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Some Studies on Investigating the Concept of Micro-electromechanical System based Piezo-resistive Pressure Sensor- A Critical Review

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Abstract— This paper deals with the topic of MEMS pressure sensor. It describes the working principle and the theory related to it. The various applications of pressure sensor such as in blood pressure measurement in medical field, tire pressure monitoring system and airbag firing system in automotive industry. Recent developments on the MEMS pressure sensor are also covered along with its future aspects.

Keywords— MEMS, diaphragm, micro-sensors, micro-machine, piezoresistors,

1. INTRODUCTION

MEMS are miniature devices, which integrate actuators, sensors, and processors to form intelligent systems. Its functional sub-systems can include electronic, optical, mechanical, thermal or fluidic.[1]
The real power of this technology is that many machines can be built at the same time across the surface of the wafer with no assembly required.
Micro-machining is one of the methods to develop mems. In this process mechanical microstructures are fabricated on the surface of a wafer by depositing different types of layers. The final structure include the structural layers while the sacrificial layers are removed in the final stage of fabrication through the edging process.[2]

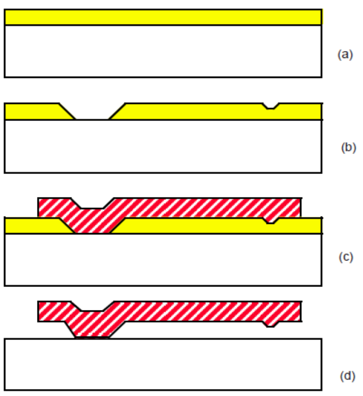

Fig. 1: Cross-sectional schematic demonstration of surface micromachining. (a) Sacrificial layer deposition, (b) definition of the anchor and bushing regions, (c) structural layer patterning, and (d) free-standing microstructure after release.

The various advantages of MEMS are that they include miniaturization, reduced cost of fabrication, and real time control.
The component used in MEMS range in between 1 to100 micrometers in size while the devices vary from 20 micrometer to few millimeters.
They consist of a central unit that process data i.e., microprocessor and several micro-sensors which interact with the surrounding.
The micro-sensors and micro-actuators are approximately categorized as transducers which are defined as devices that convert energy from to another. In this case of micro-sensors, the devices typically converts a measured mechanical signal into an electrical signal.[3]
The types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. The term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while in some other parts of the world they are called “Microsystems Technology” or “micromachined devices”.

2. PRESSURE SENSOR TECHNOLOGY

MEMS pressure micro-sensors typically use a flexible diaphragm that deform in the presence of a pressure signal.

The first monolithic integrated pressure sensor with digital (i.e., frequency) output was designed and tested in 197l at CWRU,4 as part of a program addressing biomedical applications. Miniature Si diaphragms with a resistance bridge at the center of the diaphragm and sealed to the base wafer with a gold (Au)-tin (Sn) alloy were developed for implant and indwelling applications. During field evaluation, it was found that the packaging of the sensors determined their performance, and that piezoresistive sensors were very sensitive to interference, such as sideways forces, making them inaccurate for many biomedical applications. To achieve better sensitivity and stability, capacitive pressure sensors were first developed and demonstrated at Stanford University

in 1977 and shortly afterward at CWRU. The first integrated monolithic capacitive pressure sensor was reported in 1980.[4]

In general, capacitive pressure sensors exhibit superior performance compared to traditional piezoresistive pressure sensors. However, the relatively complex design and implementation of signal-processing circuitry required for electronic readout initially limited the widespread availability of capacitive pressure sensors. During the last 15 years, various processing and transduction techniques have been used to develop new or improved Si pressure sensor designs. While such developments are ongoing, advanced piezoresistive Si pressure sensors still account for almost all of the Si pressure sensor market. During the same period, Si microsensor technology has matured substantially, and a variety of sensors have been developed for measuring position, velocity, acceleration, pressure, force, torque, flow, magnetic field, temperature, gas composition, humidity, pH, solution/body fluid ionic concentration, and biological gas/liquid/molecular concentrations. Some of these sensors have been commercialized.

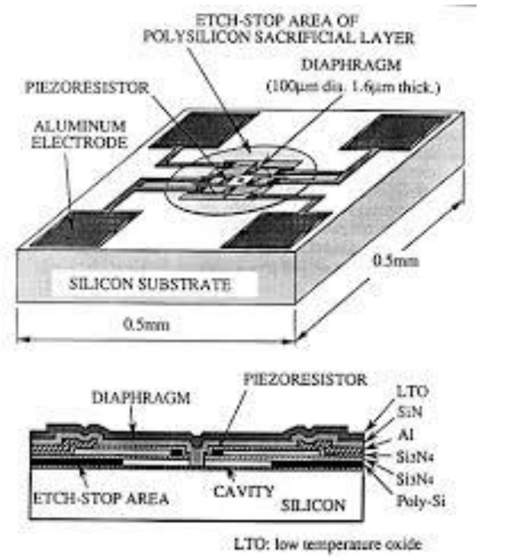

Fig. 2: Piezoresistive Pressure Gauge

It is a sealed cavity of a MEMS devices, comprises a resonant MEMS device having pressure sensor resonator element which comprises an array of opening. The resonant frequency of the resonant MEMS device is a function of the pressure in the cavity, with the resonant frequency increasing with pressure. Over the pressure range of 0 to 0.1 kpa, the average change in frequency is at least 10^{-6}/Pa. thus it is possible to sense the pressure of the device with resonance frequency that is sensitive to the pressure.

MEMS pressure sensors is created by bulk micromachining to create the silicon membrane. Piezo-resistors are patterned across the diaphragm. The sensor dies is then bonded to a glass substrate, to create a sealed cavity under the diaphragm. The die is packaged in such a way that the top side of the diaphragm is exposed to the environment. The change in ambient pressure forces a deformation of the diaphragm, resulting in a change of resistance of the piezo-resistors. On-chip electronics measure the resistance changes, resulting in a voltage signal. Thus sensors can include a temperature controller for constant temperature operation.

MEMS pressure sensors are basically categorized as piezo-resistive and capacitive type. The fabrication of piezo-resistive type is much easier as one can produce it by doping Boron ion on Silicon effortlessly.

Piezo-resistive pressure sensors technology has become a low cost, highly reliable batch fabrication manufacturing technology. In practice, the technology is slightly more complex, including ion imperfection for improved control of the piezo-resistor fabrication, etch stops for better control of the diaphragm thickness.

Major applications for pressure sensors are in automotive, medical, industrial/process control, aerospace and defense. In terms of turnover automotive and process control are the biggest segments, in terms of numbers automotive is the largest with medical coming second. A relative new segment in automotive is Tire Pressure Management. This application is becoming mandatory in the USA and needs a system with can not only detect the tire pressure, but can also transfer the information wireless, preferable this is also a system which is self-sustaining and needs therefore some form of energy harvesting.

3. APPLICATIONS:

Medical Applications:

In the medical applications market, MEMS components are used in diagnostic, monitoring, surgical, and therapeutic devices. These devices employ MEMS as pressure sensors, temperature sensors, flow sensors, accelerometers, optical image sensors, and silicon microphones, among other uses.

The techniques used to fabricate MEMS devices are similar to the techniques used to make silicon-based integrated circuits (i.e., microprocessors or memory chips), which means that MEMS manufacturing can enjoy the kind of scaling advantages and manufacturing efficiencies that have long been a hallmark of integrated circuit (IC) fabrication.[5]

Additionally, MEMS devices have several advantages for medical applications that make their use attractive: the 2 to 100μm-sized features typically found in MEMS devices are compatible in size with living cells and fine physiological structures in the human body. MEMS devices are manufactured with materials such as silicon, silicon dioxide (glass), precious metals like titanium, gold, and platinum, and organic materials like Parylene, that are biocompatible.

Automotive Applications:

A TPMS with driving status judgment and low-power measurement is designed and realized. A vibration switch is applied to judge the different status of running and stopping. Based on the judgment of driving status, pressure and temperature, different operations will be carried out in order to achieve lower power consumption. The whole system is working intermittently. It has a good performance with a theoretical lifespan of 2 years. The tested communication distance is more than 30m and the resolution is better than 4KPa. A MEMS pressure sensor using SOI wafer with high consistency and accuracy for this TPMS is designed and fabricated. Deep trench etching is adopted to make pressure reference cavity. The ratio of sensitivity variance to its average is 3.5%, which illustrates a good consistency. The total accuracy of the sensor is better than 0.3% and the nonlinearity is less than 0.2%.[6]

The MEMS pressure sensor is also designed in airbag firing system. When the vehicle experiences the strong impulsive force, there is a sudden change of pressure where the impulsive force is applied. The MEMS pressure sensor will detect this sudden change of pressure and will send a signal to fire the airbag and not as an independent document. Please do not revise any of the current designations.

Aerospace Applications:

A series of MEMS sensor clusters has been developed with a data acquisition and control module for local measurements of shear stress, pressure, and temperature on an airfoil. The sensor cluster consists of two shear stress sensors, two pressure sensors, and two temperature sensors on a surface area of 1.24 mm x 1.86 mm. Each sensor is 300 microns square and is placed on a flexible polyimide sheet. The shear stress sensor is a polysilicon hot-film resistor, which is insulated by a vacuum cavity of 200 x 200 x 2 microns. The pressure sensors are silicon piezoresistive type, and the temperature sensors are also hot film polysilicon resistors. The total size of the cluster including sensors and electrical leads is 1 Omm x 1 Omm x 0.1 mm. A typical sensitivity of shear stress sensor is 150 mV/Pascal, the pressure sensors are an absolute type with a measurement range from 9 to 36 psia with 0.8mV/V/psi sensitivity, and the temperature sensors have a measurement resolution of 0.1 degree C.

The sensor clusters are interfaced to a data acquisition and control module that consists of two custom ASICs (Application Specific Integrated Circuits) and a microcontroller. The data acquisition and control module transfers data to a host PC that configures and controls a total of three sensor clusters.[7]

4. RECENT DEVELOPMENTS

- *Optical MEMS pressure sensor based on Fabry-Perot interferometry* :

By employing the surface and bulk micro-electro-mechanical system (MEMS) techniques, it was designed and demonstrated a simple and miniature optical Fabry-Perot interferometric pressure sensor, where the loaded pressure is gauged by measuring the spectrum shift of the reflected optical signal.

From the simulation results based on a multiple cavities interference model, it was found that the response range and sensitivity of this pressure sensor can be simply altered by adjusting the size of sensing area. The experimental results show that high linear response in the range of 0.2–1.0 Mpa and a reasonable sensitivity of 10.07 nm/MPa have been obtained for this sensor.[8]

- *Novel Mems Pressure And Temperature Sensors Fabricated On Optical Fibers:*

Fabrication and initial testing of novel optically interrogated pressure and temperature sensors is fabricated directly on optical fibers using microelectromechanical systems technology. A new micromachining process for use on a flat fiber end face that includes photolithographic patterning, wet etching of a cavity and anodic bonding of a silicon diaphragm is utilized. Two prototype pressure sensors, fabricated on 400 μm diameter multimode fibers, have been tested displaying an approximately linear response to static pressure (14–80 psi).
A prototype temperature sensor, fabricated by anodically bonding an ultra-thin crystalline silicon onto a fiber end face, has been tested in the range 25–300 °C. A minimum detectable temperature variation of 6 °C is observed. Since these sensors are significantly miniaturized, they will find application in situations where small size is advantageous and where dense arrays may be useful.

- *A novel MEMS pressure sensor with MOSFET on chip:*

A novel MOSFET pressure sensor was proposed based on the MOSFET stress sensitive phenomenon, in which the source-drain current changes with the stress in channel region. Two MOSFET's and two piezoresistors were employed to form a Wheatstone bridge served as sensitive unit in the novel sensor. Compared with the traditional piezoresistive pressure sensor, this MOSFET sensor's sensitivity is improved significantly, meanwhile the power consumption can be decreased. The fabrication of the novel pressure sensor is low-cost and compatible with standard IC process. It shows the great promising application of MOSFET-bridge-circuit structure for the high performance pressure sensor. This kind of MEMS pressure sensor with signal process circuit on the same chip can be used in positive or negative Tire Pressure Monitoring System (TPMS) which is very hot in automotive electron research field.[10]

- *MEMS pressure sensors for aerospace applications*

MEMS (microelectromechanical systems) pressure sensors have been designed, fabricated and characterized. The fabrication process is fully compatible with IC (integrated circuit) fabrication such that multifunctional microelectronics can be directly integrated on the same chip for advanced aerospace applications. These pressure sensors are designed based on the piezoresistive sensing principle on surface micromachined polysilicon thin diaphragms. Both square- and circular-shape diaphragms with thickness of 2 μm and width (diameter) of 100 μm have been designed and fabricated. Prototype pressure sensors with 100 Psi in full scale have a measured sensitivity of 0.15 mV/V/Psi and a maximum linearity error of ±0.1% FSS (full scale span).

5. FUTURE OUTLOOK:

- *Small, self sustaining, wireless sensor networks:* the most important market trends are those reliant on merging functionalities in products such as cameras, music players, computing, mobile phones, and portable consumer electronics in general, as well as the merging of MST/MEMS technologies with high volume electronics. Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- *DNA chips:* Future lab-on-a-chip technology may include implantable "pharmacy-on-a-chip" devices precisely and timely releasing drugs into a body, without needing needles or injections. The delivery of insulin is one such application, as is the delivery of hormones, chemotherapy drugs and painkillers.
- *Microfluidic devices*: there are many uses expected for microfluidics in all kind of analytical equipment such as mass spectrometry and chromatography (See Figure -62-). A microfluidics platform integrates sample definition, injector, detectors and diagnostics leading to fast analysis, increased ease of use, handheld and remote operation. They will not only be used for home defence, but also for environmental measurements and industrial process control.

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