PRESSURE SENSOR MODEL ACTIVITY

Pressure Sensor Model Activity
This activity uses household materials to build a pressure sensor

- Wheatstone Bridge sensing circuit
- Flexible diaphragm
- Reference Chamber

Simulate MEMS pressure sensor

Testing your model

- Apply variable pressures
- Monitor resistance change
- Monitor voltage output of the sensing circuit
Objectives

- Demonstrate how a change in length affects a material's resistance.
- Using your pressure sensor model, demonstrate how pressure affects the resistance and output voltage of the bridge circuit.
MEMS Pressure Sensors

- Measure absolute or differential pressures
- Convert physical quantities into measurable pressure values
  - Airflow
  - Liquid levels
  - Uses a calibration curve to correlate pressures to electronic values
- MEMS sensors used with other sensors for multi-sensing applications
  - Temperature sensors
  - Accelerometers

Barometric Pressure Sensors used in wind tunnels and for weather monitoring applications.
(Photo courtesy of Khalil Najafi, University of Michigan)
Let’s take a look at some of the applications for which MEMS pressure sensor are used.
Auto Industry

- Monitor absolute air pressure within the intake manifold of the engine
- Monitor absolute air pressure within a tire
- Fuel pressure

What other applications are possible within the automotive industry?
BioMEMS Pressure Sensors

In the biomedical field, current and developing applications for MEMS pressure sensors include:

- blood pressure sensors *(see photo right)*,
- single and multipoint catheters,
- intracranial pressure sensors,
- cerebrospinal fluid pressure sensors,
- intraocular pressure (IOP) monitors, and
- other implanted coronary pressure measurements.

*MEMS Blood Pressure Sensors on the head of a pin. [Photo courtesy of Lucas NovaSensor, Fremont, CA]*
MEMS pressure sensors are also incorporated into:

- endoscopes for measuring pressure in the stomach and other organs
- infusion pumps for monitoring blockage
- Non-invasive blood pressure monitors.

Applications of MEMS pressure sensors within the biomedical field and other industries are numerous.
To understand the pressure sensor model that you will be building, you should know how it works. So – let’s take a look.

The images in the following slides are of a MEMS pressure sensor built at the Manufacturing Technology Training Center (MTTC) at the University of New Mexico (UNM).
Many MEMS pressure sensors use a Wheatstone bridge configuration \textit{(below)} as the sensing circuit. For MEMS pressure sensors, the Wheatstone bridge circuit is mounted on a membrane or diaphragm. The resistors in the Wheatstone bridge are made of a piezoresistive material, a material which undergoes a change in resistance when mechanical stress is applied.
A MEMS Pressure Sensor

In this example, a conductive material such as gold is used for the bridge circuit. The pressure sensor diaphragm is a thin film of material (such as silicon nitride) which is resistant to chemicals used in the application (see image below). One side of the diaphragm is sealed to provide a reference pressure. The other side is open to the environment and subject to air pressure variation.
A MEMS Pressure Sensor

As the diaphragm moves due to pressure changes, the membrane expands and stretches. The bridge resistors mounted on the membrane also expand and stretch. This expansion translates to a change of resistance in the conductive material of the bridge. As the conductive material stretches, its resistance increases.
Resistivity

All materials have electrical resistance. The resistance to electrical current flow of an object (resistor) is related to a material property called resistivity ($\rho$), and the object’s geometry - length, width, and thickness. It is the combination of the geometry (shape) and material property (resistivity) that determines the overall electrical characteristic (resistance).

$$R = \rho \frac{L}{A}$$
Resistivity remains constant under constant temperature and stress (e.g., pressure). It should be pointed out that the resistivity of a material, $\rho$, is inversely proportional to its conductivity, $\sigma$:

$$\sigma = \frac{1}{\rho}$$

As the conductive (resistive) material stretches, the length increases while the cross-sectional area decreases. This increase in length and decrease in cross-sectional area results in an increase in overall resistance.

$$R = \rho \frac{L}{A}$$
In this activity you build a macro-size pressure sensor that is modeled after MEMS pressure sensor designed and built at the MTTC / UNM. To better understand the components of your pressure sensor, let’s take a look at how a MEMS pressure sensor is fabricated.
MTTC Pressure Sensor

- Process developed at the UNM MTTC/CNM
- Design incorporates a Wheatstone bridge (WB) as an electronic sensing circuit
- 4 Resistors (2 fixed, 2 variable)
- Conducting metal is gold
- 4 pads as leads
Determining Change in Pressure

- A thin film of silicon nitride is the sensing membrane or diaphragm.
- Gold is deposited as the sensing circuit.
- The cavity, which is etched away from the silicon substrate is a reference cavity.
- The membrane deflects when pressures on opposite sides of the membrane are different.
- As the membrane deflects, the resistance changes in the variable resistors of the bridge circuit.
- The amount of change in resistance is correlated to the change in pressure.
- A calibration curve is created using known pressure differences.
Pressure Sensor Physical Features

- Sensing Membrane
- Wheatstone bridge electronic sensing circuit
- Reference chamber
Pressure Sensor Fabrication Process

- MTTC Pressure Sensor Process uses 2 micromachining process techniques
  - Surface micromachining
  - Bulk micromachining

- Sensing Membrane
  - Deposit Silicon Nitride thin film on silicon substrate
  - *Surface micromachining*

- Wheatstone bridge electronic sensing circuit
  - Define the circuit pattern - Photolithography
  - Deposit metal (chrome/gold) on membrane
  - *Surface micromachining*

- Reference chamber
  - Selectively etch a hole through the silicon substrate under the membrane for the reference chamber
  - *Bulk micromachining*
Silicon Nitride Deposition

A chemical vapor deposition (CVD) process is used to deposit a thin film of silicon nitride on the silicon substrate.

CVD is the most widely used deposition method. Films deposited during CVD are a result of the chemical reaction

- between the reactive gas(es) and
- between the reactive gases and the atoms of the substrate surface.
CVD Process

- Substrate is placed inside reactor
- Chamber pressure is set to process pressure.
- Heat is applied (to substrate or entire chamber)
- Select (reactants) gases are introduced.
- Gas molecules chemically react with each other or with the substrate forming a solid thin film on the wafer surface.
- Gaseous by-products produced by the chemical reaction are removed from the chamber.
Fabrication of the Wheatstone bridge sensing circuit requires photolithography and metal deposition.

The MTTC process uses metal evaporation to deposit the chrome and gold layers for the sensing circuit.
Photolithography – 3 Step process

- **Coat**: A photosensitive material (photoresist or resist) is applied to the substrate surface.
- **Expose**: The photoresist is exposed using a light source, such as Deep UV (ultraviolet), Near UV or x-ray.
- **Develop**: The exposed photoresist is dissolved with a chemical developer.
Metal Deposition - Evaporation Process

- A thin layer of chrome followed by gold is evaporated onto the wafer.
- Chamber is evacuated to process pressure.
- Source material is heated to its vaporization temperature.
- Source molecules and atoms travel to the wafers. Vacuum allows travel with minimal collisions.
- Molecules and atoms condense on all surfaces including the wafers.
Bulk Micromachining

- Bulk micromachining defines structures by selectively etching inside a substrate, usually by removing the “bulk” of a material.
- This is a subtractive process.
- Take for example the cliff dwellings at Mesa Verde that were formed below the surface of the flat topped mesa. Man and nature “bulk etched” these dwellings into the side of the cliff.
- The chamber of the pressure sensor is formed in the same manner.

[Image printed with permission from Barb Lopez]
Bulk Etch – Reference Chamber

- The silicon in the wafer substrate is selectively removed using anisotropic chemistries.
- The silicon removed is directly beneath the WB sensing circuit.
- This process allows our piezoresistive pressure sensors to be manufactured in high volume.

Front side and Backside of MTTC Pressure Sensor
[Images courtesy of MTTC/UNM]
Bulk Micromachining involves deposition, photolithography and etch.

- A silicon nitride film is deposited on the backside of the wafer.
- A pattern for the chamber “holes” is created in the silicon nitride using photolithography.
- Bulk etch (wet anisotropic etch) is used to removed the silicon from within the “holes”.

Backside of MTTC Pressure Sensor before (top) and after (bottom) etch

Silicon nitride

(100)  
(111)
In the model that you build,

- a balloon will be used as the membrane,
- graphene (graphite) as the WB circuit, and
- a sealed paint can as the reference chamber.
What is Graphene?

In this activity you will use graphite to construct the electronic circuit. Graphite consists of stacks of graphene sheets. So what is graphene? Graphene is a material formed when carbon atoms arrange in sheets. Graphene is a one-atom-thick planar sheet of carbon atoms densely packed in a honeycomb crystal lattice (as shown in the graphic below).
What is Graphene?

Graphene is used as the structural element for fullerenes such as carbon nanotubes (graphic) and buckyballs.

In this activity, the mixture of graphite (pencil lead) and rubber cement used to construct the Wheatstone bridge contains sheets of graphene. These sheets are thought to maintain contact as they slide on top of each other when the conductive material stretches. You should see the effect of this when you apply pressure to your pressure sensor model diaphragm.
Now you know how MEMS pressure sensors are used and fabricated.

Think about the micro fabrication processes as you construct your model.

Once your model is built, you will test it by applying various pressures and observing changes in resistance and voltage.
Acknowledgements

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The work presented was funded in part by the National Science Foundation Advanced Technology Education program, Department of Undergraduate Education grant #0902411.