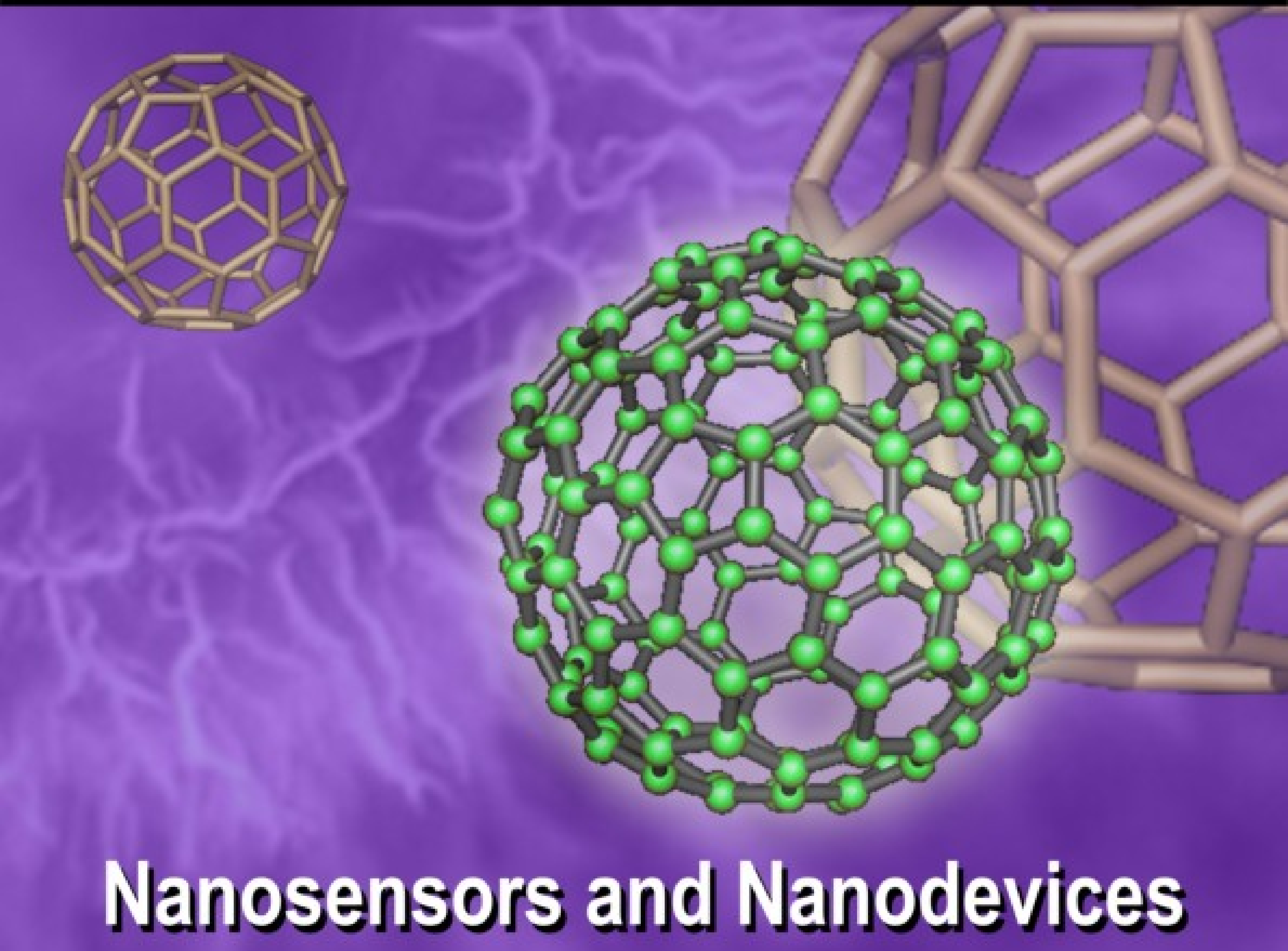
ISSN 1726-5479

SENSORS & TRANSDUCERS

11 vol. 110 /09



Nanosensors and Nanodevices

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 110, Issue 11
November 2009

www.sensorsportal.com

ISSN 1726-5479

Editors-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, Vittorio, Universitá di Brescia, Italy

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

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

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

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

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

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Nothern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Monitors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, VIT University, Tamil Nadu, India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Universite de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevich, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ.of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcala, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia

Kim, Min Young, Kyungpook National University, 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, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S. National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
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 Univ. of Radio Electronics, Ukraine
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
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, 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 Univ. of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufera Garcia, Alberto, Seville University, Spain
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 © 2009 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

Volume 110
Issue 11
November 2009

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).

Sensors & Transducers Journal, Vol. 110, Issue 11, November 2009, pp. 56-70

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Design, Modeling and Optimization of a Piezoelectric Pressure Sensor based on a Thin-Film PZT Membrane Containing Nanocrystalline Powders

Vahid MOHAMMADI, Mohammad Hossein SHEIKHI
Department of Electrical Engineering, Shiraz University, Shiraz 71344, I.R. Iran
Nanotechnology Research institute, Shiraz University, Shiraz 71344, I.R. Iran
Tel.: +98-915-5084492
E-mail: mohammadi.vm@gmail.com

Received: 1 July 2009 /Accepted: 24 November 2009 /Published: 30 November 2009

Abstract: In this paper fabrication of a 0-3 ceramic/ceramic composite lead zirconate titanate, $Pb(Zr_{0.52}Ti_{0.48})O_3$ thin film has been presented and then a pressure sensor based on multilayer thin-film PZT diaphragm contain of Lead Zirconate Titanate nanocrystalline powders was designed, modeled and optimized. Dynamics characteristics of this multilayer diaphragm have been investigated by ANSYS® FE software. By this simulation the effective parameters of the multilayer PZT diaphragm for improving the performance of a pressure sensor in different ranges of pressure are optimized. The optimized thickness ratio of PZT layer to SiO_2 was given in the paper to obtain the maximum deflection of the multilayer thin-film PZT diaphragm. A 0-3 ceramic/ceramic composite lead zirconate titanate, $Pb(Zr_{0.52}Ti_{0.48})O_3$ film has been developed to fabricate the pressure sensor by a hybrid sol gel process. PZT nanopowders fabricated via conventional sol gel method and uniformly dispersed in PZT precursor solution by an attrition mill. XRD analysis shows that perovskite structure would be formed due to the presence of a significant amount of ceramic nanopowders. This texture has a good effect on piezoelectric properties of perovskite structure. The film forms a strongly bonded network and less shrinkage occurs, so the films do not crack during process. Also the aspect ratio through this process would be increased. SEM micrographs indicated that PZT films were uniform, crack free and have a composite microstructure and a piezoelectric coefficient d_{31} of -40 $pC.N^{-1}$ and d_{33} ranged from $50pm.N^{-1}$ to $60pm.N^{-1}$. *Copyright © 2009 IFSA.*

Keywords: MEMS pressure sensor, Finite element method, ANSYS®, Lead zirconate titanate (PZT), Sol-gel method

---

1. Introduction

During recent years, the study of micro electromechanical system (MEMS) has shown significant opportunities for microsensors and microactuators based on various physical mechanisms such as piezoresistive, capacitive, piezoelectric, magnetic, and electrostatic. Compared to other MEMS technologies, piezoelectric MEMS offer many advantages [1]. Piezoelectric thin films present a great interest for microsystems thanks to their reversible effect [2]. Combining micromachined silicon membranes with piezoelectric thin films has resulted in novel micro-devices such as motors [3], accelerometers [4], pressure sensors [5], micro pumps [6], actuators [7] or acoustic resonators [8]. Many works have been presented on the MEMS pressure sensors which have been developed in the 1970's [9]. Ravariu et al. modeled a pressure sensor designed to the compute blood pressure and they made use of the ANSYS simulation in order to estimate the mechanical stress in the structure [10]. Zinck et al. presented the fabrication and characterization of silicon membranes actuated by thin piezoelectric films [11]. Liu et al. designed two novel piezoelectric microcantilevers with two piezoelectric elements (bimorph or two segments of PZT films) and three electric electrodes [1].

In this work, we present the fabrication and characterization of square membranes of Si/SiO_2/Ti/Pt/PZT/Au, and design, modeling and optimization of a multilayer thin-film PZT diaphragm contain of Lead Zirconate Titanate nanocrystalline powders used in pressure sensor is presented by means of ANSYS finite element (FE) software. The finite element method is a technique in which a given domain is represented as a collection of simple domains, called finite elements, so that it is possible to systematically construct the approximation functions needed in a variation or weighted-residual approximation of the solution of a problem over each element. We considered the structure shown in Fig. 1 for the sensor. In previous works only the membrane has been considered for simulation but at this work all the layers were taken into account in simulation by ANSYS/Multiphysics program. The simulation results can be used for studying of the characteristics and structural behaviors of this pressure sensor. Finally effective parameters for improving the performance of a pressure sensor in different ranges of pressure have been optimized.

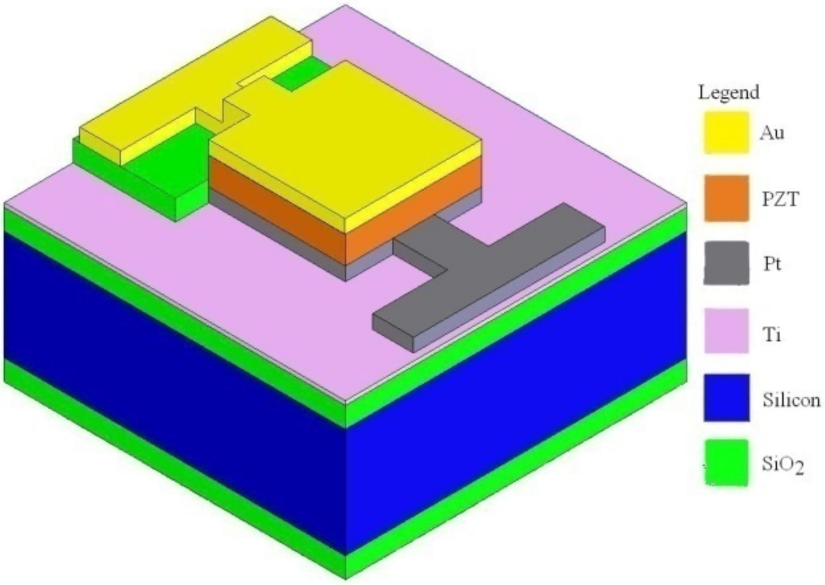


Fig. 1. Structure of the multilayer PZT diaphragm.

2. Fabrication of PZT Thin Film Layer Contain Nanopowders

The integration of $Pb(Zr,Ti)O_3$ thin films (PZT) on silicon substrates is of great interest to produce DRAM memories and piezoelectric microsystems such as membrane base sensors and actuators. Different technologies have been reported to deposit thin PZT films: MOCVD, sol-gel, laser-ablation, sputtering. Among them the sol–gel technique is the most popular because of its low cost and ease of fabrication for the PZT system [12]. In this paper fabrication of PZT thin film layer contain nanopowders is presented.

2.1. PZT Solution Preparation

The first step is the dissolution of appropriate of lead acetate trihydrate in 2-methoxyethanol solvent at 120 °C for 30 minutes. Pb is added at a composition of approximately 10 mol% more than required by stoichiometry to compensate the PbO loss during high temperature annealing. This solution was vacuum distilled until a white paste with enough moisture begins to form. In a separate flask, Zr n-propoxide and Ti isopropoxide were added drop by drop into 2-MOE and stirred at room temperature for 1 hour. While Zr and Ti mixture solution was stirring, acetylacetone as a chelating agent was added to the solution for further stabilizing. Zr/Ti mixture solution is then added to the flask with paste-like Pb lumps. It then refluxed for improved homogeneity and vacuum distilled to eliminate the byproducts and water molecules from reaction. Final solution was filtered using 0.2 µm filter paper to minimize the incorporation of particles and dust during solution preparation.

2.2. Preparation of PZT Nanocrystalline Powders

In the present study PZT powders derived from the same solution that had been prepared for film deposition. Because compare to the conventional solid state method, fabrication of powder via sol-gel method has the advantages of simple composition control, high reactivity, lower synthesis temperature, high purity, etc. Then, the solution placed in the oven at 120 °C overnight. After drying, calcination performed at 650 °C for 2 hours.

2.3. Slurry Preparation and Film Deposition

A sol-gel method combined with PZT powder will be useful for thick film deposition. During the sintering process, atomic diffusion in the PZT powder grain occurs to minimize the surface energy, which promotes crystal bonding at the interface between two adjacent particles. The added sol will increase the driving force of the system due to the presence of nanoscale particles and so lower the required sintering temperature. In addition, the sol will also function as glue, binding the larger particles together and to the substrate. Nanocrystalline PZT powder which has particle size in order of 0.8 µm dispersed in sol solution through an attrition mill to reduce the size of powders. Also 1 wt% of a phosphate ester based dispersant was added to get uniform and stable slurry for film deposition. The mass ratio of powder to sol solution fixed at 1:2. In the case of the composite sol-gel route, each microsize PZT grain will act as a site for crystallization.

The film will easily crack if the concentration is higher. However, each layer of the film will become much thinner if the concentration is lower. The resulting solution was finally spin coated onto a substrate at 3000 rpm for 30s, dried at 150 °C for 10 min, fired at 380 °C for 15 min and annealed at 650°C for 30 min. The spinning/drying/themolysis procedures were repeated until desired thickness achieved. The resulting coating is essentially a 0-3 ceramic/ceramic composite because the sol gel matrix is connected in all 3 directions and the PZT powder is not connected in any 0 directions. Since the sol gel solution and powders are the same materials, the resulting coating will have properties that compare to that of the bulk material. The overall flow chart for the fabrication of PZT 0-3 ceramic/ceramic composite film is shown in Fig. 2.

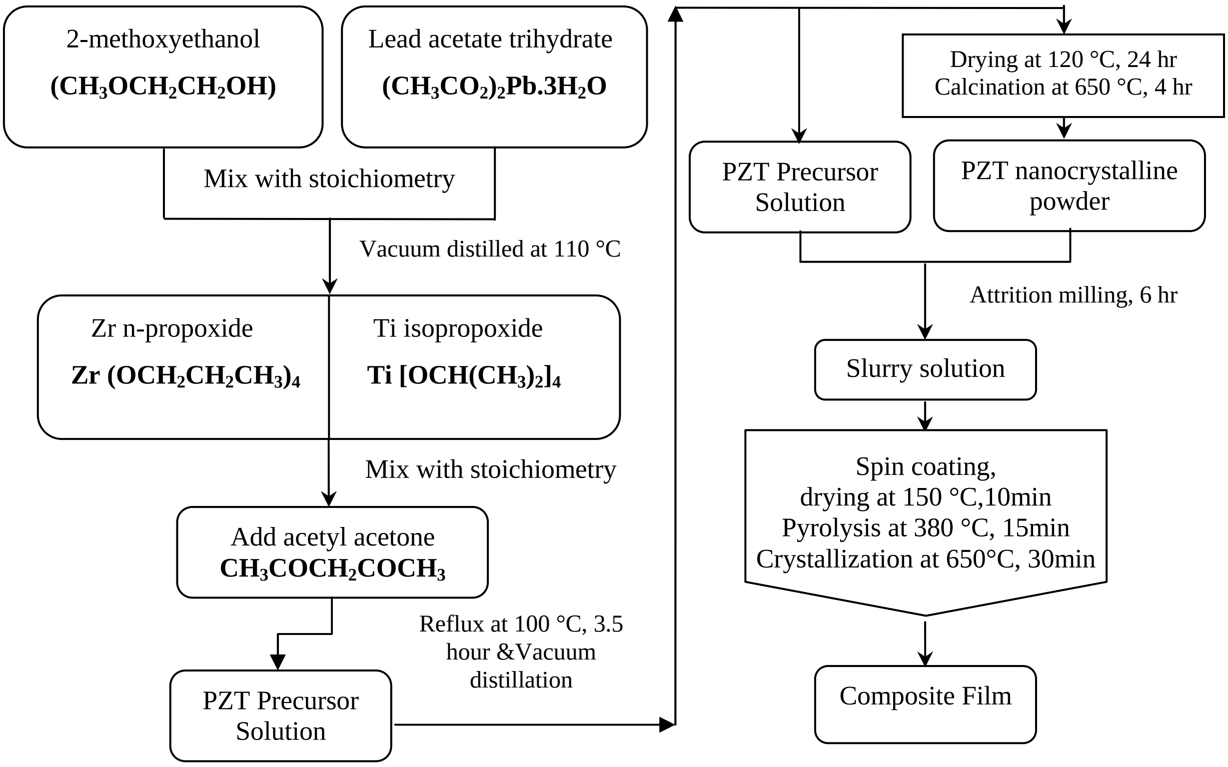


Fig. 2. Flowchart of preparation PZT composite layer.

2.4. Results and Discussions

XRD results are shown in Fig. 3. Pattern of powders shows a random orientation, rhombohedral phase of PZT. Film deposited on amorphous glass could not form any crystalline phase. But layers with powders show the main peaks of perovskite structure and have a piezoelectric coefficient d_{31} of -40 $pC.N^{-1}$ and d_{33} ranged from 50 $pm.N^{-1}$ to 60 $pm.N^{-1}$.

In Fig. 4 the result of particle size analyzing is indicated. The powders from sol gel process are agglomerated and in range of 0.8 µm. When these powders undergo attrition milling and some dispersant inserted to system, the size of particles reduces and after 6 hour stable slurry will obtain. Increasing the time of milling has opposite effect and the particles become larger. This condition could attribute to increasing the temperature and reagglomaration of particles. The average size of powders is 280 nm.

Optical microscopic pictures of samples are shown in Fig. 5. By increasing the amount of powder, the probability of crack existence in the film becomes smaller. This fact relates to formation of a strongly bonded network between sol gel film and ceramic particles. On the other hands less shrinkage in the films occurs due to the presence of powders and diminution of the percentage of sol gel in the film. However, the amount of powder greater than 50 % leads to rough microstructure and porous films. The individual thickness of each layer can be increased through this technique and ferroelectric properties affected by this special microstructure.

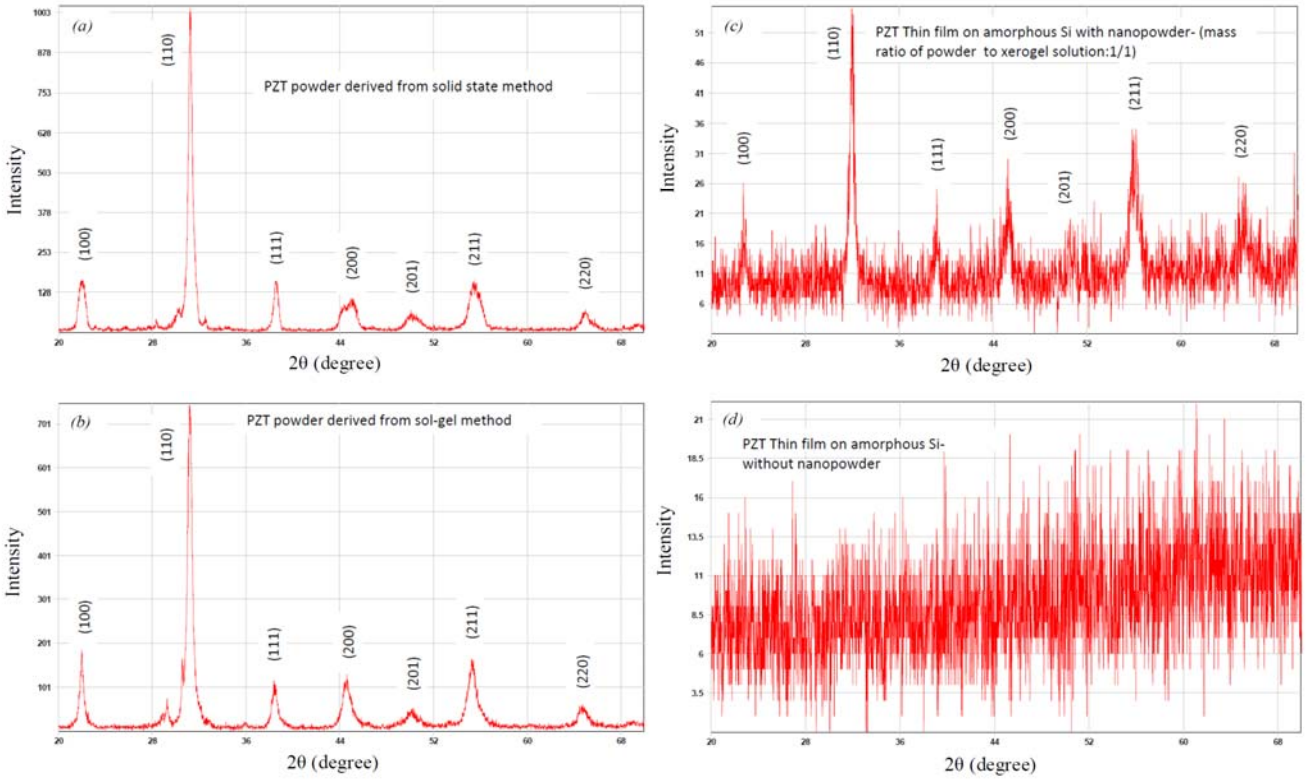


Fig. 3. XRD patterns of: (a) PZT powder derived from solid state method, (b) PZT powder derived from sol-gel method, (c) PZT Thin film on amorphous Si with nanopowder, (c) PZT Thin film on amorphous Si without nanopowders.

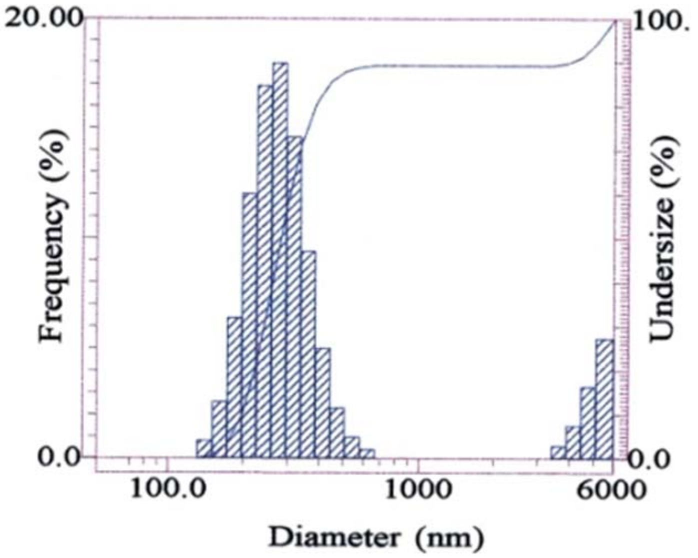


Fig. 4. Particle size analyzing of a nanopowders.

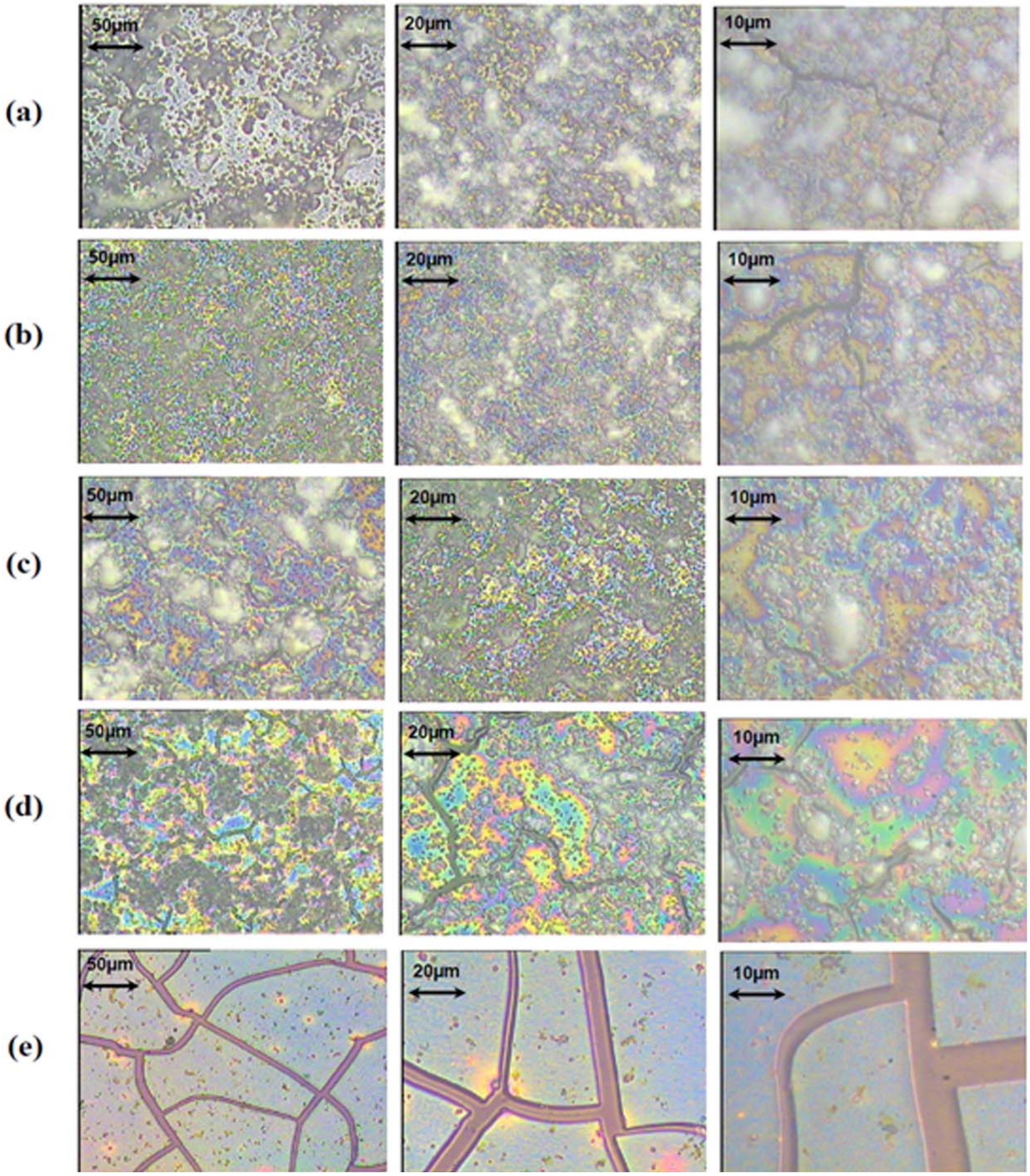
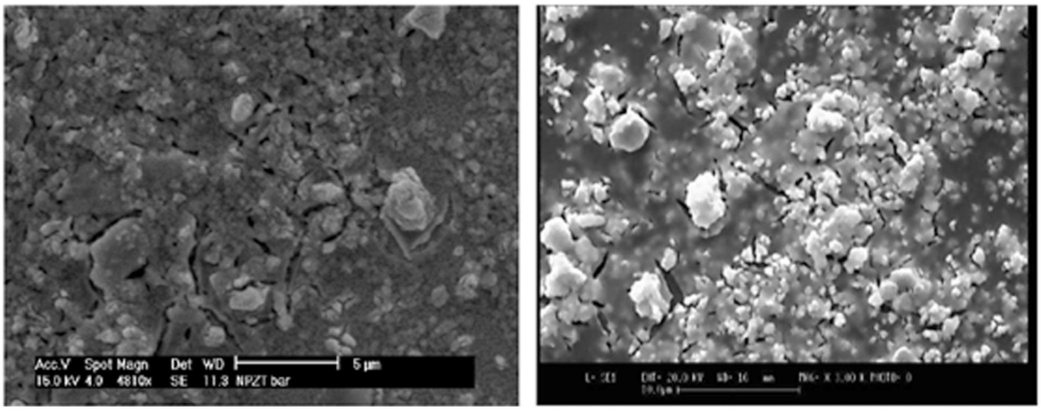


Fig. 5. Optical microscopic pictures. Mass ratio of powder to sol is (a) $^{1}/_{1}$,(b) ¾ ,(c) ½ ,(d) ¼ , (e) without powder.

In Fig. 6 SEM micrographs of films are shown. We can observe two kinds of grain in the films. One has irregular shape and larger grain size in order of 400-700 nm; another one is granular and has a smaller grain size below 300 nm. Particle loaded in slurry might be origin of the irregular shape and nucleation and growth in the sol solution forms the smaller grains group. Thus a composite island structure formed where the granular grains surrounding larger grains. This kind of microstructure will meet the requirement of both mechanical and electrical properties. From the morphologies, one can see that high density is achieved except few pinholes. However, microcracks with the length of microns distribute uniformly in the surface. This can be prevented by successful elimination of the aggregation among the nanopowders in the nanocomposite route.



(a) (b)

Fig. 6. SEM morphology of PZT composite films. Mass ratio of powder to solution: (a) ¼, (b) ½.

3. Design and Modeling of a Pressure Sensor

The cross section of the structure of the diaphragm is shown in Fig. 7. In this Figure *a* expresses the width of square multilayered diaphragm, *d* is the total width of the sensor which is approximately equal to 3*a*, and h_7 is thickness of the substrate. h_1, h_2 ... h_6 are the thickness of each layer. Due to the symmetry of the diaphragm and in order to save some time and storage space in the calculation a quarter of the whole structure is used for simulation, as it's shown in Fig. 8. The PZT film was deposited on Pt/Ti /SiO_2/Si wafer via sol-gel process. Au layer was evaporated on the surface of PZT film as a top electrode. The backside silicon was wet etched off till the SiO_2 layer. Since the substrate is made of anisotropic wet etched Si(100) wafer, the etched angle is known of around 54.7°. Therefore, the dimension of *c* can easily be determined by following equation:

$$c = \frac{1}{2}(d - a) - h_1 \cot(54.7^o) \tag{3}$$

The materials properties of each layer within the diaphragm which is in the FE modeling are listed in Table 1. There is E is Young's modulus (GPa); μ is Poisson ratio; ρ is density ($\times 10^3 kg/m^3$) and *h* is thickness (μm).

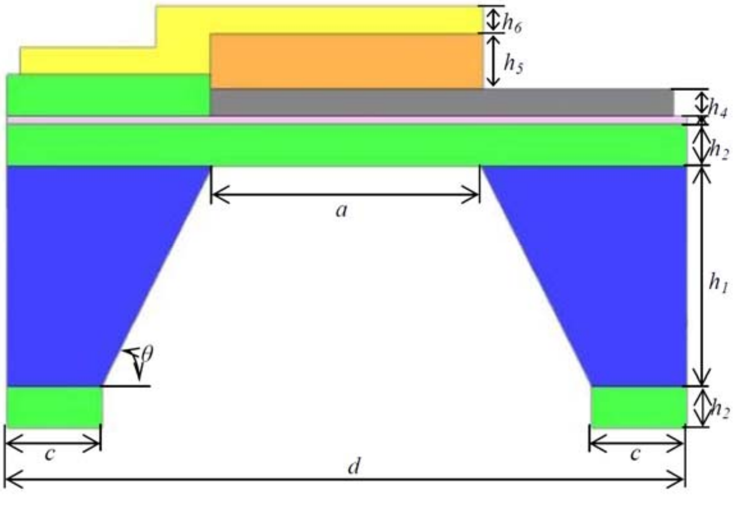


Fig. 7. Cross section of the structure of the diaphragm.

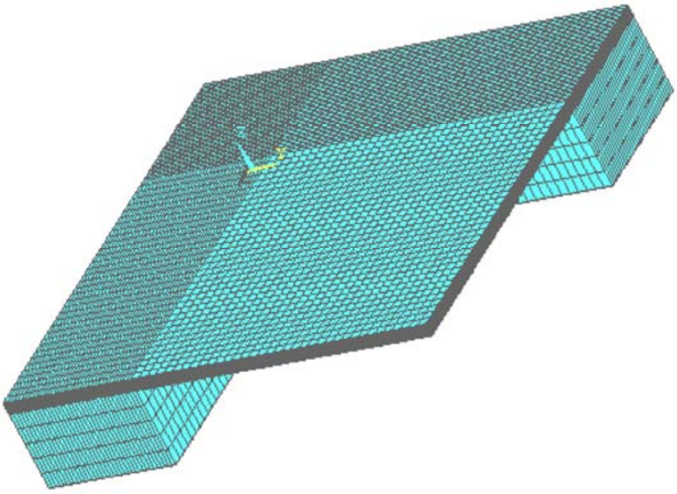


Fig. 8. The model used in ANSYS® .

Table 1. The properties of each material in the structure.

Layer	Material	Thickness	E	µ	ρ
h_1	Si	500 μm	190	0.33	2.33
h_2	SiO_2	400 *nm*	72.4	0.16	2.07
h_3	Ti	25 *nm*	102.1	0.3	4.85
h_4	Pt	200 *nm*	146.9	0.39	21.45
h_5	PZT	1 μm	86.2	0.287	7.62
h_6	Au	200 *nm*	80	0.42	19.32

4. Simulation and Results

Fig. 9 shows the displacement, stress in different directions, total stress, and strain at 60 mbar pressure. As shown in Fig. 9 the maximum displacement of the diaphragm is at the center, and the maximum stresses in different direction are along the edges of the diaphragm.

The dimensions of the model of a multilayer diaphragm that is used for obtain this results were $a = 300\ \mu m$ and $h_5 = 1\ \mu m$.

5. Finite Element Modeling

The micro piezoelectric sensor was modeled in ANSYS® [13] FE software to obtain its electro-mechanical characteristics.

Three different element types were adopted to characterize different layers in the device. Solid 46 element type which has the capability of modeling the layered solid was used to model elastic layers of Pt, Ti and SiO_2. Using this element type helped modeling of three solid layers in one element layer. Piezoelectric layer was modeled using Solid 5 element type. Substrate and Au layers were modeled using solid 45 element type.

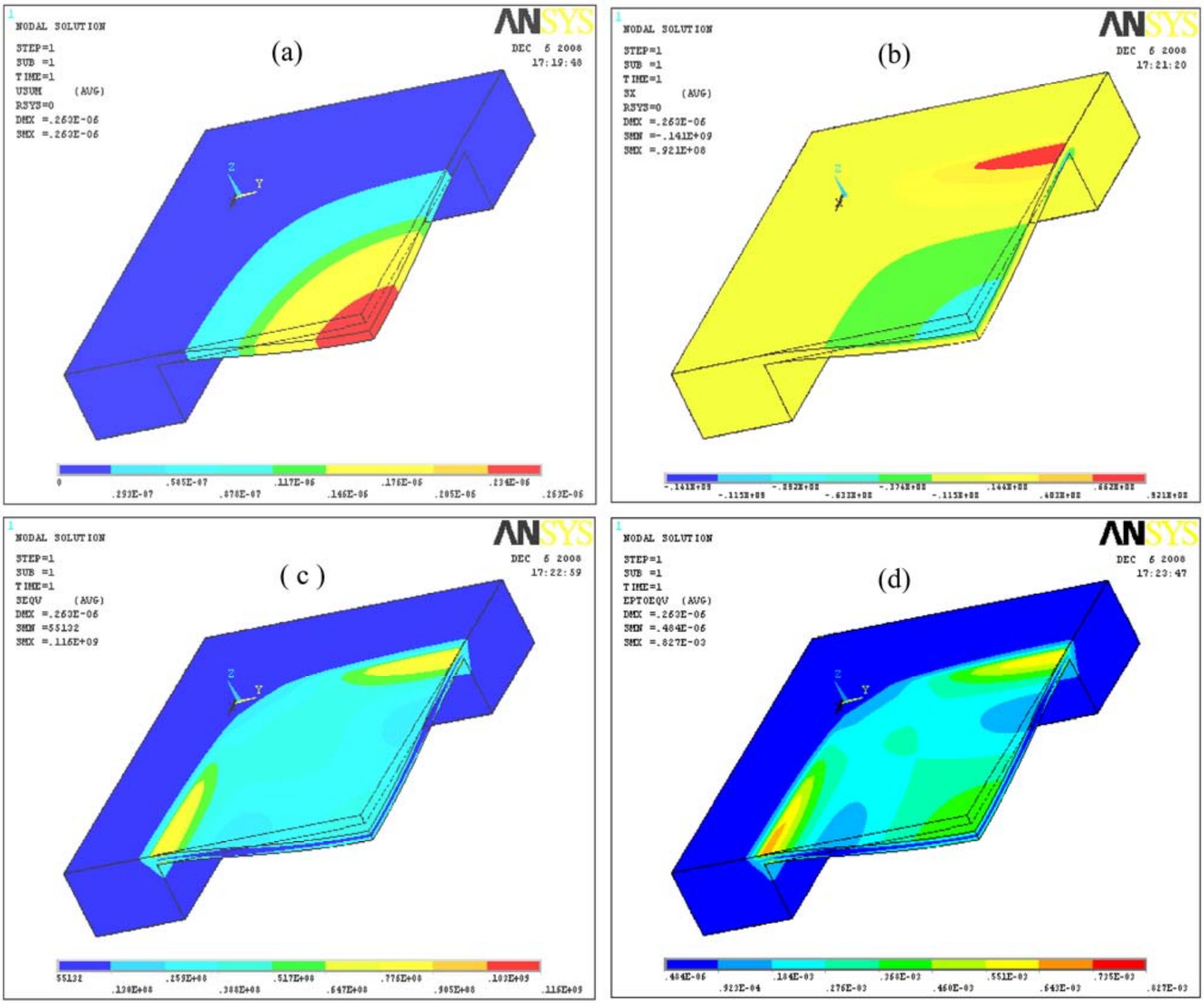


Fig. 9. The simulation result from ANSYS (a) displacement; (b) stress in x direction; (c) stress total; (d) strain.

The small thickness-width ratio is the most challenging issue in the FE modeling of the thin films. Huge amount of elements are required to achieve suitable aspect ratio. In the present work, three layers of elements in modeling the membrane and substrate requires huge amount of CPU time. Some author used simplified model to decrease the CPU time [14], only modeled the diaphragm and substituted the surrounding membrane and substrate effect with clamped boundary condition. This simplified model is very rigid boundary condition. In this study a simplified model was used which assume that the substrate is a rigid body. The nodes in the interface between substrate and membrane were fixed. Modeling the thin film layers offers more relaxed boundary condition than one which is used in [14] despite its need to more CPU time.

5.1. Validation of Numerical Analysis

The accuracy of the finite element method results depends on element type, model discretization, and solution controls which are used in the analysis. Thus the model and solution controls should be evaluated before using the FE model in the further analysis. The numerical, analytical results of frequencies of two-layered clamped PZT plate [15] were used to verify our numerical analysis process by using ABAQUS FE-codes. As mentioned in [15] the clamped square plate was laminated by an elastic layer of SiO_2 and a PZT layer of $PbZr_{0.54}Ti_{0.46}O_3$ with 1 μm in thickness, respectively. Table 2 compares the five natural frequencies obtained by ANSYS FEM software and by theoretic calculation and ABAQUS FEM software at different width of the square plate. The errors, based on ANSYS data, are within 1.30 % as comparing with the results in [15] is shown in Fig. 10. This comparison indicates the acceptance of the analysis method and element sizes used in the ANSYS FEM software.

Table 2. Comparison of the first five nature frequencies for a clamped square $PbZr_{0.54}Ti_{0.46}O_3/SiO_2$ laminated plate with each Layer of Thickness at 1 μm*.

		Width						
		100 μm	200 μm	300 μm	400 μm	500 μm	750 μm	1000 μm
Model 1	ANSYS	1378.74	344.59	153.13	86.11	55.09	24.47	13.73
	ABAQUS	1364.31 (1.05%)	342.352 (0.65%)	152.262 (0.57%)	85.669 (0.51%)	54.834 (0.46%)	24.373 (0.40%)	13.711 (0.14%)
	Theory	1388.747 (0.73%)	347.1868 (0.75%)	154.3052 (0.77%)	86.7967 (0.80%)	55.5499 (0.83%)	24.6888 (0.89%)	13.8875 (1.15%)
Model 2,3	ANSYS	2810.4	702.3	311.96	175.4	112.23	49.84	28.02
	ABAQUS	2773.57 (1.31%)	697.892 (0.63%)	310.55 (0.45%)	174.758 (0.37%)	111.867 (0.32%)	49.728 (0.22%)	27.974 (0.16%)
	Theory	2831.78 (0.76%)	707.945 (0.80%)	314.6422 (0.86%)	176.9863 (0.90%)	113.2712 (0.93%)	50.3428 (1.01%)	28.3178 (1.06%)
Model 4	ANSYS	4136.11	1034.12	459.4	258.41	165.33	73.37	41.261
	ABAQUS	4074.16 (1.50%)	1027.7 (0.62%)	457.526 (0.41%)	257.511 (0.35%)	164.852 (0.29%)	73.287 (0.11%)	41.228 (0.08%)
	Theory	4175.461 (0.95%)	1043.865 (0.94%)	463.9401 (0.99%)	260.9663 (0.99%)	167.0184 (1.02%)	74.2304 (1.17%)	41.7546 (1.20%)
Model 5	ANSYS	5029	1256.8	558.6	313.84	200.75	89.06	50.09
	ABAQUS	4953.65 (1.50%	1251.29 (0.44%)	557.209 (0.25%)	313.644 (0.06%)	200.796 (0.02%)	89.27 (0.24%)	50.22 (0.26%)
	Theory	5073.002 (0.87%)	1268.251 (0.91%)	563.6669 (0.91%)	317.0626 (1.03%)	202.9201 (1.08%)	90.1867 (1.27%)	50.73 (1.28%)

* The percent ratios in brackets are the frequency errors ANSYS results with respect to Theory and ABAQUS results [15].

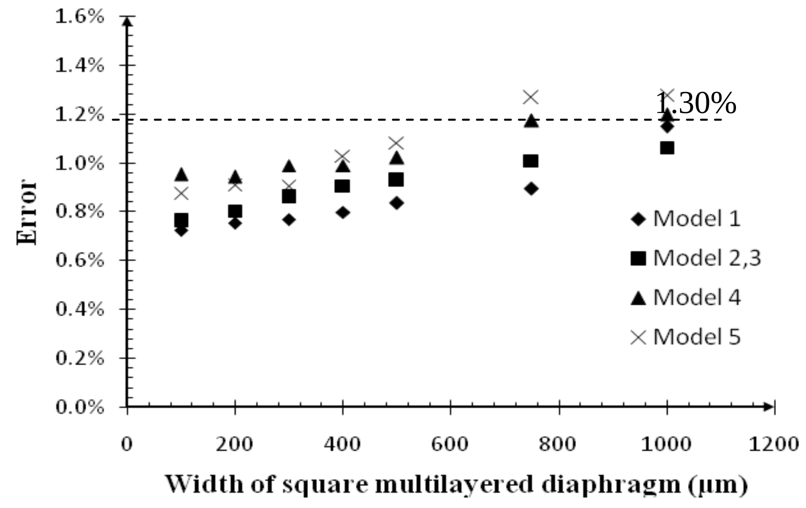


Fig. 10. The errors, based on ANSYS results based on Table 2.

6. FE Results and Optimization

A finite element model of the device allowed us to investigate a dynamics characteristics and structural behaviors of the multilayer PZT diaphragm and optimize a PZT thin film diaphragm for use in the sensors and actuators applications.

Fig. 11 shows the influence of the width of the square multilayer PZT diaphragm on the first nature frequency. The natural frequency decreases rapidly with increasing the diaphragm width especially in the larger PZT layer thicknesses. The x-axis of Fig. 11 was replaced with the reciprocal area of diaphragm, $1/a^2$, and is shown in the Fig. 12. As can be seen there is a linear relation between the 1st natural frequency and reciprocal area of diaphragm. Fig. 13 shows the 1st natural frequency versus PZT layer thickness in the different diaphragm widths. There is also a linear relation between the 1st natural frequency and PZT layer thickness. Fig. 12 and 13 can be used to predict the natural frequency in the larger models with more elements without further simulation. The dimension of the real MEMS sensors are larger than the sensor modeled in present work. There is three layers in the model, modeling a sensor which its dimension is 2 times larger than this model, require 12 times more elements than this model. Solving this huge amount of elements requires huge amount of CPU time to solve and hardware to save the model data.

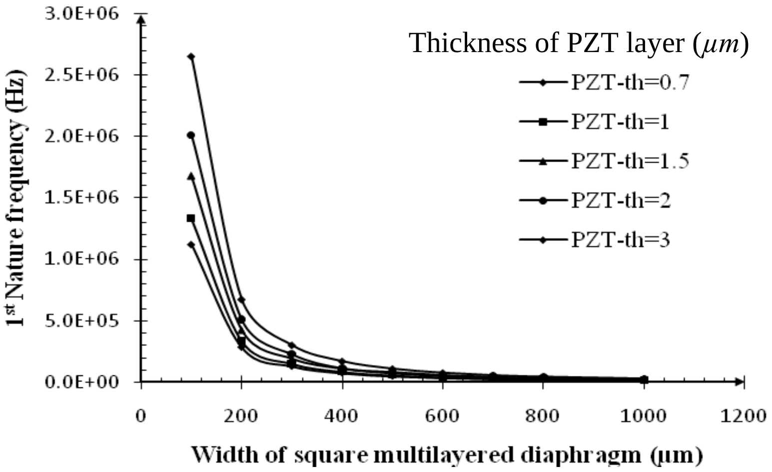


Fig. 11. Change of the first nature frequency of structure via the variation of width of square laminated diaphragm.

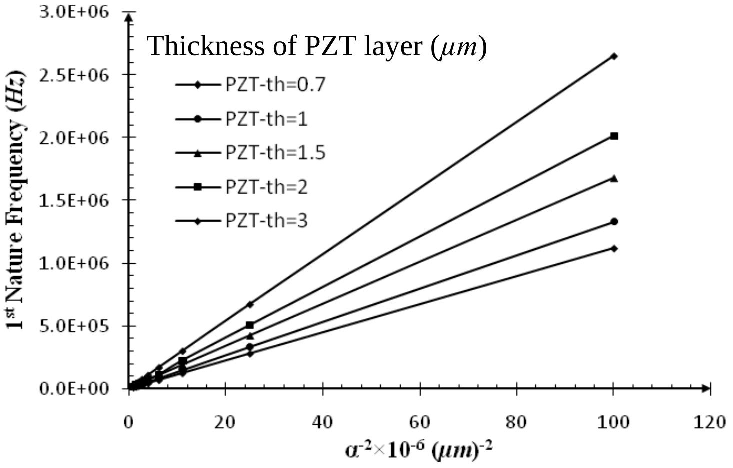


Fig. 12. Change of the first nature frequency of structure via the inverse of square of width, $1/a^2$, of square laminated diaphragm.

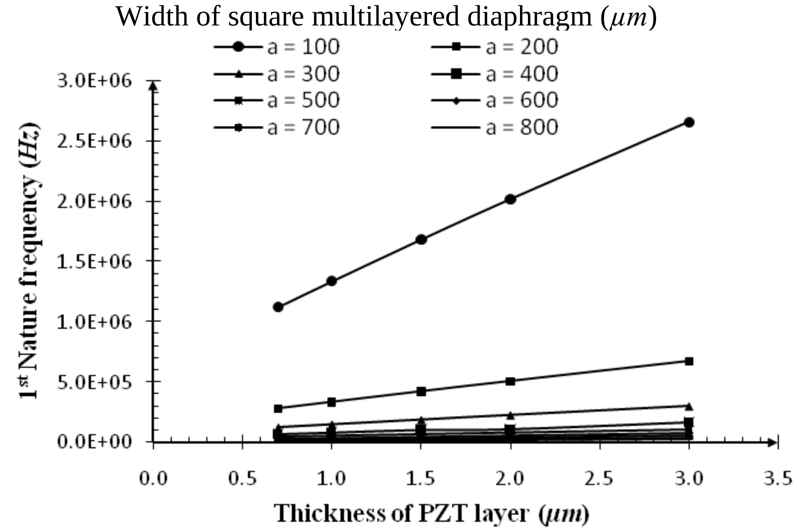


Fig. 13. Effect of thickness of PZT-layer on the structure nature frequency.

6.1. Harmonic Response of the PZT Thin Film Diaphragm

Harmonic response of the sensor was investigated under applying pressure load on the diaphragm. Since the supported silicon and surrounding multilayer film of diaphragm are not rigid solids and don't have clamped boundary, the exact model was adopted in investigation of the harmonic responses of the diaphragm. A damping ratio equal to 0.015 was assumed in the analysis. Fig. 14 shows the deflection response at center point of the diaphragm. The voltage response PZT layer is shown in the Fig. 15. The dimensions of the exact model of a multilayer diaphragm which is modeled were a = 250 µm, d = 750 µm, h_1 = 200 µm and h_5 = 1 µm.

There is a little difference between the exact model and adopted simple model result and can be neglected. The exact model took CPU time 2.15 times more than simple model and can be used in further harmonic analysis in order to save the CPU time and reduce analysis cost.

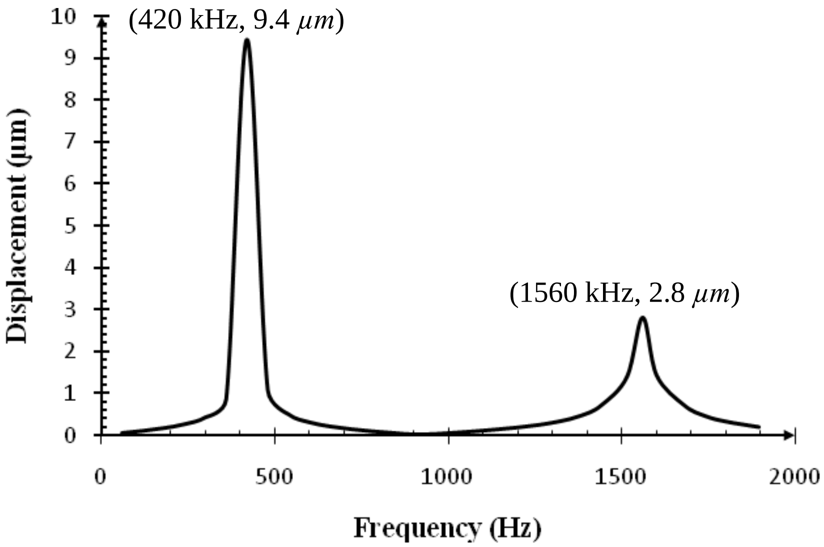


Fig. 14. Displacement at centre point of the diaphragm.

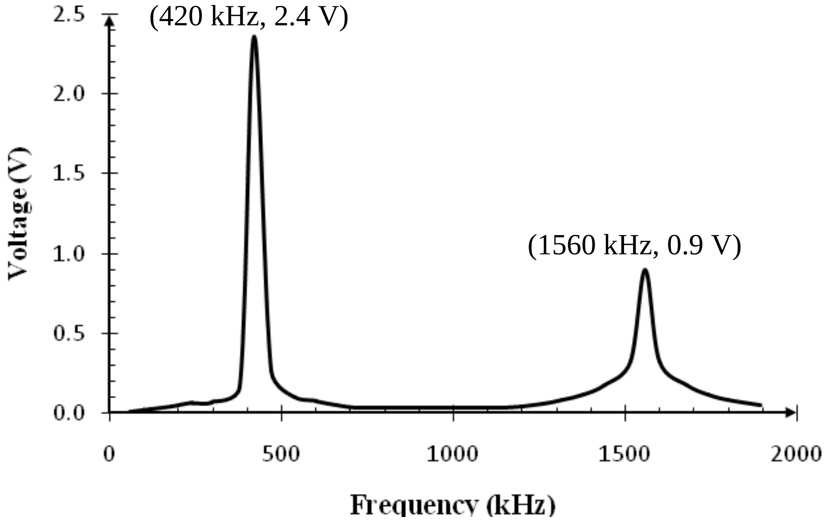


Fig. 15. Voltage response in PZT-layer at centre point of the diaphragm.

6.2. Effect of Thickness Ratio on Dynamical behavior of the PZT Thin Film Diaphragm

The thicknesses of SiO_2 and PZT are in the same order and because of it we considered variety of thickness ratios of them to study dynamical behavior of multilayer diaphragm for sensor and actuator structures are shown in Fig. 16. There exists an optimum thickness ratio of a PZT to elastic layers under which the deflection of the diaphragm will reach a maximum value. In the calculation, once the thickness of SiO_2 layer was varied, and the thickness of the PZT layer was remained at h_5 = 1 µm, and then the thickness of PZT layer was varied, and the thickness of the SiO_2 layer was remained at h_2 = 400 nm. The optimized values of thickness ratio for given widths versus the variations of PZT thickness for sensor and actuator structures are shown in Fig. 17.

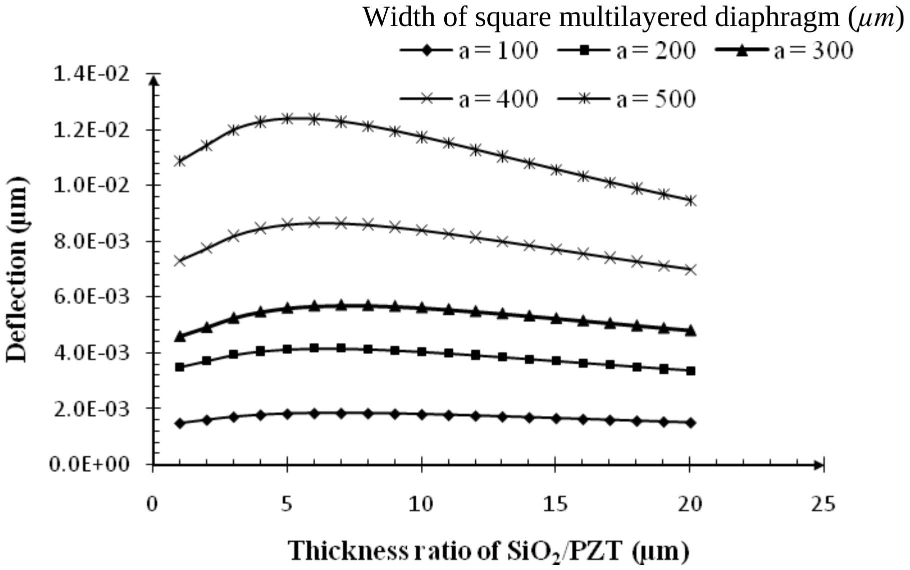


Fig. 16. Dependence of the diaphragm deflection via the thickness ratio of SiO2/PZT layers of the diaphragm of a pressure sensor.

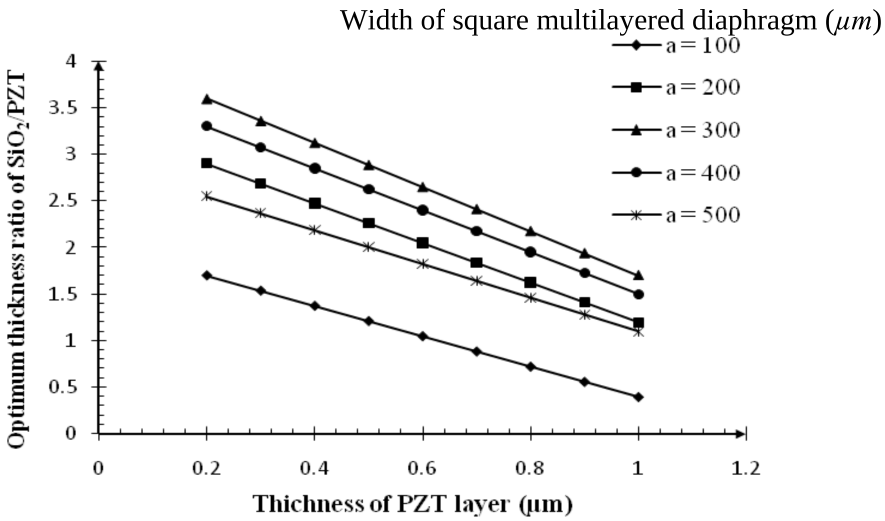


Fig. 17. Change of optimum thickness ratio of SiO2/PZT plate versus variation of PZT thickness and diaphragm width of a pressure sensor.

6.3. Sensor Response

Fig. 18 shows the voltage versus pressure diagram for different diaphragm widths. In this diagrams the PZT layer thickness is constant and equal to 1 *μm* and the SiO_2 layer thickness is so selected to obtain the optimum value of R in that diaphragm width. These curves can be used to calibrate the sensor actuator response. There is a simple linear relation between voltage and pressure in each diaphragm width. This linear relation can be used to predict larger model behavior and calibrate them.

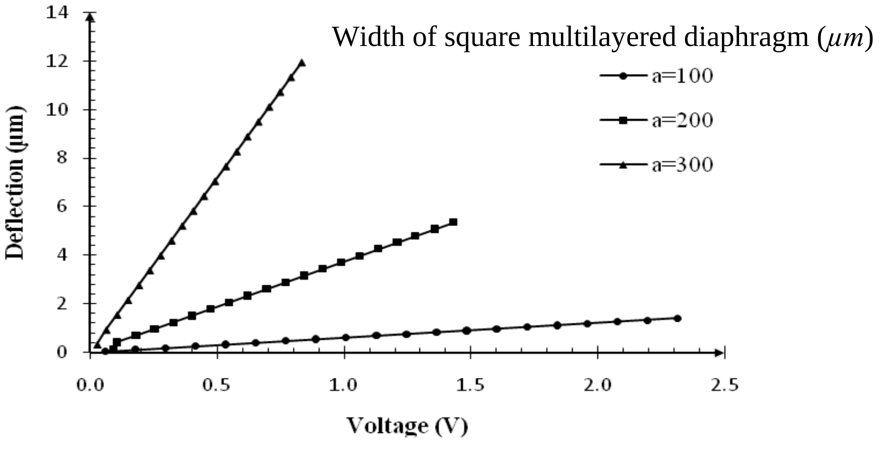


Fig. 18. Diaphragm deflection versus voltage for different diaphragm widths.

7. Conclusions

In this paper firs fabrication of a 0-3 ceramic/ceramic composite lead zirconate titanate, $Pb(Zr_{0.52}Ti_{0.48})O_3$ thin film have been presented and then a pressure sensor based on multilayer thin-film PZT diaphragm contain of Lead Zirconate Titanate nanocrystalline powders is designed, modeled and optimized. XRD analysis shows that perovskite structure would be formed due to the presence of a significant amount of ceramic nanopowders and the (100) preferred direction was induced. This texture has a good effect on piezoelectric properties of perovskite structure. And have a piezoelectric coefficient d_{31} of -40 pC.N^{-1} and d_{33} ranged from 50pm.N^{-1} to 60pm.N^{-1}. The film forms a strongly bonded network and less shrinkage occurs, so the films do not crack during process. The aspect ratio through this process would be increased. SEM micrographs indicated that PZT films were uniform, crack free and have a composite microstructure and suitable for used in fabrication of a pressure sensor based on multilayer PZT thin film. The dynamics characteristics and structural behaviors of the multilayer PZT diaphragm were investigated to obtain an optimum design of the PZT thin film diaphragm for used in the pressure sensor. By this simulation the effective parameters of the multilayer PZT diaphragm for improving the performance of a pressure sensor in different ranges of pressure are optimized. The influence of dimensions of multilayer diaphragm on nature frequency was studied. The frequency values were found to rapidly decrease with the increase in the diaphragm width, especially in the small width range, and to increase linearly with the increase in the thickness of the PZT-layer. The deflection and the first nature frequency of diaphragm as a function of the thickness ratio of PZT layer to SiO_2 layer were presented for the optimum design of actuator or sensors in MEMS applications.

References

[1]. Liu, M., Cui, T., Dong, W., Cuil, Y., Wang, J., Du, L., and Wang, L., Piezoelectric microcantilevers with two PZT thin-film elements for microsensors and microactuators, in *Proceedings of the 1st IEEE International Conference on Nano/Micro Engineered and Molecular Systems,* Zhuhai, China, 2006.

[2]. P. Muralt, Piezoelectric thin films for MEMS, Encyclopedia of Materials*: Science and Technology,* 2001, pp. 6999–7009.

[3]. M. A. Dubois, P. Muralt, PZT thin film actuated elastic fin micromotor, *IEEE Trans. Ultrason., Ferro., Freq. Cont*., 45, 5, 1998, pp. 1169–1177.

[4]. K. Kunz, P. Enoksson, G. Stemme, Highly sensitive triaxial silicon accelerometer with integrated PZT thin film detectors, *Sensor and Actuators,* A, 92, 2001, pp. 156–160.

[5]. J. Mandle, O. Lefort, A. Migeon, A new micromachined silicon high-accuracy pressure sensor, *Sensors and Actuators*, A, 46-47, 1995, pp. 129-132.

[6]. M. Koch, N. Harris, A. Evans, N. M. White, A. Brunnschweiler, A novel micromachined pump based on tick-film piezoelectric actuation, *Sensor and Actuators,* A, 70, 1998, pp. 98–103.

[7]. M. J. Mescher, M. L. Vladimer, J. J. Bernstein, A novel high-speed piezoelectric deformable varifocal mirror for optical applications, in *Proceedings of the 15th IEEE International Conference on Micro Electro Mechanical Systems 2002, Las Vegas, USA, 20–24 January 2002*, pp. 511–515.

[8]. H. H. Kim, B. K. Ju, Y. H. Lee, S. H. Lee, J. K. Lee, S. W. Kim, A noble suspended type thin film resonator (STFR) using the SOI technology, *Sensor and Actuators,* A, 89, 2001, pp. 255–258.

[9]. Liwei Lin, L., and Yun, W., MEMS Pressure Sensors for Aerospace Applications, *IEEE*, 1998.

[10].Ravariu, F., Ravariu, C., Nedelcu, O., The modeling of a sensor for the human blood pressure, *IEEE,* 2002.

[11].C. Zinck, D. Pinceau, E. Defaÿ, E. Delevoye, D. Barbier, Development and characterization of membranes actuated by a PZT thin film for MEMS applications, *Sensors and Actuators*, A, 115, 2004, pp. 483–489.

[12].R. J. Ong, T. A. Berfield, N. R. Sottos, D. A. Payne, Sol–gel derived Pb(Zr, Ti)O_3 thin films: Residual stress and electrical properties, *Journal of the European Ceramic Society,* 25, 2005, pp. 2247–2251.

[13].ANSYS guide, release 10. 0, *ANSYS, Inc*. http://www.ansys.com

[14].Lin-Quan Yao, Li Lu, Simplified Model and Numerical Analysis of Multi-layered Piezoelectric Diaphragm, *Advanced Materials for Micro- and Nano- Systems* (AMMNS), 2003.

[15].Shuo Hung Chang, Yi Chung Tung, Electro-Elastic Characteristics of Asymmetric Rectangular Piezoelectric Laminae, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 46, No. 4, 1999.

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:

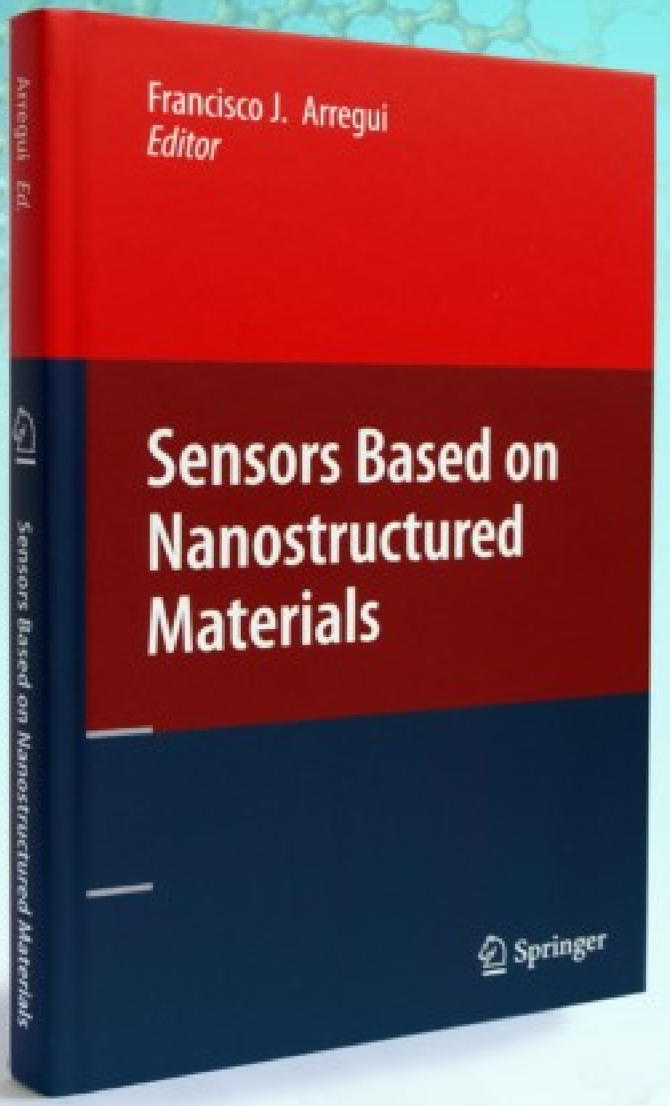
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors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


Francisco J. Arregui
Editor
Sensors Based on Nanostructured Materials
Springer
Arregui Ed.
Sensors Based on Nanostructured Materials