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A Review Article Modelling of CMOS based Highly Sensitive Mems Designing and Reducing Noise Signal and Also Enhancement Its Performance

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Abstract-This review article through light on a highly promising & demanding technology, which is set to revolutionize nearly every product category in present era, while discussing the Concept, Design & Development, Fabrication techniques and applications of micro electro-mechanical systems (MEMS) based Devices or systems. Microelectromechanical system discloses outstanding flexibility and adaptability in miniaturization devices followed by their compact dimension, low power consumption, and fine performance. The MEMS devices have numerous and very high potentials of creating a new field of applications for mobile equipment's with increased flexibility & more reliability. This work deals with research carried out for the development of MEMS based sensors & Actuators and appropriate uses of MEMS. This work carries information's regarding subsequent commercial and real life applications of MEMS and discusses various recent technological innovations carried out with their advantages & disadvantages. This work also describes the historical development of micro-electromechanical system (MEMS) sensor technology.

Keywords-MEMS, Scaling of MEMS Devices, Categorization and Applications of MEMS, Sensors, Actuators, MEMS Design & Fabrication Processes, Materials for MEMS..

I. INTRODUCTION

MEMS are typically defined as microscopic devices designed, processed, and used to interact or produce changes within a local environment. A mechanical, electrical, or chemical stimulus can be used to create a mechanical, electrical, or chemical response in a local environment. These smaller, more sophisticated devices that think, act, sense, and communicate are replacing their bulk counterparts in many traditional applications.

Micro-Electro-Mechanical-Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. These devices replace bulky actuators and sensors with micron scale equivalent that can produce in large quantities by fabrication process used in integrated circuits in photolithography. They reduce cost, bulk, and weight and power consumption while increasing performance, production volume and functionality by orders of magnitude.

Micro-Electro-Mechanical Systems (MEMS) are the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. Medical sensors, wireless communications, environments monitoring, military surveillance are some of the many applications that MEMS have been used in. MEMS technology is evolving fast, and a vast amount of conferences and scientific journals are nowadays available to keep track of current research directions, advances and results. Among the most important conferences that deal with MEMS work are the IEEE Micro Electro Mechanical Systems conference and the International Society for Optical Engineering (SPIE) conferences.

Some of the most important journals are the Journal of Microelectromechanical Systems (IEEE/ASME), the Journal of Micromechanics and Microengineering (Institute of Physics), the Journal of Microlithography, Microfabrication, and Microsystems (SPIE), the Journal of Microfluidics and Nanofluidics (Springer) [1]. This review has been conducted with consideration of all the sources cited here.

II. LITERATURE REVIEW

Xiao-Yong Fang, Destructive Reliability Analysis of Electromagnetic MEMS Micromirror Under Vibration Environment: Micro-Electro-Mechanical Systems (MEMS) micro-mirrors have shown great potential in consumer applications, such as Light Detection and Ranging (LiDAR) devices and portable laser projectors. The LiDAR based on electromagnetic MEMS micro-mirror is usually exposed to vibration loads for autonomous vehicles, which results in the necessity for the destructive reliability assessment of micromirrors under vibration environment, but such studies are rarely reported. This paper explores the destructive reliability of electromagnetic MEMS micromirror under vibration environment according to the JESD22-B103B standard. The reliability evaluation is conducted by experimental tests, finite element stress analysis and theoretical dynamic response analysis. Micromirrors are tested under sweep excitation, and they are failed with the vibration level of around 33 g.

The failure and stress analysis demonstrate that the crack fracture is located at the root of the slow axis. The nonlinear relationship between the peak displacement of the balance frame and acceleration levels is investigated through theoretical analysis. The nonlinearity of stiffness hardening is induced by the axial tensile strain of the beam, which contributes to the displacement-reduction of the gimbal. This work provides some valuable suggestions for the optimization design of MEMS micromirrors to improve the acceleration tolerance level in vibration environment.

Han Woong Yoo, Experimental Evaluation of Vibration Influence on a Resonant MEMS Scanning System for Automotive Lidars: This article demonstrates a vibration test for a resonant MEMS scanning system in operation to evaluate the vibration immunity for automotive lidar applications. The MEMS mirror has a reinforcement structure on the backside of the mirror, causing vibration coupling by a mismatch between the center of mass and the rotation axis. An analysis of energy variation is proposed, showing the direction dependency of vibration coupling. Vibration influences are evaluated by transient vibration response and vibration frequency sweep using a single tone vibration for translational y- and z- axis.

The measurement results demonstrate standard deviation (STD) amplitude and frequency errors are up to 1.64% and 0.26%, respectively, for 2grms single tone vibrations on y axis. The simulation results also show a good agreement with both measurements, proving the proposed vibration coupling mechanism of the MEMS mirror. The phased locked loop (PLL) improves the STD amplitude and frequency errors to 0.91% and 0.15% for y axis vibration, corresponding to 44.4% and 43.0% reduction, respectively, showing the benefit of a controlled MEMS mirror for reliable automotive MEMS lidars.

Kohei Shibata, A Simplified Analytical Damping Constant Model for Perforated Proof Mass Structure of MEMS Capacitive Accelerometer by Multi-Layer Metal Technology: This paper describes a simplified analytical model of a damping constant b to design a MEMS capacitive accelerometer by the multi-layer metal technology. The proposed model is introduced on the basis of combining the theoretical equation with the approximate form factor based on the measured data. In order to create the model, we fabricate several types of the MEMS capacitive accelerometers with the different structure parameters such as the etching hole area, the perforated proof mass area, and the gap. The calculation results show that the damping constant b by the proposed model is in accord with the measured b. Moreover, the Brownian noise B N calculated by the proposed model is also consistent with the measured B N . Therefore, it was confirmed that the proposed model will be effective for the analysis and the design of the MEMS capacitive accelerometer with the perforated proof mass.

SeyedfakhreddinNabavi, Surface Micromachined Out-of-plane Electrostatic MEMS Actuator Integrated with Displacement Sensor: We propose an out-of-plane electrostatic MEMS actuator capable of sensing its displacement. A repulsive force electrostatic arm is designed to form an actuator that pushes a suspended plate away from the substrate. A single capacitance sensing electrode is located beneath the moveable plate to measure the actuator vertical displacement.

We demonstrate that the actuator, which was fabricated using a standard surface micromachining process, can provide a vertical displacement of 1.8 µm when excited with a 50 V DC voltage. This movement results in a reduction of the sensing electrode capacitance. Hence, the displacement of the actuator can be monitored as a function of the change in capacitance at the sensing electrode. This self-sensing feature allows the actuator to be utilized in closed-loop control systems as well as self-aligned optical platforms.

Yung-Chian Lin, Vertical Integration of Pressure/ Humidity/Temperature Sensors for CMOS-MEMS Environmental Sensing Hub: This study presents the environmental sensing hub with vertical integration of humidity, pressure, and temperature sensors on a single chip (Fig. 1). The presented device is fabricated through TSMC 0.18 µ m 1P6M CMOS platform, and in-house post-CMOS processes. The proposed environmental sensing hub has following features: (1) monolithic integration of humidity (H), pressure (P), and temperature (T) sensors to form the sensing hub, (2) vertical integration of H/P/T sensors to reduce the footprint of chip (as compare with the existing side by side designs).

Measurement results of presented environmental sensing hub are: humidity sensor with sensitivity of 2.025fF/%RH, pressure sensor with sensitivity of 0.38fF/kPa, and diode temperature detector with sensitivity of 1.6mV/ o C.

Giuseppe Michetti, Hybridly Integrated MEMS-IC RF Front-End for IoT with Embedded Filtering and Passive Voltage Amplification: Enabling Internet of

Things (IoT) in harsh environments relies on improving battery life, which can be achieved using Wake-Up Receivers (WuRX) with high quality factor (Q) RF components. MEMS micro-acoustic RF resonators have been proposed as strategic components to provide large passive voltage amplification as well as noise and interference rejection, ultimately providing means to reduce system-level link budget and power-hungry cells count in the back-end circuitry.

In this work, we present an integration effort of high-Q MEMS with an IoT RF front-end. Integration issues are discussed first at simulation level, and then verified on anWuRX designed thanks to the integration of in-house fabricated FBAR resonator and commercial integrated circuits. The result is a compact IoT RF sensor operating at 820 MHz with an outstanding measured RF gain of 12 dB, a 3 dB bandwidth of 7 MHz and an out-of-band rejection of 23 dB. Communication test shows that digital bit streams are fully recoverable at –46 dBm RF power with zero error rates above that threshold.

Ren Kaneta, Sensitivity Enhancement of MEMS Tactile Sensor by Redesign of Microcantilever and Strain Gauge: In our previous work, MEMS tactile sensor using microcantilevers embedded in the elastomer has been developed. The gripping control of a soft object and the data acquisition which reflected the texture of the object surface has been carried out using this sensor. However, improvement of its sensitivity for more precise control or texture information is an important issue. In this work, cantilever size and strain-gauge arrangement in the sensor are newly designed for sensitivity improvement. As a result of fabrication based on the new design, it is demonstrated that a drastic sensitivity improvement is achieved. Furthermore, it is found that the sensitivity depends on the size of the cantilever.

Benjamin Cyr, Why Lasers Inject Perceived Sound into MEMS Microphones: Indications and Contraindications of Photoacoustic and Photoelectric Effects: Recent work published in the cybersecurity research community demonstrated a surprising discovery: modulated, low-power lasers can reliably inject falsely-sensed acoustic signals in MEMS microphones. However, the work remained mute on the physics-based causality with only passing conjectures on why the technique works. Until the physics of the energy transfer is understood, it will be difficult to design defenses with convincing evidence of effectiveness and reliability.

In this work, we provide a methodology to test the presence and contribution of the photoacoustic and photoelectric effects to laser signal injection in MEMS microphones. Our programmable, precise laser experiments on MEMS devices in a vacuum chamber creates conditions to sufficiently isolate photoacoustic effects from photoelectric effects in a diverse set of microphones. The results indicate a dominance of photoacoustic effects while also providing contraindications of photoelectric effects. This leads to profound implications on laser injection defenses as modern MEMS designs do not consider security requirements to protect against laser signal injection via photoacoustic phenomena.

Chiao-Teng Jordan Chung, An Ultra-low Power Voice Interface Design for MEMS Microphones Sensor: This paper develops an ultra-low power single-chip voice interface consisting of a programmable gain amplifier (PGA) and 12-bit asynchronous successive-approximation register analog-to-digital converter for MEMS microphone sensor. The PGA's current can be scaled down from 100uA to 10uA and the measured SNR in 94dBSPL (14mV) is 74dB and 67dB, respectively. It can also set a programmable gain of 40/34/31/28dB for specific demands of microphone.

Total Harmonic Distortion (THD) is measured at different output amplitudes, the design exhibits lower than 0.25% THD+N with 94 dBSPL(14mV) at 1kHz. The SAR ADC operates with an 8-kHz sampling rate and consumes only 400nW from a 1.2V VDD. The measured signal-to-noise and distortion ratio (SNDR) is 67.46 dB and spurious-free dynamic range (SFDR) is 87.97 dB. Its sampling rate can be easily scaled from 1M-S/s to 1S/s with a linear power scaling feature. The proposed circuit realized in 180nm CMOS process demonstrates a successful voice data processing (speech/voice recognition, presentation) with the MEMS sensor and an off-chip platform.

OsamahLutfQaid Al-Mahdi, Modeling of a Highly Sensitive Lorentz Force-Based CMOS-MEMS Magnetometer for E-Compass Applications: Magnetometers are devices used to measure the magnetic field, however, most commercialized magnetometers are facing several disadvantages. If not being of low sensitivity, the device attains a high cost and high-power consumption. Thus, it is a necessity to mathematically design and model CMOS-MEMS magnetometer which will be able to detect low magnetic fields. A fine simulation using ConventorWare software is applied to validate the designed magnetometer model. In this paper, Lorentz force and an integration of CMOS and MEMS technologies were implemented

The designed magnetometer is made in one mode (out-of-plane) to function in one axis (z-axis), and the CMOS-MEMS magnetometer output signal is determined by piezoresistive sensing technique as piezoresistors are connected in full Wheatstone bridge circuit. A 3-D solid model was created and meshed based on the theoretical calculations and data. A simulation result shows that theoretical and simulation results are almost the same, except that resonance frequency is of 11% difference and 11.6% for quality factor. The average percentage difference between calculated and simulated displacement when magnetic field is detected to be of 2.801%.

Saeed S. Ba Hashwan, Design and Simulation of MEMS Electrostatic Resonator for Ammonia Gas Detection Based on SOIMUMPs: The analytical modeling, design, and simulation of micromachined MEMS resonator for ammonia gas detection is presented in this paper. The MEMS resonator is designed to be vibrated electrostatically using interdigitated comb fingers. The demonstrated device is designed to be capable to carry micro-ring resonator and vibrated in-plane laterally to enhance the sensitivity of the gas detection. This MEMS resonator working principle is based on the changes in the output signal wavelength due to the change in the effective refractive index introduced by the ammonia gas.

The resonant frequency of the actuator and the pull-in voltage have been calculated theoretically and found to be 11.15 kHz and 79.7 V respectively. The design and simulation of the micromachined micro-resonator has been carried out using CoventorWare software. Furthermore, the mathematically modeled results were verified using the finite element analysis software and the result shows a good agreement within 1.06% error between the modeled and simulated frequencies where the modeled and the simulated frequencies are found to be 11.15 kHz and 11.27 kHz respectively.

Juntian Qu, MEMS-Based Platforms for Multi-physical Characterization of Nanomaterials: A Review: Functional nanomaterials possess exceptional mechanical, electrical and thermal properties which have significantly benefited their diverse applications to a variety of scientific and engineering problems. In order to fully understand their characteristics and further guide their synthesis and usage, the multi-physical properties of these nanomaterials need to be characterized accurately and efficiently.

Among various experimental tools for nanomaterial characterization, micro-electro-mechanical systems (MEMS) based platforms provide merits of high accuracy and repeatability, well-controlled testing conditions, small footprint, and compatibility with high-resolution imaging facilities (e.g., electron microscope and atomic force microscope), thus, various MEMS-enabled techniques have been well developed for characterizing the multi-physical properties of nanomaterials.

In this review, we summarize existing designs of MEMS-based platforms for nanomaterial characterization, outline critical experimental considerations for nanomaterial characterization using MEMS devices, and discuss applications of the MEMS-based platforms to characterizing multi-physical properties of the nanomaterials.

Victor S. Balderrama, MEMS Piezoresistive Pressure Sensor Based on Flexible PET Thin-Film for Applications in Gaseous-Environments: This experimental study presents the operation of pressure sensors made from low-temperature flexible substrates. Design, simulation, fabrication, and characterization are carried out with a number of fabricated flexible pressure devices. Simulations are used to optimize the sensor parameters such as the geometrical shape, electrical potential output, sensitivity and working-range of the sensor, thus predicting the sensing behavior before fabrication. The behaviour of the devices is simulated by using COMSOL Multiphysics.

The pressure structure consists of a substrate of polyethylene terephthalate (PET) thin-film used as a diaphragm. A thin layer of indium tin oxide (ITO) on the PET substrate is obtained and used as a first conductive metallic track. Subsequently, nichrome (NiCr 80/20 wt%) alloy material was deposited by electron beaming to generate four piezoresistors with thickness of 50 nm that can be used to detect resistance change using a Wheatstone bridge when the sensor is exposed to different working pressures.

Aluminum metallic tracks of 200 nm in thickness are deposited by sputtering in order to connect the four piezoresistors. A working range of pressure is applied from 0 kPa to 130 kPa. Resistivity and sensitivity measured values were 1.37 x 10-3 Ω-cm and 6.365 mV/kPa respectively. All simulations and experimental results showed that the sensor characteristics are favorable for applications where the pressure is below 130 kPa.

Shangshu Yang, JMEMS Letters Ultra-Low Relative Frequency Split Piezoelectric Ring Resonator Designed for High-Performance Mode-Matching Gyroscope: This letter presents a high-performance piezoelectric ring resonator with ultra-low relative frequency split designed for mode-matching gyroscope. Design optimization for supporting dog-leg shaped spokes and passive temperature compensation are implemented in order to minimize the frequency split and improve the temperature stability. The reported piezoelectric ring resonator is driving and sensing in a pair of degenerate third-order wineglass modes. It achieves an ultra-low relative frequency split of 11.2 ppm at its resonant frequency of 456.68 kHz. The maximum variation of the relative frequency split is smaller than 12.32 ppm within the temperature range of 25 °C to 125 °C. This work offers a new insight on the design of resonator gyroscope with low frequency split and good temperature stability.

Andrea López-Tapia, Micromotors unit based on CMOS-MEMS technology integrated on a single chip: This paper shows the design for MEMS linear and rotary micromotors including their respective control circuits, elevation voltage stage and sensors, all together in a single chip. They were designed under the rules of the standard 0.5-micron CMOS technology of On Semiconductor. With simulations carried out in OrCAD PSPice, the designed control circuits of both linear and rotary micromotors were tested; the simulation helps us to verify their correct operation. Finally, the elevation voltage stage between control circuit and electrodes allows the application of the necessary voltage to drive the micromotors.

III. CONCLUSION

The paper summarizes the current status of automated design of MEMS. The situation is that in many areas it is still in very early stages. Most presented works deal with only one level of automated design apart from very few. A relatively mature part of design automation is the model reduction techniques, where very good results were obtained to help designers to avoid the use of FEAs to simulate MEMS behavior in all design stages. The system-level modeling, although giving good results mostly using artificial intelligence techniques, was mainly applied to very simple MEMS devices and/or very simple combination of MEMS components.

Applications on more complex devices are needed to validate the level of accuracy and robustness of such techniques. On the physical level, the existing software tools are sufficiently developed. However, when it comes to the process level, very few works approached the task successfully. Moreover, they all only address simple geometries and few process variables. A more standard way of MEMS processing is the line to follow in order to make the models follow the constraints induced by the process, since there is no point in designing MEMS if it is impossible or too costly to produce /fabricate them.

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