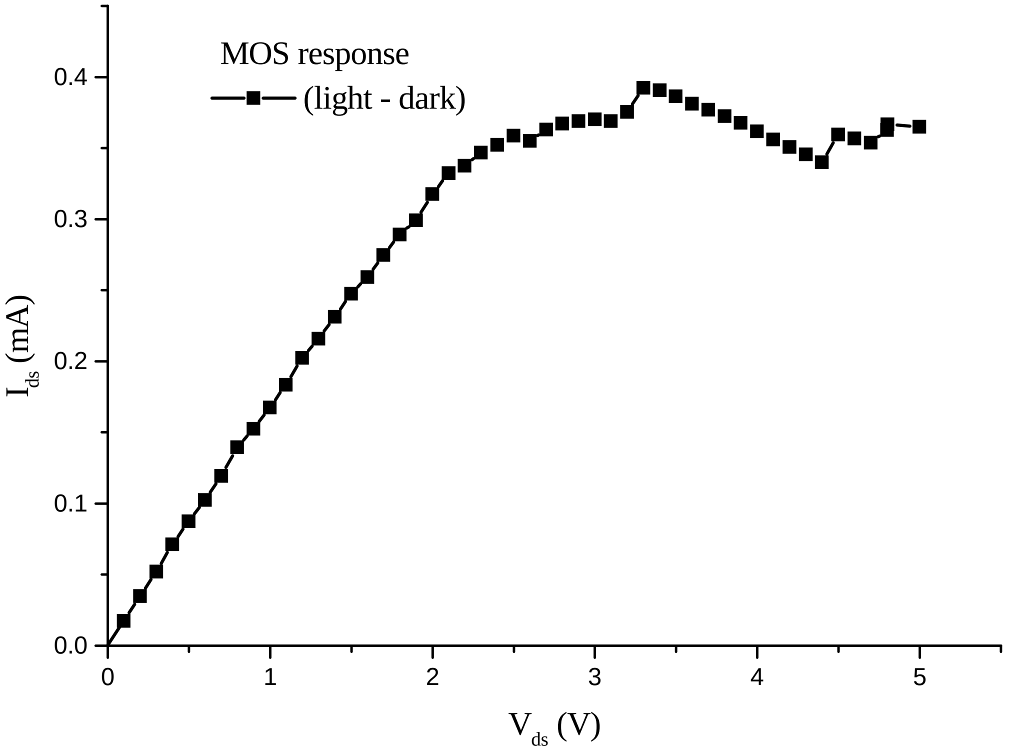


Fig. 7. MOS response in light and dark without any target molecules on gate.

Acknowledgements

We specially thank Miguel Rodriguez Jr. for extracting the PS I which was used in the experiment. We also like to extend our gratitude to Dr. V. P. Dravid of Northwestern University, Illinois for providing the cantilever embedded MOS transistors and J. W. Lee for providing Fig. 1.

References

[1]. I. Lee, J. W. Lee, A. Stubna, and E. Greenbaum, Measurement of Electrostatic Potentials above Oriented Single Photosynthetic Reaction Centers, *J. Phys. Chem. B*, Vol. 104, No. 11, Jan. 2000, pp. 2439- 2443.

[2]. S. A. Eliza, S. K. Islam, I. Lee, E. Greenbaum, M. A. Khan and M. N. Ericson, Detection of Photosystem I Reaction Centers using Chemically Derivatized High Electron Mobility Transistor, *Book of Abstracts, IEEE Sensors*, Oct. 2007, pp. 743-744.

[3]. S. A. Eliza, S. K. Islam, I. Lee, E. Greenbaum, Analysis of AlGaN/GaN HEMT Modulated by Photosystem I Reaction Centers, *International Semiconductor Device Research Symposium*, Dec. 2007.

[4]. A. Hamada, T. Furusawa, N. Saito, E. Takeda, A New Aspect of Mechanical Stress Effects in Scaled MOS Devices, *IEEE Trans. Electron Devices,* 38, Apr. 1991, pp. 895-890.

[5]. R. C. Jaeger, J. C. Suhling, R. Ramani, A. T. Bradley, J. P. Xu, CMOS Stress Sensors on (100) Silicon, *IEEE J. Solid-State Circuits,* 35, Jan. 2000, pp. 85-95.

[6]. T. Akiyama, U. Staufer, N. F. de Rooij, D. Lange, C. Hagleitner, O. Brand, H. Baltes, A. Tonin and H. R. Hidber, Integrated Atomic Force Microscopy Array Probe with Metal–Oxide–Semiconductor Field Effect Transistor Stress Sensor, Thermal Bimorph Actuator, and On-Chip Complementary Metal–Oxide–Semiconductor Electronics, *J. Vac. Sci. Technol.* B, 18, Nov. 2000, pp. 2669-2675.

[7]. G. Shekhawat, S.-H. Tark, V. P. Dravid, MOSFET-Embedded Microcantilevers for Measuring Deflection in Biomolecular Sensors, *Science*, 311, 11, Mar. 2006, pp. 1592-1595.

[8]. I. Lee, J. W. Lee, and E. Greenbaum, Biomolecular Electronics: Vectorial Arrays of Photosynthetic Reaction Centers, *Physical Rev. Lett.*, 79, 17, 1997, pp. 3294 – 3297.

2008 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(http://www.sensorsportal.com)

Sensors & Transducers Journal 2007 on CD

156.504
2007 e-Impact Factor

ISSN 1726-5479

12 Issues, 75-86 Volumes
+ Special Issue

Order online:
http://www.sensorsportal.com/HTML/DIGEST/Journal_CD_2007.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 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.

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:

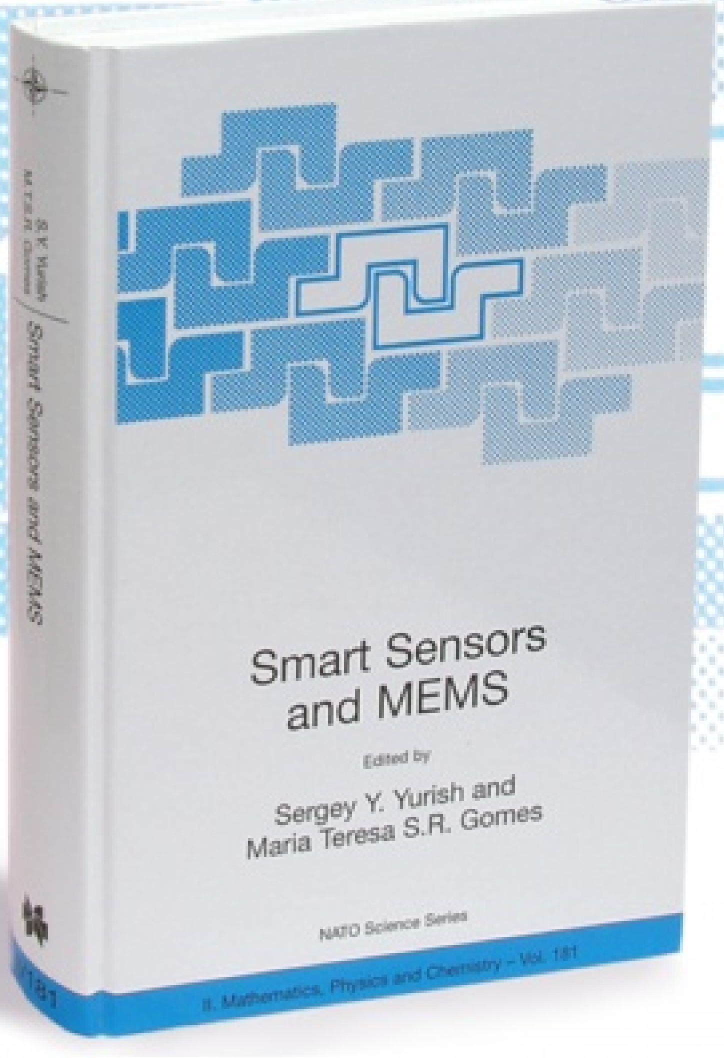
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors 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 6-14 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_2008.pdf



Smart Sensors and MEMS

Edited by

Sergey Y. Yurish and
Maria Teresa S.R. Gomes

The book provides an unique collection of contributions on latest achievements in sensors area and technologies that have made by eleven internationally recognized leading experts ...and gives an excellent opportunity to provide a systematic, in-depth treatment of the new and rapidly developing field of smart sensors and MEMS.

The volume is an excellent guide for practicing engineers, researchers and students interested in this crucial aspect of actual smart sensor design.

Kluwer Academic Publishers

Order online:
www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensors_and_MEMS.htm

www.sensorsportal.com