ISSN 1726-5479

SENSORS & TRANSDUCERS

12/10
vol. 123

Sensor Market Trends

International Frequency Sensor Association Publishing

Sensors & Transducers

Volume 123, Issue 12,
December 2010

www.sensorsportal.com

ISSN 1726-5479

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

Editors for Western Europe
Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Universitá di Brescia, Italy

Editor South America
Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe
Sachenko, Anatoly, Ternopil State Economic University, Ukraine

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

Editor for Asia
Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific
Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Nothern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Monitors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, 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
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic 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, Univ.of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcala, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
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
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA

Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
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
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S. National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shah, Kriyang, La Trobe University, Australia
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhbha Atomic Research Centre, Mumbai, India
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
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, 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

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

Sensors & Transducers Journal

Contents

Volume 123
Issue 12
December 2010

www.sensorsportal.com

ISSN 1726-5479

Research Articles

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).

IARIA

The Third International Conference on Bioinformatics, Biocomputational Systems and Biotechnologies

BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy

IFSA
www.sensorsportal.com

Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications
- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems
- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing
- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

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

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

IARIA

The Seventh International Conference on Networking and Services

ICNS 2011

May 22-27, 2011 - Venice, Italy

IFSA
www.sensorsportal.com

Important deadlines:

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

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

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

IARIA

The Sixth International Conference on Systems

ICONS 2011

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

IFSA
www.sensorsportal.com

Important deadlines:

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

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

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

Sensors & Transducers Journal, Vol. 123, Issue 12, December 2010, pp. 16-24

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Design of Piezoelectric PZT Cantilever for Actuator Application

[1]Abhay B. JOSHI, [2*]Dhananjay BODAS and [1]S. A. GANGAL
[1] Department of Electronic Science, University of Pune, Pune 411 007 India
[2] Agharkar Research Institute, GG Agarkar road, Pune 411 004 India
Tel.: +91-20-25695195, fax: +91-20-25695301
*E-mail: sag@electronics.unipune.ernet.in

Received: 14 October 2010 /Accepted: 21 December 2010 /Published: 28 December 2010

Abstract: Piezoelectric MEMS cantilever is used as a basic element in sensing and actuation. This paper proposes a structural design of MEMS cantilever for actuator application based on bulk MEMS micromachining technique. The structure consists of a silicon dioxide cantilever with an attached piezoelectric layer. The cantilever is designed using analytical modeling and simulation tool: CoventorWare2009. Analytical and simulation results demonstrate deflection of 5.9 µm/V and 2.9 µm/V respectively with a resonant frequency of 23 kHz. Obtained results are discussed and compared with the reported data. *Copyright © 2010 IFSA.*

Keywords: PZT, Actuators.

---

1. Introduction

Ferroelectric thin films show great potential in the application area of electronics and opto-electronics due to their piezoelectric and pyroelectric properties. In the piezoelectric materials, energy conversion from electrical to mechanical domain and vice-versa; offer potential application in the field of sensors and actuators. Incorporation of piezoelectric materials in the current fabrication technologies is possible due to recent advances in thin film deposition.

The range of piezoelectric materials like ZnO, AlN, polyimide, PVDF and PZT has been studied for their applications in MEMS field [1-3]. These materials, except PZT, have very low piezoelectric coefficient, thus their use is restricted in MEMS to certain extent. Many new materials like lead titanate (PT) lead zirconium titanate (PZT), lead magnesium niobate (PMN) etc. are the focus of interest worldwide. Lead zirconate titanate (PZT) is promising piezoelectric material having high piezoelectric coefficient which makes an attractive choice for MEMS application. Even though material like PMN has higher piezoelectric coefficient, these material cannot be made in thin film form. PZT thin film deposition adds extra advantage of being processed along existing fabrication technology for batch device fabrication and thus preferred over other piezoelectric materials.

Piezoelectric PZT thin films are extensively used in the field of MEMS sensors and actuators due to its high piezoelectric and dielectric properties. A successful demonstration of PZT cantilever for application area such as, SPM/AFM cantilevers tip [4], accelerometer [5], touch button [6], chemical sensor [7], energy harvesting device [8] and RF switch [9] is reported. PZT cantilever shows promising applications in bio-sensing and is demonstrated by antibody-antigen detection and microfluidics [10-11].

A fix-free cantilever structure is chosen due to the higher deflection obtained. In-depth knowledge of piezoelectric behavior and cantilever modeling in order to design and develop PZT cantilever in certain applications is essential. Many theoretical models have been reported to explain the piezoelectric behavior of ferroelectric materials [12] and for piezoelectric cantilever modeling [13].

Piezoelectric based actuator use electric field induced strain including longitudinal, transversal and shear derived by the piezoelectric coefficient d_{33}, d_{31} and d_{15} respectively. Depending upon the use of induced strain, two types such as d_{33} and d_{31} type PZT cantilevers are mainly used as shown in Fig. 1.1 and Fig. 1.2 respectively. The use of the shear coefficient for cantilever application adds trouble to fabricate devices and consequently not preferable.

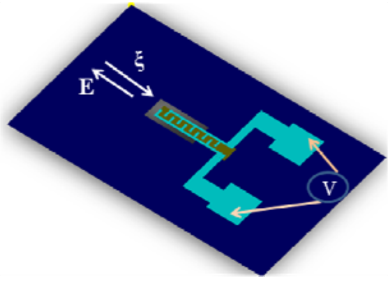


Fig 1.1. d_{33} type cantilever.

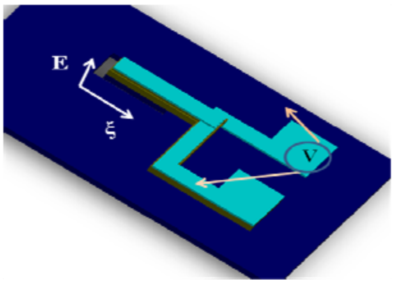


Fig 1.2. d_{31} type cantilever.

In d_{33} type cantilever (see Fig. 1.1), in-plane electric field (E) induces the in-plane strain (ξ) contracting or expanding the PZT material, resulting into bending. This is generally achieved by using two metal interdigited (IDT) electrodes on top of piezoelectric PZT thin film. In the second type (d_{31} type cantilever) (see Fig. 1.2), strain (ξ) is induced normal to the applied electric field (E). These induced strain, force PZT film to contract or expand and thus force cantilever to bend. This is generally achieved by sandwiching the piezoelectric PZT layer in two metal electrodes. In d_{33} type cantilever, PZT layer is partially covered by the metal IDT electrodes. PZT, not covered by metal electrodes suppress transverse displacement and generate stress concentration; which is undesired. In d_{31} type cantilever, as PZT layer is completely covered by the metal electrode, above mentioned problem is absent and thus d_{31} type cantilever based design is selected in this paper.

Cantilever displacement and resonating frequency is always a concern with the design. To achieve this, analytical modeling of PZT cantilever is presented in this paper. The piezoelectric PZT cantilever is modeled for actuation application using analytical calculations and its behavior is presented. Piezoelectric model is discussed on the basis of PZT crystal structure. The proposed design is simulated for applied electric field using finite element method (FEM) by 3D CoventorWare2009 software [14]. The analytical calculations are presented for cantilever deflection and resonant frequency. The design is simulated for cantilever deflection, stress generated on cantilever and resonant frequency. Analytical and simulation results are discussed and compared with the reported data. Finally, the process of PZT cantilever beam fabrication is discussed.

2. Modeling

PZT is a ferroelectric material which belongs to the ABO_3 perovskite materials group. Basic cubic unit cell of PZT material is shown in the Fig. 2.1. Atom A (Pb in PZT case), B (Ti/Zr) and O (oxygen) are located at the corner, body center and face center position respectively. It is seen from Fig. 2.1 that, Zr/Ti atom is at the center of cube and structural symmetry is maintained.

When voltage is applied to the piezoelectric structure, bonding between body centers Ti/Zr atom and face center oxygen (O) atom gets disturbed, which causes asymmetry in structure. This shifting of center (Ti/Zr atom) causes strain in the material as shown in Fig. 2.2. This induced strain is relaxed by causing expansion or contraction of the material leading to mechanical deflection of the structure. This mechanism is smartly used in the MEMS cantilever for actuation.

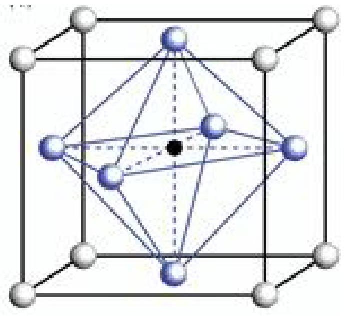


Fig 2.1. PZT structure. ABO_3.

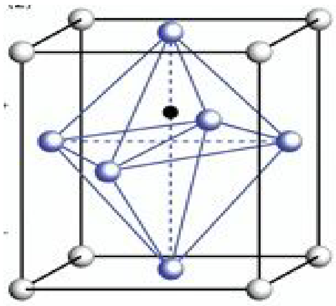


Fig 2.2. PZT structure after center Ti/Zr displacement.

Using this piezoelectric material property, d_{31} type PZT cantilever is proposed for actuation application. The proposed structure of PZT cantilever is as shown in Fig. 3. The structure consists of silicon dioxide (SiO_2) layer, used as a structural layer and PZT to convert electrical field in to mechanical displacement. Thin platinum (Pt) layer is used as an electrode material on both sides of the PZT thin film. The PZT cantilever is realized using silicon bulk micromachining (KOH) by forming v-groove. This technology was earlier used for fabrication of SiO_2 cantilevers and can be used to fabricate PZT cantilever too [15].

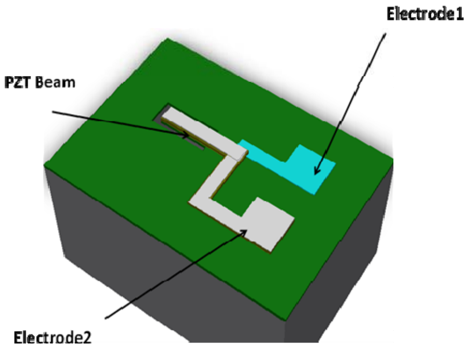


Fig. 3. PZT beam structure.

2.1. Analytical Design

Applied electric field to piezoelectric film induces strain in the material, disturbing the structural geometry and forces to deflect. The relation between applied electric field (E) and electric displacement (D) is given by:

$$D = \varepsilon_o \varepsilon_r E + dT \ , \tag{1}$$

where d is the piezoelectric coefficient; T is the stress and E is the relative dielectric permittivity.

The piezoelectric beam tip deflection in terms of physical dimensions of PZT cantilever is given:

$$d = \frac{l^3 d_{31}\left(\frac{V}{t_p}\right)(t_p + t_e)A_e E_e A_p E_p}{4(A_e E_e + A_p E_p)(E_p I_p + E_e I_e) + (t_e + t_p)^2 A_e E_e A_p E_p} \ , \tag{2}$$

where V is the applied voltage; A_i is the area of layer i; I_i is the moment of inertia of layer; d_{31} is the piezoelectric constant; E_i is the Young's modules; d is the tip displacement; t_i is the layer thickness; e stands for elastic layer (SiO_2) and p stands for piezoelectric (PZT) [16].

In addition to cantilever deflection, the natural resonance frequency of a two layer cantilever structure fixed on one end was calculated [12]

$$f = \frac{(1{,}875)^2}{2\pi L^2}\sqrt{\frac{(EI)}{w(\rho_e h_e + \rho_p h_p)}} \ , \tag{3}$$

where

$$(EI) = \frac{w}{12} * \frac{(E_e h_e + E_p h_p)}{E_e^2 h_e^4 + E_p^2 h_p^4 + E_e E_p h_e h_p (4h_e^2 + 6h_e h_p + 4h_p^2)} \tag{4}$$

In these equations, *E* is the Young's modulus, *I* the moment of inertia, *h* the layer thickness, w is the width; *L* is the length of the cantilever and ***p*** the density respectively. Suffix e stands for elastic layer (SiO_2) and p stands for piezoelectric (PZT). For the calculation, layer widths of silicon dioxide and PZT were kept equal. Therefore, the resonance frequency is independent of the cantilever width.

In proposed work, PZT layer is used as a piezoelectric and SiO_2 as the supporting layer. The material properties used in analytical calculation are shown in Table 1.

Table 1. Material property used for analytical modeling.

	Young's modulus	**Piezoelectric coefficient (d_{31})**	**Thickness (t)**	**Width (w)**	**density**
PZT	70 Gpas	171	0.6μm	60 μm	7.55 (g/cm^2)
SiO_2	70 Gpas	-	0.85 μm	60 μm	2.3 (g/cm^2)

Using equation (2) and material properties (see Table 1), the cantilever deflection was calculated for applied voltage of 1-10V for cantilever dimensions l = 200 μm, w = 60 μm and t= 0.6 μm.

3. Simulation

The proposed PZT cantilever structure was simulated using CoventorWare2009 simulation tool. MEMMECH and CoSolve modules were used to find to out the cantilever displacement in accord with applied voltage and its resonating frequency. In this paper, as PZT cantilever is proposed for application in RF MEMS structure; where up bending model is required thus simulation results for only up bending are presented.

3.1. Physical Structure Optimization

For simulation of PZT based cantilever, optimization of physical dimensions was done by considering effect of various length, width and the fabrication parameters. Cantilever deflection behavior was studied by simulating PZT cantilever for various length and width by applying fixed voltage of 1 V. Effect of variation in cantilever length and width on PZT cantilever up bending is illustrated in Fig. 4. It could be seen from the figure that, cantilever deflection increases linearly with increase in the cantilever length. The deflection varies from 265 nm for 50 µm to 7.99 µm for 400 µm long cantilevers. This trend is in good agreement with PZT cantilever modeling; as beam deflection is proportional to the cube of cantilever length (l^3). An increase in length tends to decrease the resonant frequency of cantilever. Longer PZT cantilever are subjected to more curling during the fabrication process. Minimum tip deflection of 3 µm is expected in the design at an applied voltage of 1 V and thus cantilever length was restricted to 200 µm.

The variation in cantilever width is shown in curve (b) of Fig. 4. From this figure, it could be seen that, deflection of the cantilever was less sensitive to the width. The cantilever deflection changed from 2.8 µm for 15 µm wide beam to 3.19 µm for 120 µm width. In the cantilever fabrication process, wider cantilever will need longer processing time to realize in silicon bulk micromachining, and low width cantilever add extra burden in optimization of two Pt electrode contact pads. Thus, PZT cantilever width was optimized to 60 µm in the present work. Considering the PZT processing steps, fabrication difficulties, PZT thin film cracking problem and required piezoelectric response, PZT thickness was optimized to 600 nm.

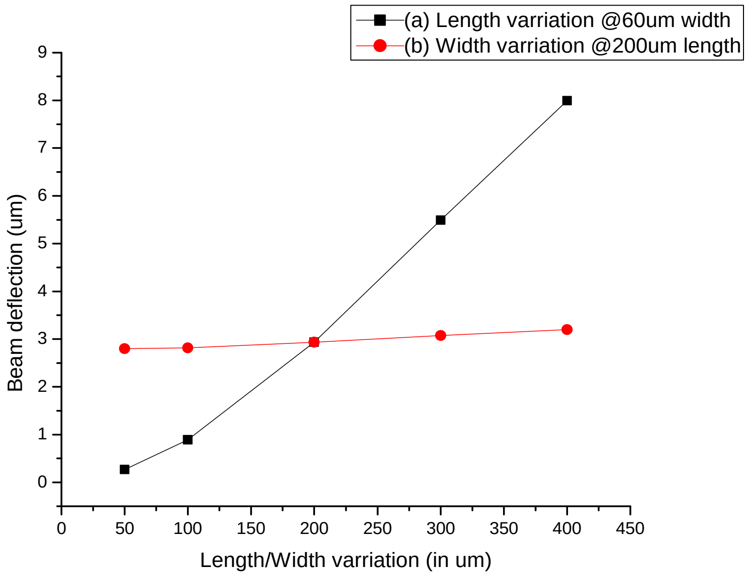


Fig. 4. Effect of cantilever length and width variation on beam deflection.

3.2. Deflection Due to Applied Voltage

Piezoelectric actuator response of the PZT cantilever was simulated by applying voltage to top and bottom electrodes and measuring deflection. From the simulated up bended model of PZT cantilever (see Fig. 5) one could derive that the deflection is higher at free end of the cantilever and zero deflection at the fixed end. Simulation and analytical calculation were carried down for up deflection of beam in accordance with the applied voltage range of 1-10 V.

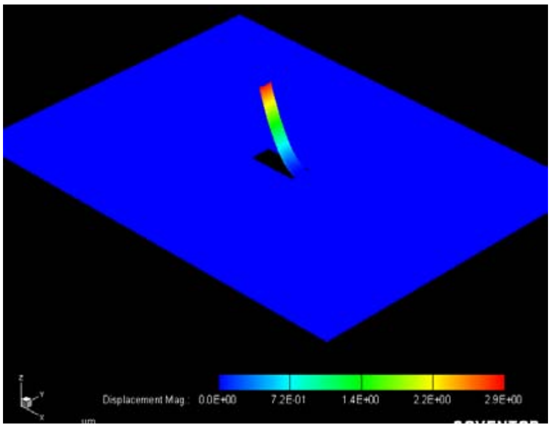


Fig. 5. PZT cantilever up deflection.

Obtained simulated and analytical results are plotted as shown in the Fig. 6. It could be observed that there is linear variation of tip deflection with respect to applied voltage. In analytical design, tip deflection was 5.9 µm for 1 V applied, while maximum deflection of 59.4 µm was observed for applied voltage of 10 V. Whereas CoventorWare simulation result shows that the PZT beam deflected for 2.9 µm for applied voltage of 1V and maximum deflection of 26.4 µm achieved for applied voltage of 10 V. This difference in analytical calculation and simulation results is attributed to increased structure thickness in simulation. In simulation two platinum layers of 150 nm were used as the electrodes. These layers increase the PZT beam stiffness and stiffer beam tends to deflect less.

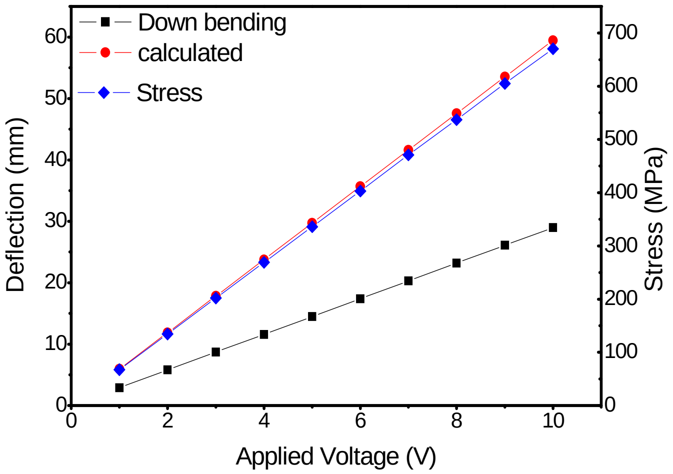


Fig. 6. PZT beam deflection and stress variation against applied voltage.

Stress developed on PZT cantilever during up bending is in accordance with the applied voltage of 1-10 V (Fig. 6). Stress appeared on beam was 67 MPa for deflection of 2.9 µm, which increase up to 670 MPa for the deflection of 26.4 µm. The observed stress variation was linear with respect to up bending of the cantilever. As this design is proposed to actuate in 3-10 µm range, the stress generated was 67-201 MPa.

Fig. 7 shows stress concentration along the PZT cantilever. It could be derived that, generated stress was concentrated at the fixed end. In case of PZT cantilever, when beam is deflected to 2.9 µm deflection, the maximum stress of 67 MPa was at fixed end and 50 MPa was along the cantilever. This generated stress value is lower than the fracture limit of cantilever and thus this design is reliable for actuation application.

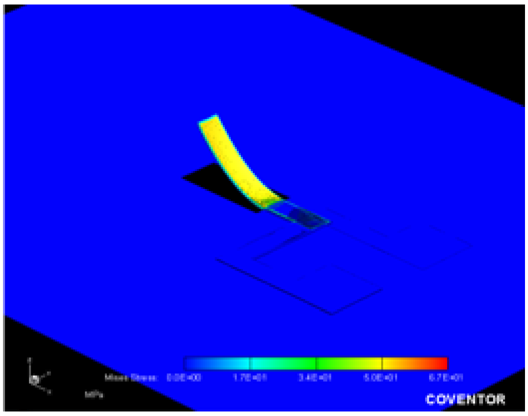


Fig. 7. Stress concentration on PZT cantilever.

In analytical design, if beam length changes to 500 µm, then the calculated deflection was 37 µm, which closely matches with the reported value of 34.7 µm [12]. Analytical calculations are in accord with the reported deflection values of 3 µm for 4 V [9]. The proposed structure deflects for 5.9 µm for 1 V, which is best suitable for application in RF MEMS switches.

Analytically calculated resonant frequency of the structure was 22.15 KHz and that obtained from simulations using CoSolve simulator was 23 KHz. The lower value of resonating frequency is appreciated for small signal application along with lower actuation voltage [12]. The resonant frequency can be further lower down by increasing PZT layer thickness, with appropriate fabrication process consideration. These result shows that the proposed design with deflection of 2.9 µm/V and resonating frequency of 23 KHz is well suited for small signal application and also for RF MEMS switch application.

4. Fabrication Flow

The proposed PZT cantilevers fabrication needs less fabrication time and reduce the use of critical process like deep reactive ion etching (DRIE) or use of very good masking materials like silicon nitride (Si_3N_4) [8] and polymers masking material like polyvinyl difluoride (PVdF)/polytetrafluoro ethylene (PTFE) [17].

PZT based cantilever fabrication flow is proposed using silicon bulk micromachining. Starting with n type <100> silicon wafer, silicon dioxide layer of 800 nm is grown using thermal oxidation (Fig. 8.a). The oxide layer is patterned in order to expose underneath silicon material to etchant (Fig. 8.b). The

150 nm Pt layer is then sputter deposited and patterned to serve as a bottom electrode (Fig. 8.c). The titanium layer is used as adhesive layer prior to deposition of Pt layer. The 600 nm thin PZT is deposited on Pt surface using single target RF magnetron sputtering system. The sputtered PZT layer is patterned and annealed to obtain perovskite phase (Fig. 8.d). The 150 nm Pt layer is sputtered on PZT surface and patterned to serve as top electrode (Fig. 8.e). Finally the PZT cantilever is released using silicon bulk micromaching using KOH solution. The released PZT cantilever is shown in Fig. 8.f and close view of released PZT cantilever is shown in Fig. 8.g.

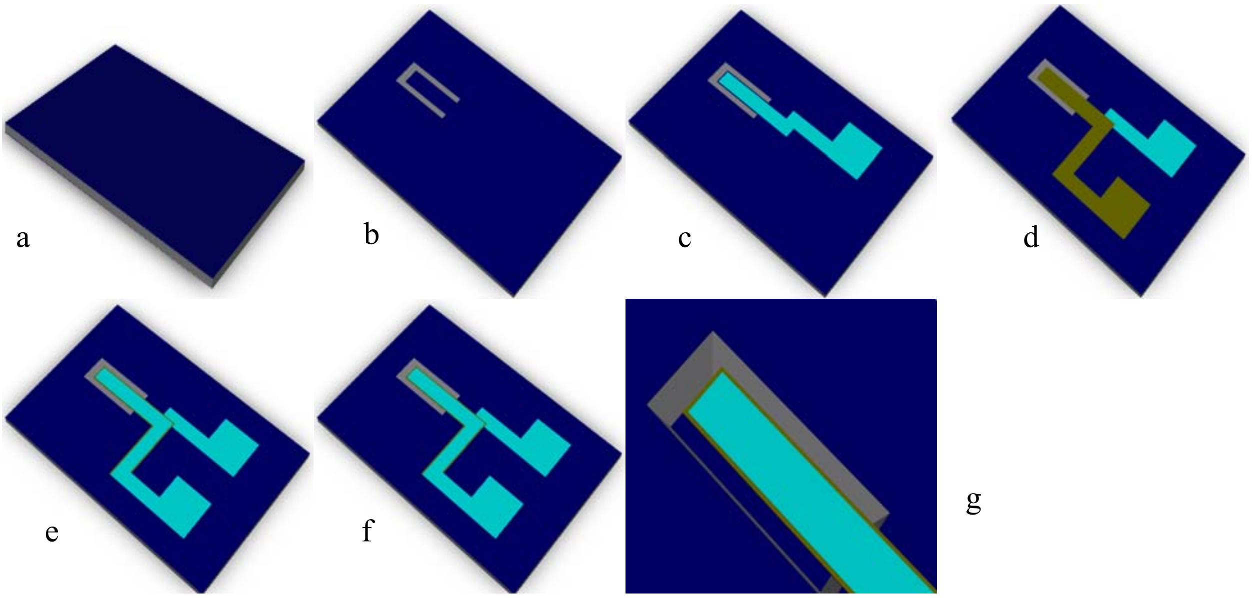


Fig. 8 (a-g). Fabrication flow of PZT based cantilever.

5. Conclusion

Piezoelectric PZT beam device is proposed for the actuation application. The proposed device shows deflection value of 5.9 µm/V and simulated results show deflection of 2.9 µm/V. The difference in yield is due to increase in stiffness of PZT cantilever with two Pt electrodes. Analytically calculated resonant frequency of the device is 22.1 kHz. The resonant frequency of the device is 23 kHz which is suitable for small signal application. Proposed device offers an easy fabrication method and is ideally suitable for low actuation voltage application as well as small signal application.

Acknowledgment

Authors are thankful to NPMASS, Government of India for funding of CoventorWare facility. Abhay Joshi is thankful to Department of Science and Technology (DST), Govt of India for financial support.

References

[1]. S. T. Mckinstry, P. Muralt, Thin Film Piezoelectric for MEMS, *Electroceramics*, Vol. 12, 2004, pp. 7–17.
[2]. Eiichi Fukada, History and Recent Progress in Piezoelectric Polymers, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 47, Issue 6, Nov 2000, pp. 1277-1290.

[3]. G. M. Atkinson, R. E. Pearsod, Z. Ounaiesb, C. Park, J. S. Harrisond, S. Dogan, and J. A Midkiffl, Novel piezoelectric polyimide MEMS, in Proc. *the l2*^{lth} *International Conference on Solid Slate Sensors, Actuators and Microsystems.* Boston, June 2003, pp. 8-12.

[4]. C. S. Lee, H. J. Nam, Y. S. Kim, W. H. Jin and J. U. Bu, PZT Cantilevers Integrated with Heaters and New Piezoelectric Sensors for SPM-Based Nano-Data Storage Application, *J. of the Korean Phys. Soc.,* Vol. 45, Issue 1, 2004, pp. 227-230.

[5]. D. L. DeVoe, A. P. Pisano, Surface Micromachined Piezoelectric Accelerometers (PiXLs), *Journal of MEMS*, Vol. 10, Issue 2, 2001, pp. 180-86.

[6]. Raditron web page (http://www.radiotron.com).

[7]. W. Zhou, A. Khaliq, Y. Tang, Haifeng Ji, R. R. Selmic, -Simulation and design of piezoelectric microcantilever chemical sensors, *Sens. and Actu. A,* Vol. 125, 2005, pp. 69-75.

[8]. W. J. Choi, Y. Jeon, J.-H. Jeong, R. Sood, S. G. Kim, Energy harvesting MEMS device based on thin film piezoelectric cantilevers, *J Electroceramic,* Vol. 17, 2006, pp. 543–548.

[9]. H. C. Lee, J. Y. Park, K. H. Lee, H. J. Nam, J. U. Bu, Silicon Bulk Micromachined RF MEMS Switches with 3.5 Volts Operation by using Piezoelectric Actuator, *2004 IEEE MTT- S,* Digest, pp. 258-88.

[10]G. Y. Kang, G. Y. Han, J. Y. Kang, Il-H. Cho, H. Park, S. Paek, T. S. Kim, Label-free protein assay with site-directly immobilized antibody using self-actuating PZT cantilever, *Sens. and Actu. B,* Vol. 117, 2006, pp. 332-338.

[11].I.-H. Hwang, J. H. Lee, Self-actuating biosensor using a piezoelectric cantilever and its optimization, *Phys.: Conference Series,* 34, 2006, pp. 362–367.

[12].M. Hoffmann, H. Kiippers, T. Schneller: U. Bottger, U. Schnakenberg, W. Mokwa, R. Waser, Theoretical Calculations and Performance Results of a PZT Thin Film Actuator, *IEEE Transaction on Ultrasonic and Ferroelectric and Frequency Control,* Vol. 50, Issue 10, 2003, pp. 1240-1246.

[13].M. S. Weinberg, Working Equations for Piezoelectric Actuators and Sensors, *MEMS,* Vol. 8, Issue 4, 1999, pp. 529-533.

[14].Coventor web page (http://www.convetor.com).

[15].Marc J. Madue, Fundamental of Microfabrication, Second edition, *CRC Press*, 2006.

[16].Chang Lue, Foundation of MEMS, *Pearson*, 2002.

[17].P. Gaucher, D. Eichner, J. Hector, W. Von Munch Piezoelectric bimorph cantilever for actuating and sensing applications, *J. Phys. IV,* Vol. 8, 1998, pp. 235-238.

IARIA

The Second International Conference on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France

IFSA
www.sensorsportal.com

Important deadlines:

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

Tracks:
- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- Sensor device technologies
- Sensors signal conditioning and interfacing circuits
- Medical devices and sensors applications
- Sensors domain-oriented devices, technologies, and applications
- Sensor-based localization and tracking technologies

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

IARIA

The Fifth International Conference on Sensor Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France

IFSA
www.sensorsportal.com

Important deadlines:

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

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

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

IARIA

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

CENICS 2011

August 21-27, 2011 - French Riviera, France

IFSA
www.sensorsportal.com

Important deadlines:

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

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

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

Guide for Contributors

Aims and Scope

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

Topics Covered

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

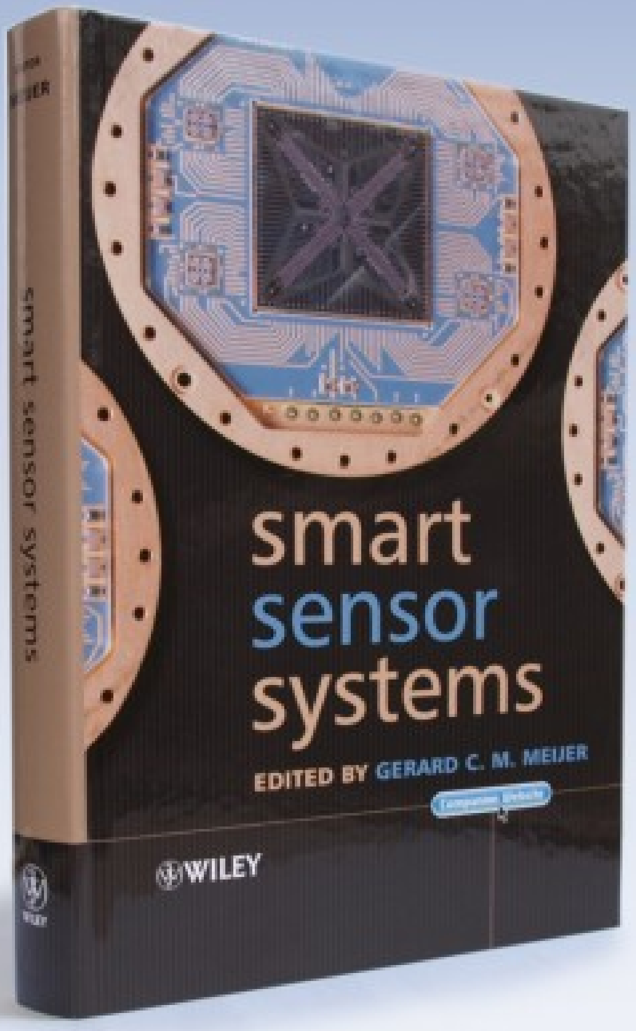
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors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

Submission of papers

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

Advertising Information

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


smart
sensor
systems
EDITED BY GERARD C. M. MEIJER
WILEY
smart sensor systems
MEIJER


UTI03
A99A
UTI03
A99C