


ISSN 1726-5749

SENSORS & TRANSDUCERS

10 Special
Issue
/07



**MEMS & NEMS:
Devices and Systems**

International Frequency Sensor Association Publishing





Sensors & Transducers

Special Issue
October 2007

www.sensorsportal.com

ISSN 1726-5479

Editor-in-Chief: Sergey Y. Yurish
Guest Editors: Elena Gaura and James P. Brusey

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editors for North America

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

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

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-Pyoun, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, Priyadarshini College of Engineering and Architecture, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad de La Salle, 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
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA

Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding Jian, Ning, Jiangsu University, China
Djordjevic, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, University of Ulm and KTB mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
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 Ros, Juan Jose, University of Cadiz, Spain
Grael, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Hashsham, Syed, Michigan State University, USA
Hernandez, Alvaro, University of Alcala, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK

Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Koh Young Technology, Inc., Korea South
Ko, Sang Choon, Electronics and Telecommunications Research Institute, Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Laurent, Francis, IMEC, Belgium
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, Michigan State University, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, Universidade NOVA de Lisboa, Portugal
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
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, Benemirita Universidad Autonoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, DIMET, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mukhopadhyay, Subhas, Massey University, New Zealand
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucin, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimitar, 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
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Rezazadeh, Ghader, Urmia University, Iran
Robert, Michel, University Henri Poincare, France
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Sadana, Ajit, University of Mississippi, USA
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemeni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shearwood, Christopher, Nanyang Technological University, Singapore
Shin, Kyuho, Samsung Advanced Institute of Technology, Korea
Shmaliy, Yuriy, Kharkiv National University of Radio Electronics, Ukraine
Silva Girao, Pedro, Technical University of Lisbon Portugal
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technology, India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Institute for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vaseashta, Ashok, Marshall University, USA
Vazques, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Advanced Micro Devices, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung University of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Wuqiang, The University of Manchester, UK
Ymeti, Aurel, University of Twente, Netherland
Yu, Haihu, Wuhan University of Technology, China
Yuferra Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zeni, Luigi, Second University of Naples, Italy
Zhong, Haoxiang, Henan Normal University, China
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhou, Zhi-Gang, Tsinghua University, China
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Special Issue
October 2007

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Foreword

Elena Gaura and James P. Brusey..... 1

Nano-Structure or Nano-Systems: Opportunities and Pitfalls

P. J. French and C.-K. Yang..... 1

New Trends on MEMS Sensor Technology for Harsh Environment Applications

Patricia M. Nieva 10

Healthcare for the Healthy People: Miniaturization, Sensing and Actuation Trends and Needs in Preventive and Predictive Medicine

Alberto Sanna, Marco Nalin, Riccardo Serafin..... 21

Global Environmental Micro Sensors Test Operations in the Natural Environment (GEMSTONE)

Mark Adams, John Manobianco and Matthew Buza..... 30

Frequency Domain Modeling of SAW Devices for Aerospace Sensors

William Wilson, Gary Atkinson..... 42

Development of Materials and Sensors for the U.S. Army's Active Coatings Technology Program

James L. Zunino III 51

Microfabrication and Characterization of an Integrated 3-Axis CMOS-MEMS Accelerometer

Hongwei Qu, Deyou Fang and Huikai Xie..... 60

Characterization and Optimization Design of the Polymer-based Capacitive Micro-arrayed Ultrasonic Transducer

De-Yi Chiou, Mu-Yueh Chen, Hsu-Cheng Deng, Ming-Wei Chang..... 68

Fabry-Perot Diaphragm Fiber Optic Sensor (DFOS) for Acoustic Detection

Yan Sun, Guanhua Feng, George Georgiou, Edip Niver, Karen Noe and Ken Chin..... 76

Micromechanical GaAs Hot Plates for Gas Sensors

Jiri Jakovenko, Miroslav Husak, Tibor Lalinky, Milan Drzik..... 84

Integration of Microfluidics and Microacoustics Components for Miniature Flow Cytometry Systems

Surendra K. Ravula, Darren W. Branch, Jennifer Sigman, Paul G. Clem, Igal Brener..... 93

Design and Characterization of MEMS Thermal Converter

Jiri Jakovenko, Miroslav Husak, Tibor Lalinky..... 101

Fabrication of a Real Time Reactive Ion Etching Resonant Sensor Using a Low Temperature Sacrificial Polymer

Bryan G. Morris, Paul J. Joseph and Gary S. May..... 111

| | |
|--|-----|
| Perturbation Stochastic Finite Element Analysis of Thermoelastic Quality Factor of Micro-Resonators <i>S  verine Lepage and Jean-Claude Golinval</i> | 124 |
| A Semi-Analytical Model for Calculating Touch-Point Pressure and Pull-in Voltage for Clamped Diaphragms with Residual Stress <i>Anurekha Sharma and P. J. George</i> | 131 |
| The Development of Chemical Nanosensors <i>A. J. Jin, J. Li, Y. Lu</i> | 140 |

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

Foreword

The 10th annual NSTI Nanotech Conference and Trade Show was held this year during 20-24 May at the Santa Clara Convention Center, in Santa Clara, California. The conference has grown this year to host 3000 attendees and 250 exhibitors, while the resulting proceedings boasts over 3000 pages of peer-reviewed micro and nanotechnology research.

A number of authors publishing in the Joint Electronics and Microsystems Symposia track were invited to submit a revised version of their papers to this special issue. Papers were selected from a number of symposia within the track, including: MEMS & NEMS, Sensors & Systems, Micro & Nano Fluidics, and MSM – Modeling Microsystems. These symposia brought together researchers from a number of disciplines to discuss topics ranging from theoretical developments, to design and fabrication, through to industrial applications of MEMS and NEMS sensors, devices and systems.

The joint symposia are motivated by the dream of smarter, smaller, and more complex systems that integrate micro and nano system technologies with intelligence, power and communication ability at the same micro or nano scale. The resulting increase in complexity poses an enormous challenge to engineers when designing, modeling, and fabricating such integrated micro and nano systems. The joint symposia aimed at bringing together researchers from different disciplines to exchange ideas about how to best develop such systems.

As with the joint symposia, this special issue includes papers ranging from those with a higher level focus to those covering low-level physical aspects of MEMS and NEMS devices and their modeling and fabrication. Four of the papers presented in this special issue correspond to invited talks: Sanna et al., examine miniaturization trends in preventative medicine and include some results from the EU project ANGEL; Adams et al., describe the results of the NASA funded GEMSTONE project, which involved creating and field-testing a small system of atmospheric probes; French and Yang explore the opportunities and pitfalls of scaling, whilst Nieva presents a number of new trends for using MEMS sensors in harsh environments.

We are very thankful both to the NSTI directors and Nanotech chairs (Dr. Matthew Laudon and Dr. Bart Romanovicz) and to the *Sensors & Transducers Journal* for offering the opportunity to publish this special issue.

Guest Editors:



Dr. Elena Gaura

Reader in Pervasive Computing
Director of Cogent Computing Applied Research Centre
Faculty of Engineering and Computing
Coventry University, UK
e.gaura@coventry.ac.uk
www.cogentcomputing.org



Dr. James P. Brusey

Senior Lecturer in Systems Engineering
Senior Research Fellow of Cogent Computing Applied
Research Centre
Faculty of Engineering and Computing
Coventry University, UK
j.brusey@coventry.ac.uk
www.cogentcomputing.org

New Trends on MEMS Sensor Technology for Harsh Environment Applications

Patricia M. NIEVA

Department of Mechanical and Mechatronics Engineering,
University of Waterloo, 200 University Ave. West, Waterloo, N2L 3G1
E-mail: pnieva@uwaterloo.ca
<http://simslab.uwaterloo.ca>

Received: 7 September 2007 / Accepted: 19 September 2007 / Published: 8 October 2007

Abstract: MEMS and NEMS sensor systems that can operate in the presence of high temperatures, corrosive media, and/or high radiation hold great promise for harsh environment applications. They would reduce weight, improve machine reliability and reduce cost in strategic market sectors such as automotive, avionics, oil well logging, and nuclear power. This paper presents a review of the recent advances in harsh-environment MEMS and NEMS sensors focusing on materials and devices. Special emphasis is put on high-temperature operation. Wide-bandgap semiconductor materials for high temperature applications are discussed from the device point of view. Micro-opto mechanical systems (MOEMS) are presented as a new trend for high temperature applications. As an example of a harsh environment MOEMS sensor, a vibration sensor is presented. *Copyright* © 2007 IFSA.

Keywords: MEMS, NEMS, MOEMS, Sensors, Harsh Environments, Fabry-Perot Interferometry

1. Introduction

Micro and nano electro mechanical systems (MEMS and NEMS) have emerged as a technology that integrates micro/nano mechanical structures with microelectronics, mainly for sensing and actuation applications. Silicon-based MEMS technology has enabled the fabrication of a broad range of sensor and actuator systems. These systems are having a great impact in areas that benefit from miniaturization and increased functionality. They have been commercialized for applications such as ink jet printing, crash sensing, and optical projection to name a few. The main advantage of silicon-based technology is the possibility of integration with microelectronics. A great deal of attention is being drawn to the development of integrated MEMS and NEMS to produce smart devices and systems. In automotive or aerospace for example, a misfiring cylinder has a negative impact on the

health of the engine and the emissions control. When a cylinder misfires, the remaining cylinders operate at abnormally higher loads resulting in excessive cylinder pressure levels, overheating, knock, pre-ignition, and severe engine damage. Misfire is also accompanied with high emissions of unburned hydrocarbons and CO. Smart MEMS sensors capable of operating “in cylinder”, where the temperatures are around 400 °C for automotive engines or up to and above 900 °C for gas turbine engines, could continuously monitor the combustion quality of the cylinders of automotive engines reducing emissions and improving fuel economy. However, the mechanical and electrical properties of silicon (Si) limit their application in harsh environmental conditions. When the environment temperature is too high (>180 °C), conventional microelectronics suffer from severe performance degradation [1]. Hence, they must reside in cooler areas or be actively cooled. The additional components such as longer wires, extra packaging and/or bulky expensive cooling systems, add undesired size and weight to the system, which at the same time impact the overall reliability of the system. They also require extra supply voltage, which is undesirable for HT applications where power source is very limited. It is then clear that further development, in terms of new MEMS/NEMS materials (including new functional layers such as piezoelectric films) and/or new technologies, is needed to minimize these difficulties. This is especially important where high temperature capability is crucial to realizing improved electronic control and reducing weight.

Silicon carbide (SiC) [2, 3] and group III nitride device technologies [5, 6] are promising for smart MEMS/NEMS sensors operating in harsh environments. In the past decade, tremendous progress has been made in the growth of single crystal SiC wafers and epitaxial growth of crystalline SiC layers on Si and/or SiC wafers [2, 10-15]. However, SiC wafers are not (yet) suitable for MEMS and NEMS, as micromachining of these wafers is still a challenge [2-4]. Issues such as high mechanical stress, deposition uniformity and low etch rates need to be tackled before high-quality SiC structural films can be produced [3]. In addition, the affinity of SiC to form carbides and/or silicides by reacting with metals at temperatures above 600 °C affect metal contacts degrading the performance of SiC MEMS and NEMS sensors [4]. Furthermore, very little is known about the elastic behavior and long-term stability of SiC micro- and nano-structures at elevated temperatures. Hence, despite the obvious benefits of using SiC for the development of MEMS and NEMS for harsh environments, there are still many hurdles that have to be overcome before it becomes appropriate for manufacturing and can be used reliably in commercial applications [2, 3]. Group III nitrides are beneficial as piezoelectric functional components for high temperature operation. For example, Aluminum nitride (AlN) preserves its piezoelectric properties up to 1150 °C [5] and gives the opportunity of building up on-chip smart systems with a high degree of processing control. However, only a few reports exist about such applications [6] and despite of all the progress made in the last few years, they still cannot be used for integrated MEMS or NEMS devices.

Remote sensing through optical signal detection has major advantages for safe signal transmission in harsh environments. It is highly resistant to electromagnetic interference (EMI) and radio frequency interference (RFI) and at the same time, it eliminates the necessity of on-board electronics, which has been one of the main obstacles in the development of smart MEMS sensors for high temperature applications. An economical way to deal with higher temperatures and other aggressive environmental conditions is to build MEMS sensors out of robust materials (e.g. Si, Silicon nitride, SiC) and integrate them with optical signal detection techniques to form MOEMS [7-9]. For instance, Fabry-Perot (FP) microstructures have been used to meet the demand of MEMS sensor systems for harsh environments [7, 8]. In this combination, the small and precise size of the sensing elements offers considerable flexibility in choosing the response range and sensitivity of the final sensors. Optical technology has also been used to power a wireless telemetry module for high temperature MEMS sensing and communication [9]. In this paper, we review the current status and the main obstacles in wide bandgap semiconductor devices and microsystem components for MEMS and NEMS. We also highlight recent advances and trends in MOEMS sensors in the context of using them for high temperature applications. The use of Fabry-Perot microstructures for the development of a new MOEMS

displacement sensor for high temperature applications is discussed. Analysis, modeling and experimental results are presented to show their sensitivity and accuracy.

2. Silicon Carbide Semiconductor Devices

SiC is the most mature and the only wide bandgap semiconductor that has silicon dioxide as its native oxide [10]. This allows for the creation of metal oxide semiconductor (MOS) devices. The outstanding material and electronic properties and chemical inertness of SiC make it a leading candidate for MEMS and NEMS in a variety of harsh conditions [2, 10-17]. Regarding its material properties, SiC has a Knoop hardness of 2480 kg/mm² compared to that of silicon (850 kg/mm²) [12]. In addition, SiC has a Young's Modulus of 700 GPa, as compared to Si (190 GPa) [11a] or other wide bandgap semiconductors such as Gallium Nitride (295 GPa) [13] and AlN (310 GPa) [5]. When compared to silicon, SiC has a larger bandgap (2.3-3.4 eV), a higher breakdown field (30x10⁵ V/cm), a higher thermal conductivity (3.2-4.9 W/cm K), and high saturation velocity (cm/s) [12]. Piezoresistive- and capacitive-based sensors are among the most widely used SiC MEMS and NEMS sensing mechanisms.

2.1. Piezoresistive-Based Sensors

The piezoresistive effect in SiC has been used for pressure, force, and acceleration sensors. In general, the piezoresistivity for wide band-gap semiconductors is comparable to that of Si but they can operate at much higher temperatures. However, the contact resistance variation at elevated temperatures can be indistinguishable from the piezoresistance change [16]. In addition, SiC has a relatively low gage factor (30 compared to 90 of Si [11]) which decreases the sensitivity of the sensors as the temperature increases. Okojie et al. [13] developed a piezoresistive pressure transducer which was made of 6H-SiC piezoresistors on a 6H-SiC substrate. The sensor was tested up to 600 °C and 200 psi but due to the significant decrease of the gage factor at high temperatures, the output of the transducer required a temperature compensation scheme above 400 °C. More recently, Wu et al. [14] developed bulk micromachined pressure sensors for HT applications using polycrystalline and crystalline 3C-SiC piezoresistors grown on a Si substrate. The piezoresistors fabricated from poly-SiC films showed -2.1 as the best gauge factor and exhibited sensitivities up to 20.9-mV/V psi at room temperature. Single-crystalline 3C-SiC piezoresistors exhibited a sensitivity of 177.6-mV/V psi at room temperature and 63.1-mV/V psi at 400 °C. Their estimated longitudinal gauge factor along the [100] direction was estimated at about -18 at room temperature but dropped to -7 at 400 °C. Atwell et al. [15] developed a bulk-micromachined 6H-SiC piezoresistive accelerometer for impact applications. The accelerometer was tested up to 40,000 g. Sensitivities ranging from 50 to 343 nV/g were measured for differing sensing elements but non-linear behavior was observed over the shock range relative to a commercial accelerometer (with sensitivity of 1.5 µV/g).

2.2. Capacitive-Based Sensors

Capacitive-based sensors have also been used to sense pressure, force, acceleration, and flow rate. They are attractive for HT applications because the device performance is not susceptible to contact resistance variations but they exhibit performance degradation due to the wiring parasitic capacitances and test setup. SiC capacitive sensors are mainly used for pressure sensing and they are mainly fabricated using bulk-micromachining techniques. Young et al. [16] developed a single crystal 3C-SiC capacitive pressure sensor fabricated on a silicon substrate. The sensor demonstrated sensing capabilities up to 400 °C and was tolerant of contact resistance variations. However, it exhibited different responses at different temperatures of operation, which was attributed to trapped air inside the

cavity and thermal mismatch. A promising approach to pressure sensing in corrosive environments was developed by Pakula et al. [17] using post-processing surface micromachining. The sensing membrane was fabricated in low-stress PECVD SiC. To avoid problems related with wiring parasitic capacitances, the sensor was integrated monolithically to a CMOS readout circuit. The sensor showed stable behavior from 10 mbar up to 5 bar.

3. Optical MEMS Sensors

Optical MEMS sensors are highly adaptable to harsh environments, can measure displacement, pressure, temperature and stress, can be easily incorporated into sensor arrays by using multiplexing methods, and are suitable for liquid and gas measurements. In addition, they are highly resistant to electromagnetic interference (EMI) and radio frequency interference (RFI) and at the same time, they eliminate the necessity of onboard electronics. However, simpler processing techniques and therefore lower manufacturing costs are desirable. Moreover, simplification of the sensing elements and the fabrication processes will be helpful for their mass production and commercialization. Fiber-Optic MEMS and MOEMS sensors are lately being developed for harsh environmental conditions [7, 18-20].

3.1. Fiber-Optic MEMS Sensors

Fiber-optic MEMS are robust, highly resistant to EMI and RFI, and can potentially detect displacements on a sub-nanometer scale. However, their performance depends on mechanical-thermal noise, photodetector noise, fabrication imperfections, and assembly. From all these, the main disadvantage is the need to adjust the optical interrogation system relative to the moving MEMS component. Eklund and Shkel [18] demonstrated that the finesse of a Fiber Optic Fabry-Perot MEMS can decrease up to one order of magnitude due to surface roughness, curvature or a slight deviation from parallelism, thus greatly reducing the resolution of the sensor. Xiao-qi et al. [19] developed a fiber-optic MEMS pressure sensor for harsh environments based on Fabry-Perot interferometry. A dual-wavelength demodulation method was used to interrogate the sensor and results show that the sensor has reasonable linearity and sensitivity within 0.1 MPa to 3 MPa. However, the fabrication is complicated and expensive. In addition, misalignments between the sensor and the fiber cause an increase of the signal-to-noise ratio due to instability of the reflected signal. To overcome these limitations, integration techniques have to be developed which can be either hybrid (e.g. detachable connection of optical fibers with sensor heads). Another solution could also be the integration into MOEMS employing substrate integrated waveguides. However, one of the disadvantages of these waveguides is that leakage losses can be substantial, especially at high temperatures.

3.2. MOEMS Fabry-Perot Sensors

Fabry-Perot Interferometric techniques can be easily applied to membranes or cantilevers that, if fabricated with robust materials (e.g. Si, silicon nitride, SiC, etc.), can be utilized to develop contact-free sensor components with high sturdiness in harsh conditions. Compared to sensors that utilize optical fibers or multi-chip structures [18, 19], single-chip Fabry-Perot MOEMS sensors do not require alignment or sophisticated optical stabilization techniques [7, 8, 20]. In contrast to cumbersome and ambiguous fringe-counting optical detection schemes associated with large cavity FP sensors used in the literature, the small cavity length of these sensors (2-3 μm) allows small intensity shifts to be uniquely related to the relative displacement of the moving mirror. This high resolution results in an improvement of functionality, reliability and sensitivity compared to classical fiber-optic sensors, and make them ideal for the manufacturing of on-chip smart systems at a minimum cost.

Haueis et al. [8] developed a Si-based resonant force sensor packaged with fiber-optic signal detection for high temperature operation. An off-chip capacitive detection system was also used to verify the operation of the sensor up to 175 °C. The optical detection showed a resolution of the resonator deflection to be more than ten times better than the capacitive detection. Wang et al. [20] developed a new Fabry-Perot pressure microsensor which has been successfully tested up to 30 psi and 120 °C. Over the pressure ranging from 0 to 21 psi, very small cross sensitivity to temperature was observed in mid or higher end of the pressure range. However, because of the bridge configuration of the sensor, a corrugated diaphragm needs to be used to alleviate both, the signal averaging effect and the cross-sensitivity to temperature.

4. Fabry-Perot MOEMS Sensor for High Temperature Applications

We have developed the MOEMS Fabry-Perot displacement sensor (MFPD) shown in Fig. 1 that is suitable for high temperature applications and can be easily integrated with standard Si micromachining. Details on the development and fabrication were presented in Ref. [7]. The MFPD consists of a cantilever beam fabricated in low-stress LPCVD silicon nitride. The cantilever beam forms the top mirror of the Fabry-Perot interferometer while the silicon substrate below provides the bottom mirror. As shown schematically in Fig. 4, the two mirrors form an optical microcavity for a monochromatic laser beam incident at the top. For this cavity arrangement, the total interferometric light back-reflected depends on the height of the optical microcavity at the location where the laser beam is directed (spot). When the substrate vibrates, there is a relative deflection of the beam with respect to the substrate and hence a change in the microcavity height. If the mechanical characteristics of the device are known, the amplitude of the substrate motion can be calculated by measuring the back-reflected light.

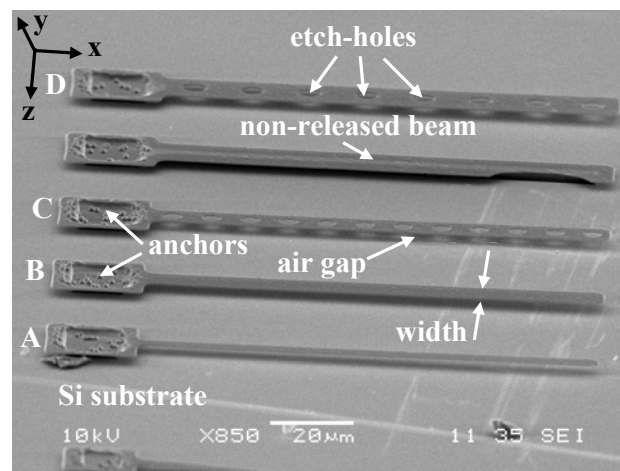


Fig. 1. Fabry-Perot MOEMS displacement sensors with a fundamental resonant frequency of ~ 45 kHz [7].

To the best of our knowledge this MFPD sensor is the first surface micromachined Fabry-Perot in the literature that employs a single layered cantilevered structure together with a new extrinsic intensity-modulated optical interrogation method based on the reflectance of the device (and not the transmittance) to measure displacement in high temperature environments. Cantilever beams have advantages over bridge structures because the lowest natural frequency is 16 % of a bridge with the same dimensions, allowing measurement of lower frequencies. Also residual stresses do not significantly affect the resonant frequency of cantilevers [21], but do change the resonant frequency of

a bridge operating at high temperatures [22]. In addition, they eliminate problems due to stress-stiffening effects and variation of the optical path length due to coupled photo-elastic and thermal-optical effects, all of which are critical to the successful realization of sensors for high temperature applications.

4.1. Optical Signal

The optical microcavity of the MFPD corresponds to a Fabry-Perot in reflectance and its optical response is given by the *power reflectance*, R , of the top of its surface [7]. Assuming no variation in the top mirror thickness (t) or the relaxed cavity height (h), R is only a function of the top layer thickness and the time-dependant air cavity height at the location of the laser beam spot. Fig. 3 shows the power reflectance of the MFPD as a function of the relaxed air gap height (dotted curve). This function was obtained from the optical signal shown in Fig. 2, measured for the MFPD type A shown in Fig. 1, vibrating at a frequency of 62 kHz, and fitted to the AC component of the theoretical power reflectance model described in detail in Ref. [7] with h , δ_r , and t_1 as the fitting parameters. As it can be easily observed, the function is periodic (period $\lambda/2$) and represents the optical transfer function of the microcavity of the sensor.

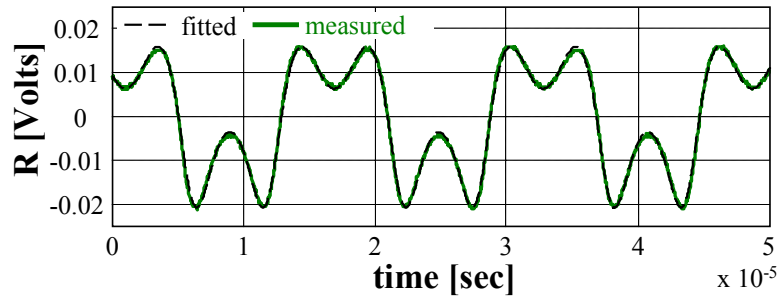


Fig. 2. Measured interferometric optical signal from the MFPD cantilever beam A (Fig. 1) vibrating at an amplitude of the relative displacement of ~ 143.8 nm and fitted to the theoretical power reflectance.

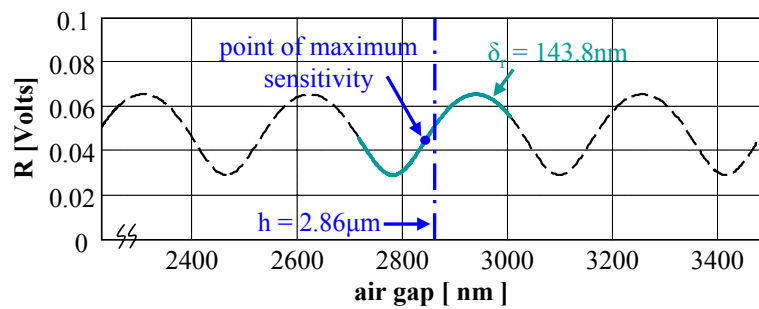


Fig. 3. Reflectance of the MFPD type A shown in Fig. 1 as a function of air gap height.

The total displacement of the beam with respect to the substrate is indicated by the solid line. The fitted values of h and t_1 are within ~ 3.3 % and ~ 1.5 %, respectively, of the measured values listed in Table 1. The static air gap height at the location of the laser beam spot defines the operation point of the sensor which in this case is very close to the point of maximum slope or maximum sensitivity of the transfer function [7]. Motions as small as tenths of nanometers can be resolved using this new extrinsic intensity-modulated optical interrogation method.

Table 1. Summary of measured parameters for the Fabry-Perot MOEMS displacement sensors shown in Fig.1.

| Beam Type | Length (μm) | Width (μm) | Etch-Hole diameter (μm) | Air Gap @ spot (μm) | Spot Location (μm) |
|-----------|--------------------------|-------------------------|--------------------------------------|----------------------------------|---------------------------------|
| A | 122.5 | 4.25 | - | 2.84 | 5 |
| B | 119.6 | 8.17 | - | 2.66 | 17.5 |
| C | 123.5 | 9.31 | 3.92 | 2.60 | 17.5 |
| D | 118.5 | 13.39 | 5.56 | 2.62 | 22.5 |

4.2. Frequency Response

The experimental setup used for the determination of the frequency response of the MFPD sensors was described in Ref. [7] and it is presented schematically in Fig. 4. The optical measurement system detects the interferometric optical signal coming from the vibrating Fabry-Perot structure and transforms it into an electrical signal. This electrical signal is then processed to determine the relative deflection of the top mirror with respect to the bottom mirror of the MFPD at the frequency of excitation. The MFPD frequency response is determined by repeating this sequence for the different frequencies in the range of interest.

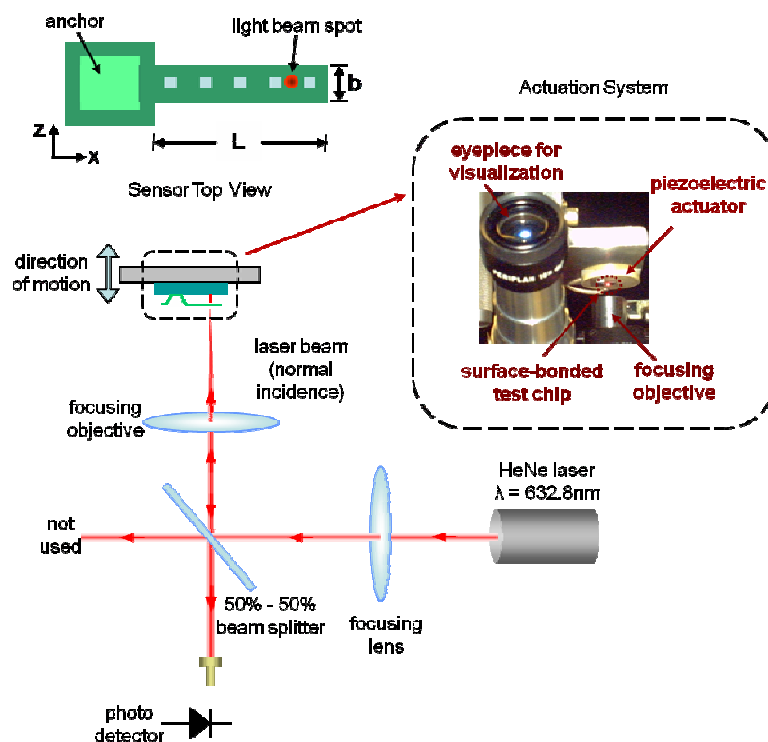


Fig. 4. Schematic of the optical setup for the measurement of the interferometric back-reflected light (MFPD sensor shown as mounted).

The experimental frequency response of all the MFPD cantilever beams listed in Table 1 and measured using the technique described above are shown in Fig. 5. These measured frequency responses were measured using a 10 nm amplitude harmonic excitation. The tests were performed at atmospheric pressure (14.7 psi) and room temperature (23 °C). Their average fundamental frequency is 43.5 ± 3 kHz and their total viscous damping factor (mode 1) vary from 0.19 to 0.3. Also shown in this figure are these responses fitted to the analytical vibration mechanical model with the resonant frequency (f) and the total viscous

damping factor (ζ) as fitting parameters. The excellent agreement between the experimental measurements and the analytical mechanical models suggests that air viscous damping is the dominant source of dissipation for these structures. For details in the analytical modeling the reader may refer to Ref. [7]. Furthermore, by decoupling the effects of squeeze-film and airflow damping, an array of MFPD microsensors will allow for the simultaneous detection of pressure and temperature in addition to displacement [22]. The primary means of viscous damping differentiation is the dependence of the viscosity and density of the air on temperature and pressure. By microfabricating an array of MFPD structures with different geometries, the air viscous damping effects can be modeled based on the height of the microcavities, resonant frequencies, and temperature and pressure of operation. Thus, successful decoupling of the damping coefficients will result in a sensitive sensor array capable of measuring both temperature and pressure in addition to displacement. Experimental verification of the use of the MFPD as a multifunctional sensor is underway.

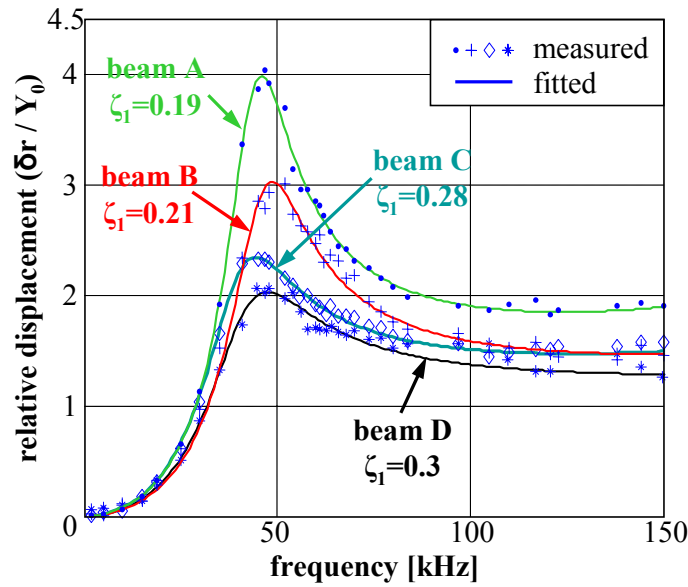


Fig. 5. Measured and fitted frequency response for all MFPD sensors listed in Table 1 [7].

4.2. Temperature Dependence

The mechanisms leading to temperature dependence of the MFPD frequency response are mainly due to (1) shift of the resonant frequency arising from the variation of the Young's modulus, density and coefficient of thermal expansion of the Si_xN_y film (2) variation of the take-off angle of the beam curling due to induced uniform stress (3) variation of the viscous damping coefficient due to variation of the density and the viscosity of the air, and (4) changes of the optical path lengths due to the coupled thermal-optical and photo-elastic effects [7].

For the MFPD type A depicted in Fig. 1, a variation of temperature from 23 °C to 600 °C causes a drift in the fundamental resonant frequency of about 6.1 %, which is much less than the 20 % drift reported for bridges in Ref. [23]. For the same MFPD, the take-off angle is ~ 5.7 mrad. Neglecting the effects of stress gradients, the same temperature change produces a variation in the take-off angle of ~ 0.38 mrad. This variant decreases the air gap height at the spot location by about 43 nm moving the point of operation of the sensor about 1.3 % and hence, decreasing the sensor's optical sensitivity [7]. However, if the temperature of operation of the sensor is known, both these effects can be corrected for.

Another mechanism that leads to sensor temperature dependence is the air viscous damping which depends on the viscosity and the density of the air, both of which are dependent on temperature. Fig. 6 shows the variation of the air viscous damping as a function of temperature for the FPMOD type A for the first two modes of vibration and at atmospheric pressure. It can be seen that the variation in viscous damping for a temperature varying from 23 °C to 600 °C is ~ 0.14 . This corresponds to a decrease in relative displacement of ~ 2 and hence, a decrease of sensor sensitivity around the fundamental resonant frequency. However, the same variation of temperature only corresponds to a small variation of the optical path length (around 2.27 nm) due to the coupled thermal-optical and photo-elastic effects. Fig. 7 shows that the effect of the temperature is less significant if the point of operation is close to the point of maximum sensitivity [7].

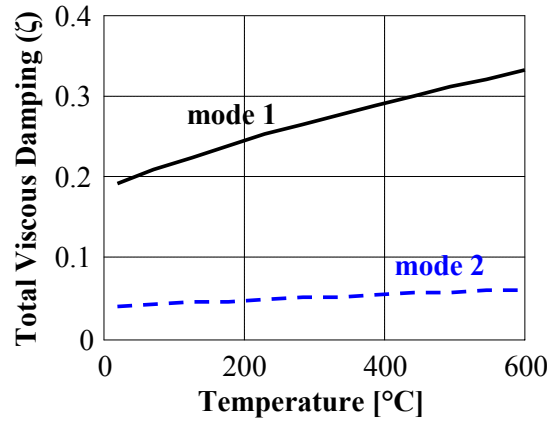


Fig. 6. Calculated temperature dependence of the total air viscous damping coefficient ($n = 1, 2$) for MFPD type A.

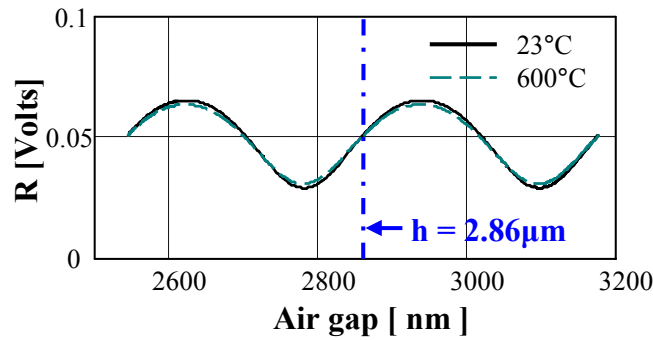


Fig. 7. Shift of the optical transfer function of the MFPD type A due to the temperature dependence of the optical path length.

The above results show that the sensitivity of the MFPD at high temperatures is mainly influenced by the effects of the thermally induced stress and the air viscous damping. Thermally induced stress can shift the operation point of the sensor, thus affecting the optical sensitivity, but it has a small effect on the variation of the optical path length. The significant effect that the temperature has on the air viscous damping reduces the overall sensitivity of the sensor, especially in regions around the fundamental resonant frequency. However, if the temperature is known, both of these effects can be compensated. A temperature-controlled sensor chamber is being designed to measure the effect of temperature in the frequency response of the MFPD cantilever beam at high temperatures.

Compared to standard interferometric techniques for the measurement of displacement (e.g.

stroboscopic and laser Doppler interferometers), the MFPD sensor needs neither a reference arm nor sophisticated stabilization techniques. Fig. 6 and Fig. 7 show that the power reflectance of the MFPD is a very sensitive measure of the air gap height. Using the solid MFPD cantilever beam type A, relative displacements as small as $0.139 \text{ nm}/\sqrt{\text{Hz}}$ were measured [7]. Furthermore, the small size of the sensor, the materials in which it can be built, and its simple construction make it suitable for on-chip integration and ideal for high-temperature applications. Though the optical detection of the frequency response of the MFPD cantilever beam has been implemented for a bare sensor, our experimental results demonstrate the accuracy of the optical interferometric readout on the determination of the frequency response of any free standing micromechanical device at the wafer level. The very simple configuration offered by this optical interferometric system is being considered in the future for integration in the sensor package.

5. Conclusions

We have reviewed recent advances in MEMS sensors for harsh-environments focusing on fabricated devices. SiC and group III semiconductor materials such as AlN, are an excellent candidate for the development of MEMS and NEMS for harsh environments. The excellent physical properties of particularly SiC enables its operation in harsh environments (e.g. high temperature, high pressure, high g, radiation and biological or chemical corrosive media). Piezoelectric properties of AlN, and good optical properties of robust materials such as SiC and silicon nitride may allow the improvement of functionality, reliability and sensitivity of classical sensors giving the opportunity of building up on-chip smart systems with a high degree of processing control. The review of different SiC sensor technologies shows unambiguously that although all necessary technology steps are well developed for the fabrication of SiC based MEMS devices, major problems such as reliability, packaging, wiring, and integration issues have to be overcome before they can be manufactured and used reliably in commercial high temperature applications.

The adaptability, resistance to EMI and RFI and high sensitivity make MOEMS sensors ideal for applications in harsh environments. In the past few years, much progress has been made in the development of simpler processing techniques and simplification of MEMS sensing elements. A new Fabry-Perot MOEMS displacement sensor for HT applications was presented. Results show that the small influence of high temperatures on the sensitivity of this sensor offers advantages in terms of size, cost, and operation in high temperature applications. In addition, by microfabricating an array of MFPD structures with different geometries, successful decoupling of the damping coefficients will result in a sensitive sensor array capable of measuring both temperature and pressure in addition to displacement. Finally, the simple configuration of the optical detection system makes it ideal for integration in the sensor package.

References

- [1]. J. Goetz, Sensors that can take the heat, *Sensors Magazine*, 20-38, June 2000.
- [2]. M. Mehregany, X. Fu and L. Chen, Silicon Carbide Micro/Nano Systems for Harsh Environment and Demanding Applications, *In Proceedings of the NSTI-Nanotech Conference 2006*, 3, pp. 471-474.
- [3]. D. Gao, M. Wijesundara, C. Carraro, R. Howe and R. Maboudian, Recent Progress Toward a Manufacturable Polycrystalline SiC Surface Micromachining Technology, *IEEE Sensors Journal*, 4, 4, 2004, pp. 441-448.
- [4]. C. Jacob, P. Pirouz, H. I. Kuo and M. Mehregany, High temperature ohmic contacts to 3C-Silicon Carbide Films, *Solid State Electronics*, 42, 12, 1998, pp. 2329-2334.
- [5]. R. C. Turner, P. A. Fuierer, R. E. Newnham and T. R. Shrout, Materials for High Temperature Acoustic and Vibration Sensors: A Review, *Applied Acoustics*, 41, 1994, pp. 299-324.

- [6]. D. Doppalapudi, R. Mlcak, J. Chan, H. Tuller, J. Abell, W. Li and T. Moustakas, Sensors based on SiC-AIN MEMS, *Electrochem. Soc. Proc.*, 6, 2004, pp. 287-299.
- [7]. P. Nieva, N. McGruer and G. Adams, Design and characterization of a micromachined Fabry-Perot vibration sensor for high-temperature applications, *J. Micromechanics and Microengineering*, 16, 2006, pp. 2618-2631.
- [8]. M. Haueis, J. Dual, C. Cavalloni, M. Gnielka, and R. Buser, A fully packaged single crystalline resonant force sensor, *J. Micromechanics and Microengineering*, 11, 2001, pp. 514-521.
- [9]. M. Suster, W. Ko and D. Young, An Optically Powered Wireless Telemetry Module for High-Temperature MEMS Sensing and Communication, *J. Microelectromechanical Systems*, 13, 3, 2004, pp. 536-541.
- [10]. S. Dakshinamurthy, N. R. Quick and A. Kar, Temperature-dependent optical properties of silicon carbide for wireless temperature sensors, *J. Physics D: Applied Physics*, 2007, pp. 353-360.
- [11]. M. Mehregany, C. A. Zorman, SiC MEMS: opportunities and challenges for applications in harsh environments, *Thin Solid Films*, 355-356, 1999, pp. 518-524.
- [12]. R. Nowak, M. Pessa, M. Suganuma, M. Leszczynski, I. Grzegory, S. Porowski, and F. Yoshida, *Applied Physics Letters*, 75, 1999, pp. 2070.
- [13]. R. Okojie, G. Beheim, G. Saad and E. Savrun, Characteristics of a Hermetic 6H-SiC pressure sensor at 600 °C, In *Proc. of the AIAA Space 2001 Conference and Exposition, Albuquerque, NM*, 2001, pp. 1-8.
- [14]. C. Wu, C. Zorman and M. Mehregany, Fabrication and Testing of Bulk Micromachined Silicon Carbide Piezoresistive Pressure Sensors for High Temperature Applications, *IEEE Sensors Journal*, 6, 2, 2006, pp. 316-324.
- [15]. A. Atwell, R. Okojie, K. Kornegay, S. Roberson and A. Beliveau, Simulation, fabrication and testing of bulk micromachined 6H-SiC high-g piezoresistive accelerometers, *Sensors and Actuators A*, 104, 2003, pp. 11-18.
- [16]. D. J. Young, J. Du, C. Zorman and W. Ko, High-Temperature Single-Crystal 3C-SiC Capacitive Pressure Sensor, *IEEE Sensors Journal*, 4, 2004, pp. 464-470.
- [17]. L. Pakula, H. Yang, H. Pham, P. French and P. Sarro, Fabrication of a CMOS compatible pressure sensor for harsh environments, *J. Micromechanics Microengineering*, 14, 2004, pp. 1478-1483.
- [18]. E. Eklund and A. Shkel, Factors affecting the performance of micromachined sensors based on Fabry-Perot interferometry, *J. Micromechanics Microengineering*, 15, 2005, pp. 1770-1776.
- [19]. N. Xiao-qi, W. Ming, C. Xu-xing, G. Yi-xian and R. Hua, An optical fibre MEMS pressure sensor using dual-wavelength interrogation, *Meas. Sci. Technol.* 17, 2006, pp. 2401-2404.
- [20]. W. Wang, R. Lin, D. Guo and T. Sun, Development of a novel Fabry-Perot pressure microsensor, *Sensors and Actuators A*, 116, 2004, pp. 59-65.
- [21]. R. A. Buser and N. F. De Rooij, Resonant Silicon structures, *Sensors and Actuators A*, 17, 1989, pp. 145-154.
- [22]. P. M. Nieva, G. G. Adams, N. E. McGruer, Design and modeling of a multifunctional MEMS Fabry-Perot sensor for the simultaneous measurement of displacement, pressure and temperature, In *Proc. of Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2007*, San Diego, CA, USA, Vol. 6529, 2007, p. 23.
- [23]. M. Fonseca, J. English, M. von Arx and M. Allen, Wireless Micromachined Ceramic Pressure Sensor for High-Temperature Applications, *J. Microelectromechanical Systems*, 11, 2002, pp. 337-343.

Guide for Contributors

Aims and Scope

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

Topics Covered

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

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

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submition.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2007.PDF

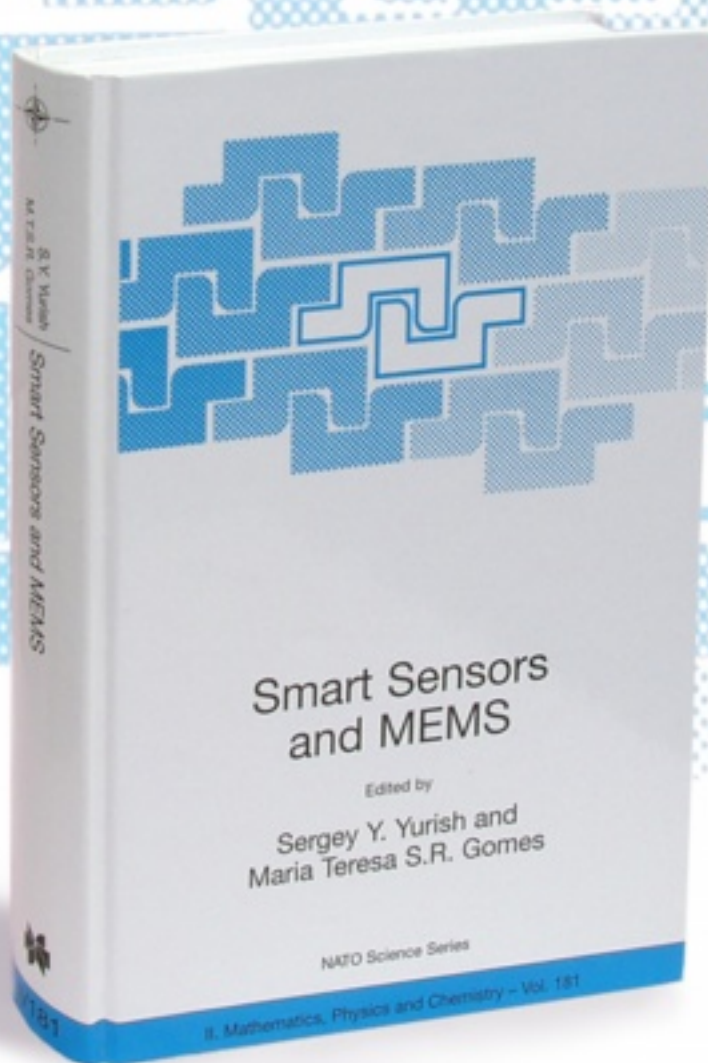
Smart Sensors and MEMS

Edited by

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

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

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



Kluwer Academic Publishers

Order online:

www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensors_and_MEMS.htm

www.sensorsportal.com