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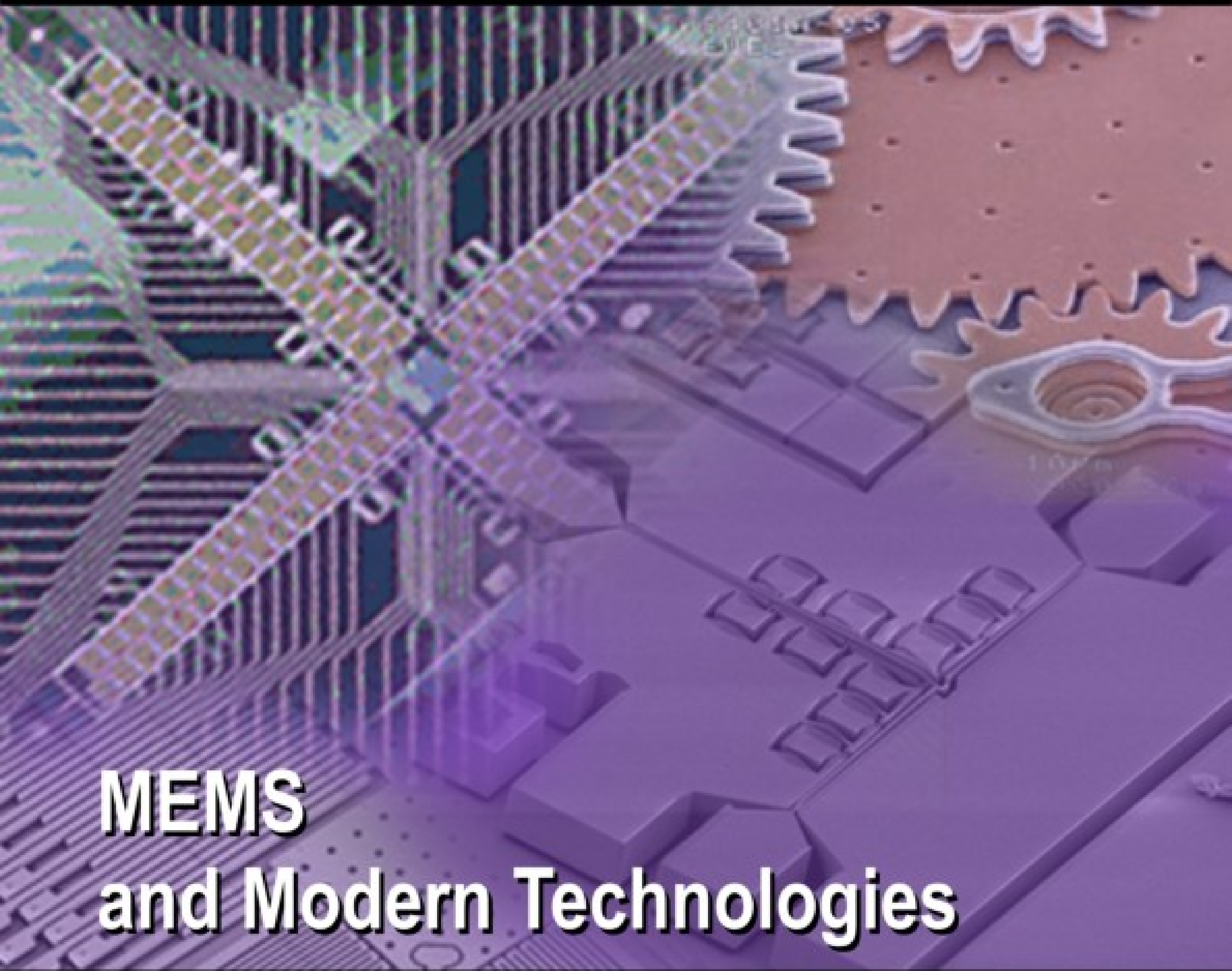

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Contents

Volume 91
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ISSN 1726-5479

Research Articles

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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Piezoelectric Zinc Oxide Based MEMS Acoustic Sensor

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Abstract: An acoustic sensors exhibiting good sensitivity was fabricated using MEMS technology having piezoelectric zinc oxide as a dielectric between two plates of capacitor. Thin film zinc oxide has structural, piezoelectric and optical properties for surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices. Oxygen efficient films are transparent and insulating having wide applications for sensors and transducers. An rf sputtered piezoelectric ZnO layer transforms the mechanical deflection of a thin etched silicon diaphragm into a piezoelectric charge. For 25-micron thin diaphragm Si was etched in tetramethylammonium hydroxide solution using bulk micromachining. This was followed by deposition of sandwiched structure composed of bottom aluminum electrode, sputtered 3 micron ZnO film and top aluminum electrode. A glass having 1 mm diameter hole was bonded on backside of device to compensate sound pressure in side the cavity. The measured value of central capacitance and dissipation factor of the fabricated MEMS acoustic sensor was found to be 82.4 pF and 0.115 respectively, where as the value of ~176 pF was obtained for the rim capacitance with a dissipation factor of 0.138. The response of the acoustic sensors was reproducible for the devices prepared under similar processing conditions under different batches. The acoustic sensor was found to be working from 30 Hz to 8 KHz with a sensitivity of 139 μV/Pa under varying acoustic pressure. *Copyright © 2008 IFSA.*

Keywords: Acoustic sensor, Zinc oxide, Rf sputtering

1. Introduction

Acoustic sensors are devices that employ elastic waves at frequencies from few Hz to low GHz range to measure physical, chemical or biological quantities. ZnO [1] was first piezoelectric material to be used for commercial applications e.g. accelerometers, force sensors, pressure sensors, acoustic sensors, ultrasonic transducers, etc. [2-8]. Because of its high piezoelectric coupling coefficient, great stability of its hexagonal wurtizite structure and its pyroelectric properties, it plays an important role in research and development of acoustic sensors. Sputtered ZnO piezoelectric layer [9] transforms the mechanical deflection of etched silicon diaphragm into a piezoelectric charge distribution. The first microphone [10] type acoustic sensor was realized in 1983 by using bulk micromachining of silicon. The sensor having circular electrode design [4] provides cancellation of temperature induced parasitic signal due to pyroelectric effect in ZnO. However circular silicon diaphragm formation is not possible by wet chemical etching due to inappropriate crystal orientation.

In our work, square diaphragm (3.6 x 3.6 mm^2) was realized using anisotropic etching of <100> silicon wafer in tetramethyl ammonium hydroxide (TMAH) solution at 80°C having SiO_2 as a masking layer. This paper represents the results of MEMS acoustic sensor fabrication technology using Rf magnetron sputtered ZnO piezoelectric layer. The diaphragm etched was having thickness 25 µm. The mask layout and layer detail is as shown in Fig. 1.

2. Experimental

A both side polished, 4” diameter, N – type, <100> oriented, 10 – 20 ohm-cm resistivity, 500 µm thickness wafer was used to fabricate MEMS acoustic sensor. Standard cleaning processes HNO_3 and RCA were used for wafer cleaning, followed by 1 µm thick thermal oxidation at 1000°C, which is used as masking layer for silicon anisotropic etching in tetra methyl ammonium hydroxide. A 25 µm thin diaphragm was etched in the TMAH solution at 80^0C. Processing steps after diaphragm formation by etching silicon in TMAH are like deionised water rinse, oxide etching in buffer HF and RCA cleaning. A fresh 0.5 µm thick silicon dioxide was thermally grown at 1000^0 C using wet oxidation before aluminum deposition by RF sputtering. A Dektak 6M double side mask aligner was used for patterning the bottom electrode followed by aluminium etching. This aluminium electrode was covered by 0.35µm thick PECVD silicon dioxide to avoid the interdiffusion of zinc oxide with aluminum and to increase the resistivity of zinc oxide for low frequency applications. Now 3.0 µm thick ZnO layer was deposited using RF sputtering at 250 watt. The XRD analysis of ZnO film is shown in Fig. 2.

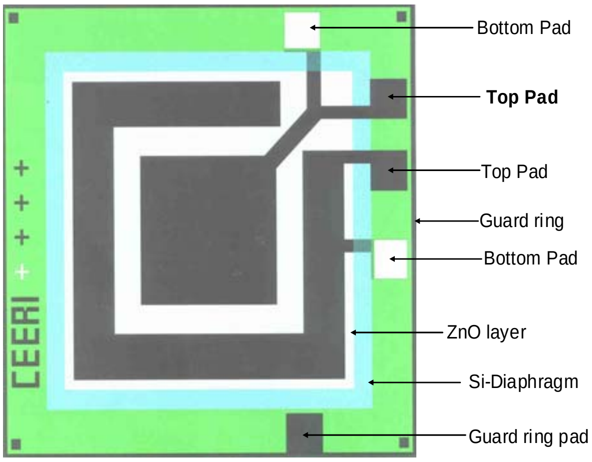

Fig. 1. Mask Layout of MEMS Acoustic Sensor.

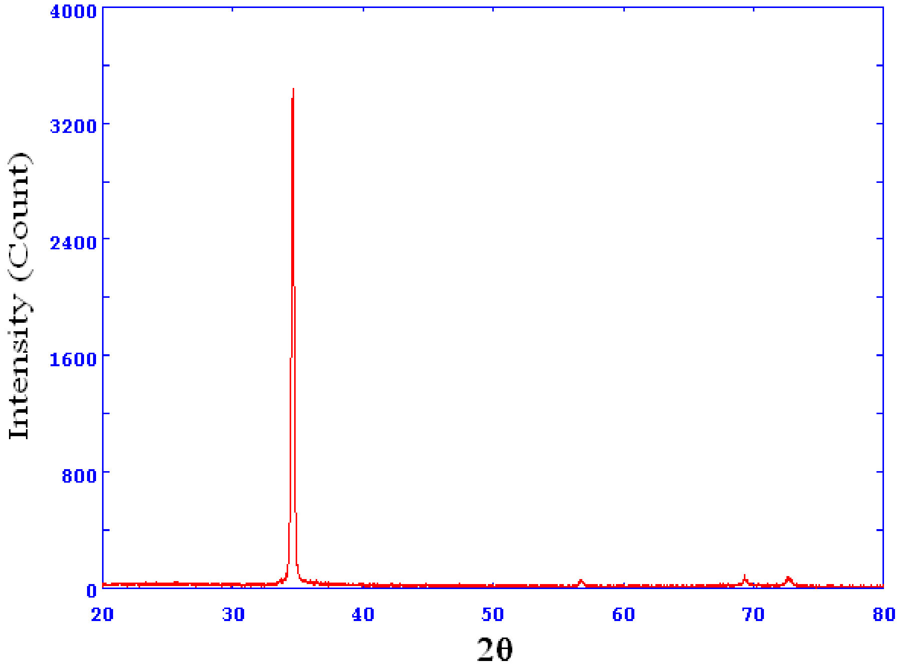

Fig. 2. XRD scan of zinc oxide by RF sputtering.

From the scan the value of 2θ is found to be 33.76°, which is slightly less than the bulk value 33.42° incating that films are in state of tensile stress. Surface morphology of the ZnO films has been studied using atomic force microscopy (AFM) and is shown in Fig. 3. The film structure is found to be dense, smooth and grain size is about 25 nm.

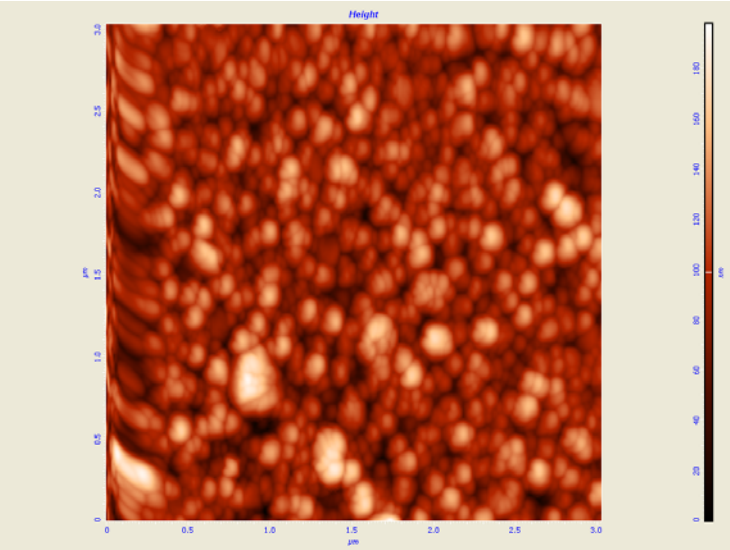

Fig. 3. AFM image of rf sputtered zinc oxide thin film.

Second lithography followed by ZnO etching in 1 % HCL, delineated the piezoelectric ZnO pattern. Again, 0.35 µm PECVD silicon dioxide covers the piezoelectric film. Third lithography using resist coating followed by aluminium etching makes top electrodes of the sensor. Finally 0.30 µm PECVD oxide covers the top electrode. Fourth lithography using thick oxide followed by RIE of PECVD oxide layers till aluminum bottom electrode was arrived and the device is open. Finally the photo resist was removed in acetone to complete the device fabrication.

The finished 4” wafer with various acoustic sensor chips was bonded with Pyrex glass having 1 mm diameter hole at center using glass to silicon anodic bonding as shown in Fig. 4. The chips get separated using dicing of complete wafer and then get packaged. The packaged acoustic sensor chip is shown in Fig. 5.

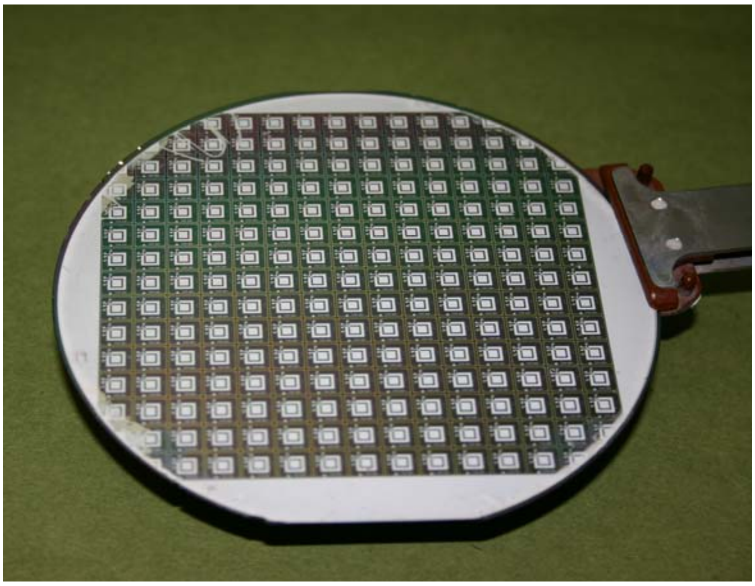

Fig. 4. Four inch complete fabricated wafer.

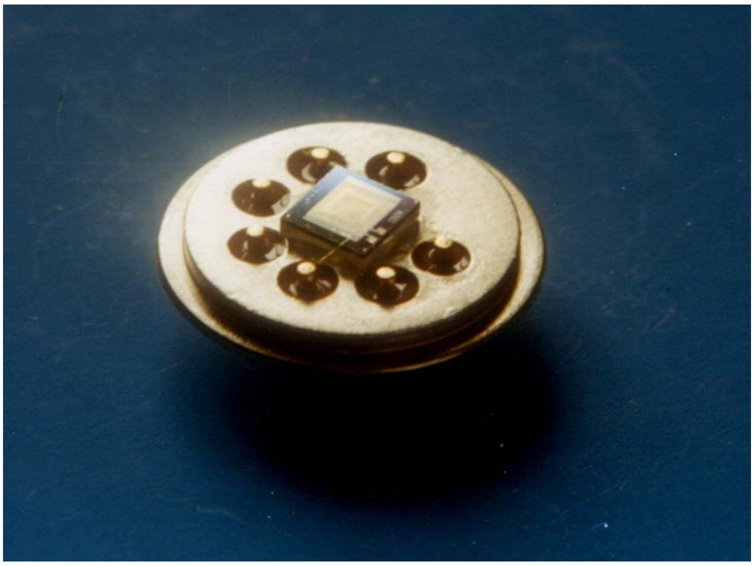

Fig. 5. Packaged MEMS Acoustic Sensor chip.

3. Response of Acoustic Sensor

The performance of acoustic sensor fabricated has been tested in packaged mode over a wide frequency range from 30 Hz to 8 kHz at different sounds pressure levels (SPL) from 120 to 180 dB.

The values of central and rim capacitance are found to be 82.4 and 171 pF. The loss (tanδ) is found to be relatively lower in magnitude 0.115 and 0.138 for central and rim capacitor indicating the effect of fabrication of layered structure on the MEMS diaphragm with fine interface without any inter-diffusion. The effect of change in ambient temperature on the device performance has also been studied and found to be negligible in the temperature range 25–95 ºC. The sensitivity of the diaphragm has been determined by using following formula [11, 12]:

$$S = Q_d/\omega A P\mathrm{ac},$$

where A is the area of the diaphragm, ω the angular frequency and Q_d the average volume displacement. The sensitivity is found to be 139 µV/Pa. The acoustic sensor is found to be working as a pressure sensor and the response is found to be upto120 psi. The variation of capacitance with pressure applied is as shown in Fig. 6.

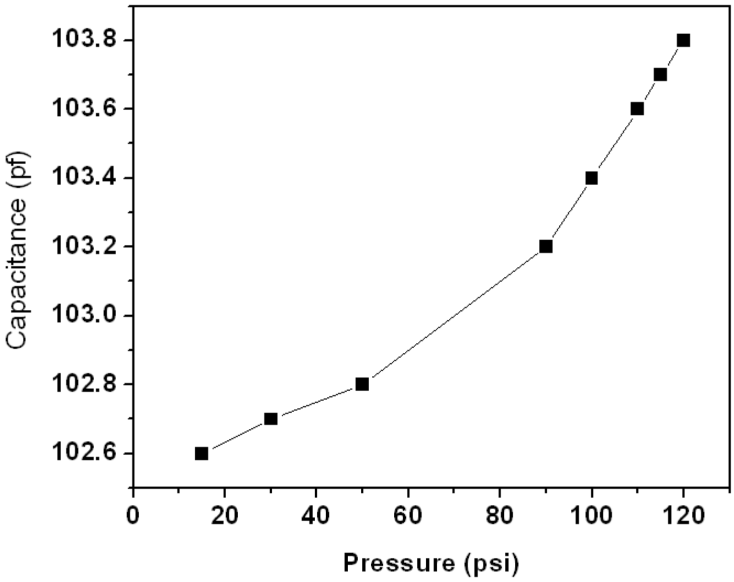

Fig. 6. Variation of capacitance with pressure.

4. Result

The acoustic sensor consists of silicon diaphragm etched from the bulk of silicon, piezoelectric ZnO layer and pair of Al electrodes is deposited over Si diaphragm. The measured value of central capacitance was 84.2 pf having dissipation factor 0.115 against the designed value of 81 pf. While the measured value of rim side capacitance was 176.0 pf having dissipation factor 0.138 against designed value of 171 pf. This small deviation on the capacitances values may be due to variation on the thickness uniformity of zinc oxide between two electrodes. Here the guard ring was also made around the device to avoid the parasitic capacitance. The acoustic sensor is found to be working as pressure sensor up to 120 psi.

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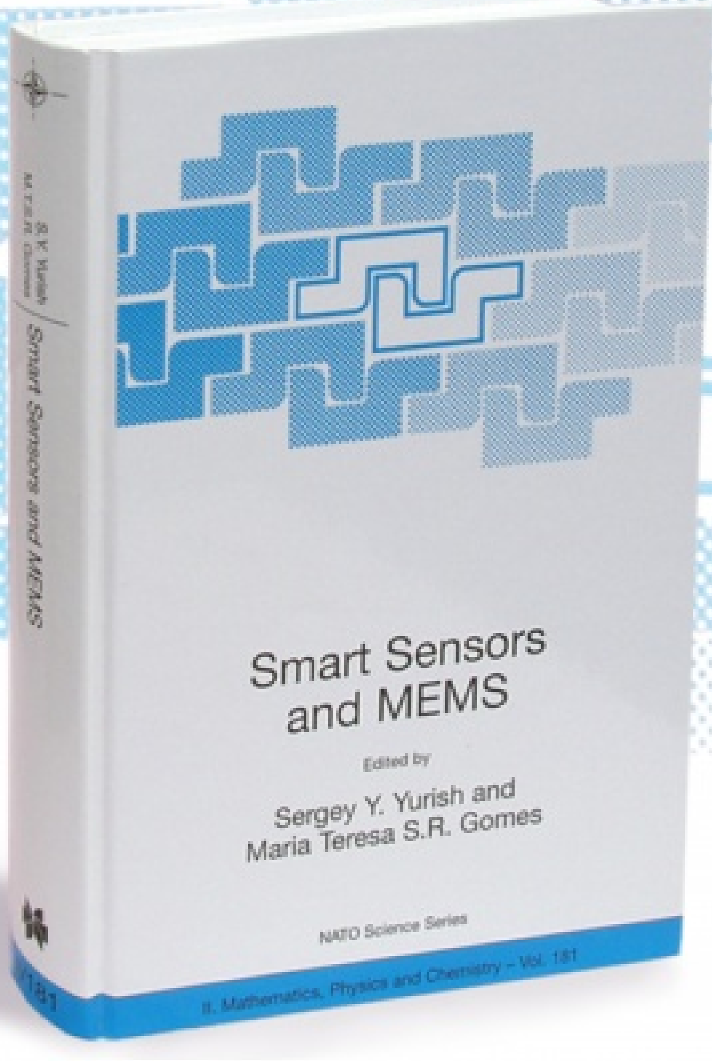

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