Fabrication of MEMS Pressure Sensor on Thin Film Membrane

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Abstract: This study focuses on the fabrication of a Microelectromechanical Systems (MEMS) pressure sensor utilizing a thin film membrane. The fabrication process involves intricate techniques to create a sensitive and reliable sensor capable of detecting pressure variations. Various aspects such as material selection, fabrication methods, and sensor design are explored to optimize sensor performance. Key considerations include ensuring mechanical robustness, thermal stability, and sensitivity to pressure changes. The MEMS pressure sensor's potential applications range from industrial monitoring to medical diagnostics, where accurate pressure measurement is essential. Through this research, a comprehensive understanding of MEMS pressure sensor fabrication on thin film membranes is achieved, offering valuable insights into improving sensor performance and reliability.

Keywords: MEMS, pressure sensor, thin film membrane, fabrication, microfabrication, sensor design, pressure measurement, mechanical stability, thermal stability, sensitivity.

INTRODUCTION

A generalized Micro Electro Mechanical System (MEMS) consists of mechanical components, sensors, actuators and integrated circuit all integrated in the same environment. The evolution of MEMS has depended largely on the advancement in micro fabrication technology for the development of solid state sensors and actuators. Micro electromechanical Systems (MEMS) offer a powerful new technology for both optical and RF systems. The integration of optics and MEMS has created a new class of micro-opto-electro-mechanical devices and integrated circuits that are smaller, faster, more accurate, more rugged, and consume less power than macro scale devices. MEMS allows moveable micro-mechanical parts to be integrated with micro-optical elementsand3-Dstructures,enabling miniaturized free-space optical systems to be mass- produced at low cost by batch fabrication processes. Since the physical effect caused by mechanical movement is usually larger than conventional electro-optic or free-carrier effects, very efficient light modulators, switches, broadly tunable semiconductor lasers, detectors, and filters can be realized with the optical MEMS technology. Applications of optical MEMS include fiber optic switches, optical cross connect, projection and head mount display, optical data storage, printing, optical scanners, modulators, fiber optic sensors, and packaging of optoelectronic components.In the area of microwave/wireless communication, switches are widely used in RF/microwave systems and subsystems for signal routing, impedance matching, and amplifier gain adjustment. Traditional mechanical switches provide excellent electrical isolation and low contact resistance, yet they are heavy, bulky, and power

hungry for switching control. Conventional solid state switches are small in size but have significant insertion loss (typically > 1 dB) and poor RF isolation (typically < -30 dB). So thedesign, fabrication, and performance of a MEMS switch that can handle broadband microwave signals while maintaining a minimal insertion loss and excellent electrical isolation. This MEMS switch uses a suspended silicon dioxide micro-beam as the cantilever arm, a platinum-to-gold electrical contact, and electrostatic actuation as the switching mechanism. Compared to its semiconductor counterparts, the MEMS switch is superior in both performance and power consumption.

Some of the other MEMS application include pressure sensors, accelerometers, micro valves, electromechanical switches and relays, inkjet nozzles, gyroscopes, micro manipulators and connectors, micro motors , AFM(Atomic Force Microscopy) tips and optical components like lenses, gratings, mirrors and tunable waveguides. The fabrication of these micro mechanical parts involves precise isotropic and anisotropic silicon etching, high a spectra tio lithography , silicon bonding techniques (Fusion bonding and Anodic bonding), plating, thin film deposition and standard I.C fabrication steps. Here one such MEMS component Pressure sensor is described. This includes MEMS overview, application area and fabrication process of MEMS pressure sensor. This work has done in Millimeter Wave Devices Laboratory of Central Electronics Engineering Research Institute, Pilani.

MEMS=Miniature Mechanical System +Integrated Circuit

MEMS Pressure Sensor

Micro fabricated pressure sensors comprise a small but useful subset of integrated circuits. Integrated sensors of high quality can be very sensitive to pressure changes, making them ideal for applications in which bulky machined sensors are not able to perform, or are too large, or consume too much power.

Typical applications of integrated pressure sensors include microphones, biomedical instrumentation (*e.g.*, blood and fluid pressure), vacuum sensing, wind-tunnel model instrumentation, automobile power and acceleration measurement, and even household electronics.

All mechanical sensors are based on material changes caused by stress placed on a membrane or other flexible element. On the sub millimeter scale of integrated devices, materials like silicon show very little or no fatigue, which is apparently a macro scale phenomenon. Thus integrated sensors can be flexed indefinitely, and have a long lifetime. There also exist high-precision sensors based on capacitive effect. A membrane is also used, with one plate of a capacitor mounted on the membrane and the other plate suspended above it, usually fabricated on a relatively inflexible material such as Pyrex glass. The deflection of the membrane changes the distance between the plates and thus changes the capacitance. The other form of sensing pressure is through variation of resistance of resistors. Resistance is dependent on length and area. So when pressure is applied on the membrane the dimension of the membrane changes, in accordance the resistance changes. The change of resistance will change output voltage/current in the output. By proper calibration of the output voltage the pressure is detected. Here we will discuss regarding the pressure sensor based on resistors.

When standard or modified CMOS or bipolar processes are used in order to fabricate the sensor, signal processing can be done at the source. On-chip amplification of the signal is the first necessary step to ensure minimizing the effect of noise on the output. On-chip circuitry is also necessary in a

high-quality system to compensate for temperature variation. Temperature-dependent behavior is seen as the limiting factor in integrated sensors.

Some materials, such as silicon, exhibit sensitivity to alterations induced by stress exerted on their crystalline lattice. Particularly, the resistance of these materials is contingent upon the variations in length provoked by the stress. Resistive alterations are non-isotropic, segregating into two distinct functions: one aligning parallel to the direction of stress and the other perpendicular to it, represented as:

The equations provided describe the relationship between the change in resistance (ΔR) and the perpendicular ($\sigma\perp$) and parallel ($\sigma\|$) components of stress. The resistive changes are influenced by both components of stress and are represented by the equations:

$$\frac{\Delta R}{R} = \pi\sigma\| + \pi\sigma\perp$$

$$\frac{\Delta R}{R} = \pi\sigma\perp + \pi\sigma\|$$

Where $\pi\perp$ and $\pi\|$ are the perpendicular and parallel resistive coefficients, respectively. These coefficients vary with temperature and doping concentration. The stresses are proportional to
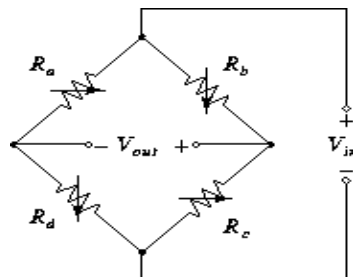
Wheatstone Bridge circuit

pressure and to the square of the ratio L/h, where h is the thickness of the membrane and L is the distance from the membrane center to the edge. One of the simplest sensor circuits employing resistors is the Wheatstone bridge, depicted below.

The bridge is made of four resistors located on the four edges of the sensor membrane, close to the edges where the stress is greatest when vertical pressure is applied to the center (or uniformly across) the membrane. Two of the resistors are positioned parallel to the direction of the stress, and their resistance increases with pressure. The other two resistors are oriented perpendicular to the direction of the stress, and their resistance decreases with pressure. This configuration is shown in the figure below.
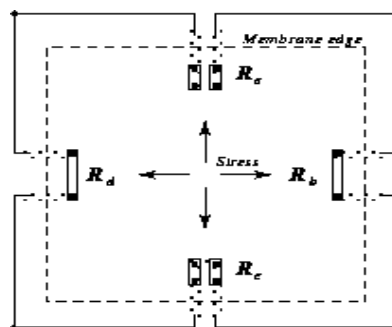
Configuration of resistors around a membrane.

The solution to the Wheatstone bridge, depicted in the schematic above, can be expressed as:

$$VOUT = Vin \frac{Rc}{Ra+Rc} - \frac{Rd}{Rb+Rd} \quad VOUT = Vin \frac{Ra}{Ra+Rc} - \frac{Rd}{Rb+Rd}$$

Resistors Ra and Rc are oriented parallel to the stress, while resistors Rb and Rd are oriented perpendicular to it. Therefore, any variation in resistance due to applied pressure results in a change in the output voltage. This configuration represents the fabricated sensor, with the resistor ends connected to bonding pads.

The pressure sensor can be integrated with an integrated circuit to form a complete system.

FABRICATION STEPS The pressure sensor is fabricated using a double-sided polished Silicon substrate. The fabrication steps are outlined below:

1. N-TYPE SILICON, Double side Polished
2. OXIDATION $0.8 \mu M$
3. Photolithography (Define Area)
4. Oxide etch for Active Area
5. Photolithography (Resistor Defining)
6. Boron Doping
7. Metallization
8. Photolithography for metal contact
9. Initial Testing of Resistors
10. Backside photolithography
11. Bulk etching Silicon from Backside
12. Silicon to Glass Anodic Bonding for Mechanical Support
13. Final Testing

WHY Silicon
- As Hard as Diamond
- Elastic Limit More compared to Steel. Beyond Elastic Limit, deformation of shape occurs in Steel but Silicon Breaks
- Saturated Technology
- MEMS Device can be integrated with other circuit components to form systems
- Silicon Surface when treated properly can provide optical surface of high quality (Flat & Scatter free)
- Excellent mechanical properties of silicon allow fabrication of fatigue-free devices.

Photolithography The process of transferring patterns of geometric shapes on a mask to a thin layer of radiation-sensitive material covering the surface of a semiconductor wafer. Steps:
1. Apply Photoresist +ve
2. Spinned at 3000 rpm for 20 sec
3. Prebake at 90°C for 30 min
4. Alignment of specified mask
5. Exposure of UV ray for 14 sec
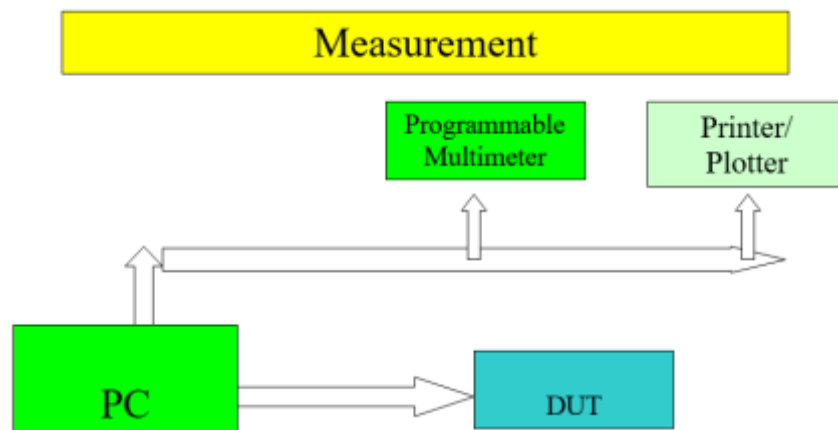6. Developing 45 sec in +ve developer (1:1) DI
7. Post Baking at 140°C for 30 min

Pressure sensor cross-sectional view:
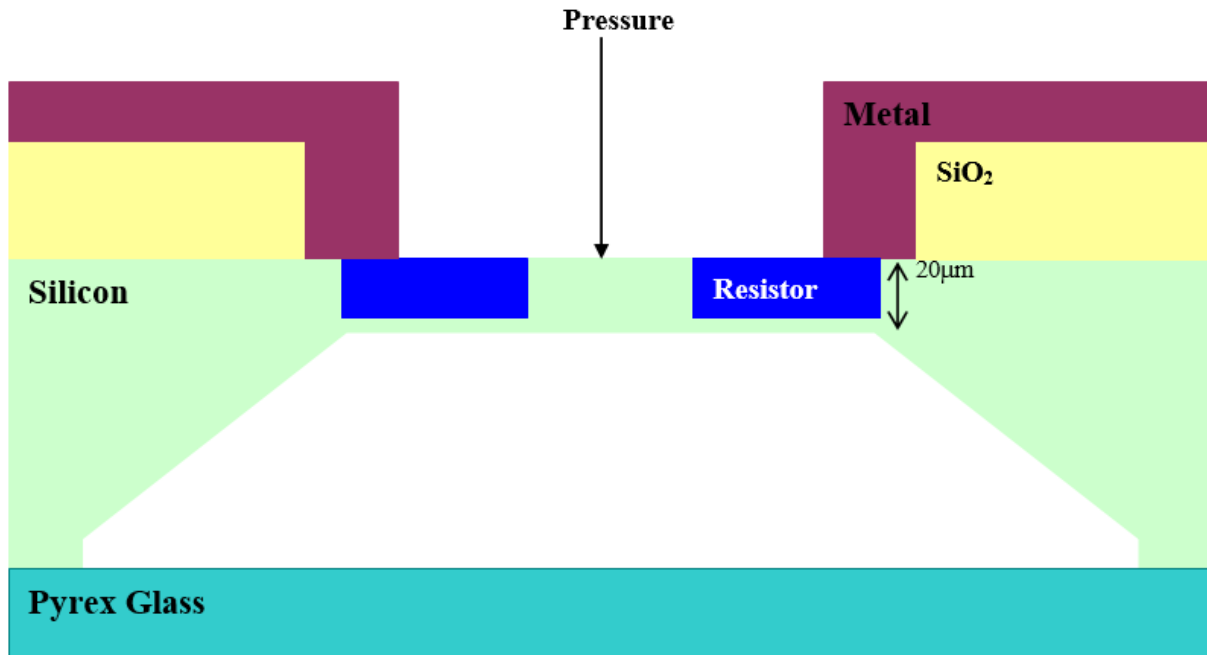
[Image: Pressure Sensor Cross Section]

Design of MEMS

1. Modeling (FEM, FDTD)
2. Design (Cadence, Tanner, Sonnet)
3. Simulation (Cadence, Tanner, Sonnet)
4. Layout (Cadence, Tanner)
5. Mask Preparation
6. Fabrication (As outlined in Fabrication Steps)
7. Testing

Shapes that can be fabricated using this technology include:
- Diaphragms: Pressure Sensor, Pumps

- Needles: Connectors, Micro Probes, Heat Sinks
- Walls: Heat Sinks
- Cantilevers: Springs, Suspensions, Resonators
- Trenches & Grooves: Gas Sensor, Micro Channel
- Pyramids: Tips, Tactile Sensors
- Cavities & Holes: Valves & Nozzles

Application Areas:
- Optical Communication
    - Precision micro components for micro optics
    - V-Grooves for optical Fiber
    - Digital Micro Mirror Devices
    - Optical Switches
    - WDM Components
    - Optical Attenuators
    - Tunable Lasers
    - Micro mirrors & micro lenses for wavelength selection and optical routing in network switches.
- RFMEMS
    - RF Switch
    - High Q inductors and capacitors
    - Tunable Wave guides
- Robotics
    - Tactile GRIP Sensors
    - Movement in 2-D/3-D Direction
    - Pattern and Speech Recognition
    - Guided Movement
- Computer Peripherals
    - Printer Heads, Disk heads
    - Laser Disk Heads
    - Micro Switches
    - Scanners and CD Writers
- Medical Prosthesis
    - Reciprocating, Rotary Movements
    - Crushing of Blood Clots
    - Slow Dispensing of Medicine
    - Smart on-chip Clinical Analysis

Typical MEMS:
- Micro Sensors
    - Pressure
    - Force
    - Acceleration
    - Vibration
    - Flow Rate, etc.
- Micro Mechanical Actuators
- Micro Relays

- Micro Optical Components
- Micro gas/fluid dispensers
- Micro flow controllers

Future:

- Micro Robots: To see, diagnose, and correct a defect in an organ (Use Scalpel/Crushers/Dispenser)
- Optical Communication: WDM and DWDM Components
- High-Quality Factor MMIC Components, inductor, capacitor, switch

Conclusion:

This pressure sensor is fabricated in the Millimeter Wave Devices Laboratory of Central Electronics Engineering Research Institute of Pilani. This is a part of work sponsored by ISRO, Bangalore. The work was done under the guidance of Dr. S. Ahmad, Director, CEERI, Pilani, and Dr. V. K. Dwivedi, senior scientist of CEERI, Pilani. Thanks to all technical staff of microelectronics processing of CEERI, Pilani for their support during the fabrication process.

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