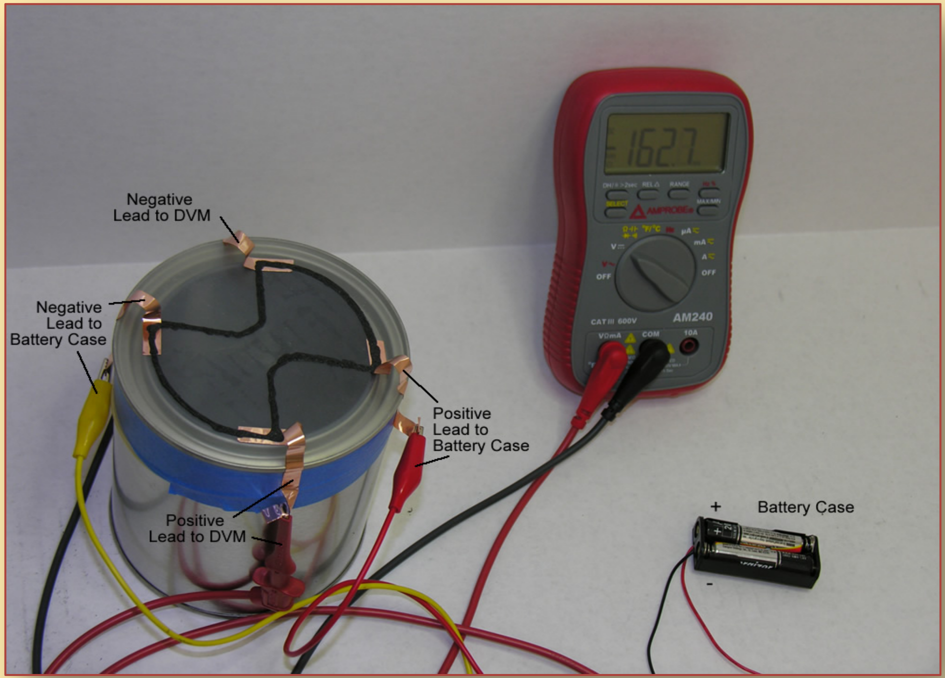
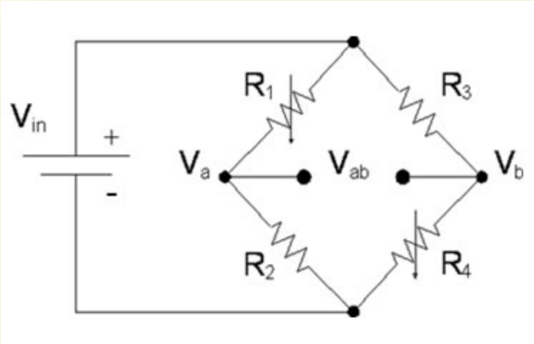
MODELING A MICRO PRESSURE SENSOR ACTIVITY



Unit Overview



In this activity you will use basic materials to build a macro pressure sensor with a Wheatstone bridge sensing circuit *(circuit right)* on a flexible diaphragm.

You will test your sensor and analyze how it works.

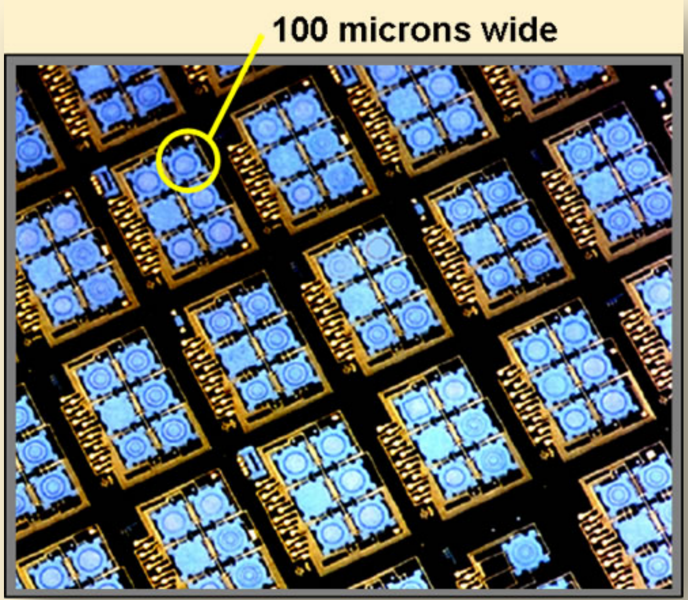
Results simulate those found in micro pressure sensors.

Objectives

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

Micro Pressure Sensors

- Designed to measure absolute or differential pressures.
- Convert physical quantities such as air flow and liquid levels into pressure values that are measured by an electronic system.
- Used in conjunction with other sensors such as temperature sensors and accelerometers for multisensing applications.



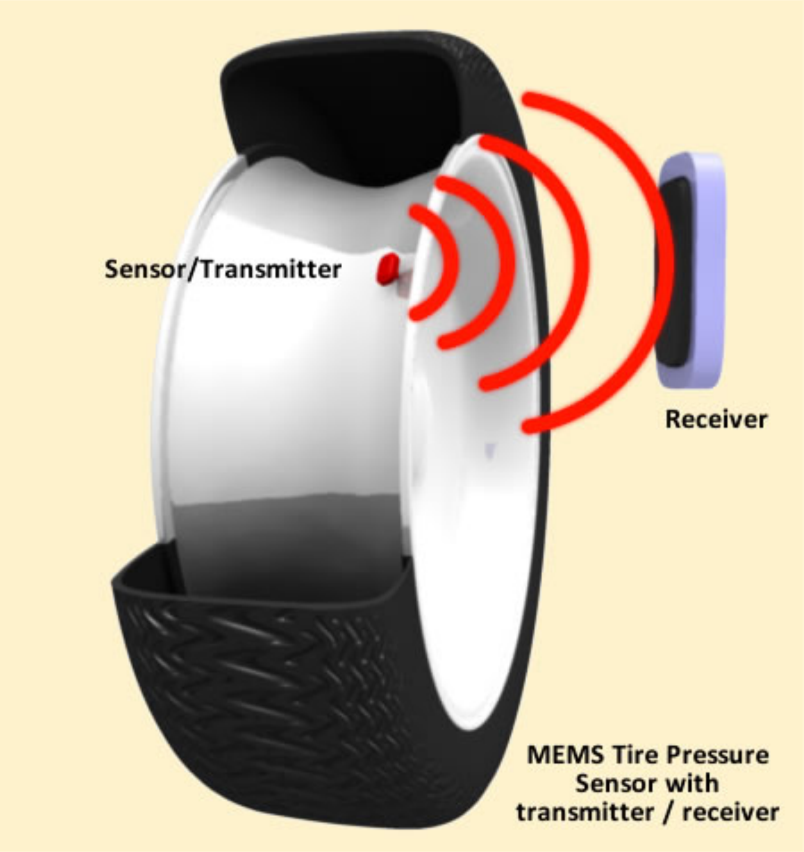
Barometric Pressure Sensors used in wind tunnels and for weather monitoring applications.
(Photo courtesy of Khalil Najafi, University of Michigan)

Micro Pressure Sensor Applications

Let's take a look at some of the applications for which micro pressure sensor are used.

Micro Pressure Sensor Applications

In the automotive industry, micro pressure sensors monitor the absolute air pressure within the intake manifold of the engine or within a tire *(graphic right)*. They have also been designed to sense tire pressure, fuel pressure, and air flow.



What other applications are possible within the automotive industry?

BioMEMS Pressure Sensors

In the biomedical field, current and developing applications for micro 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 – microelectromechanical systems*

MEMS Blood Pressure Sensors on the head of a pin. [Photo courtesy of Lucas NovaSensor, Fremont, CA]

BioMEMS Pressure Sensors

Micro pressure sensors are also incorporated into

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

Applications of micro pressure sensors within the biomedical field and other industries are numerous.

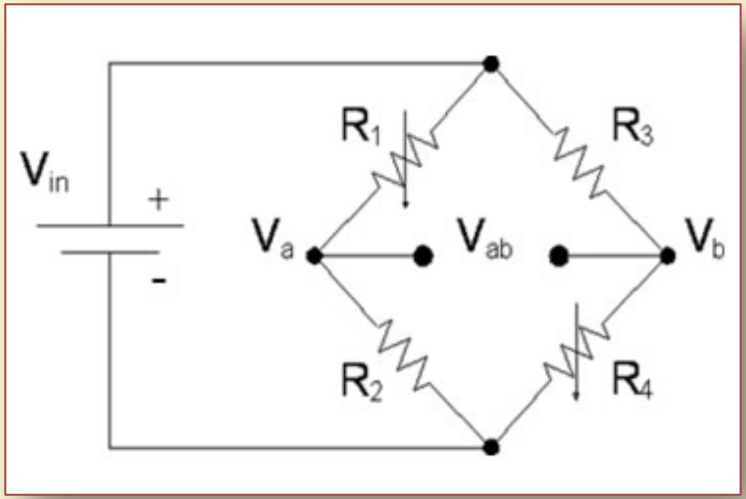
Micro Pressure Sensor Operation

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 micro pressure sensor built at the Manufacturing Technology Training Center (MTTC) at the University of New Mexico (UNM).

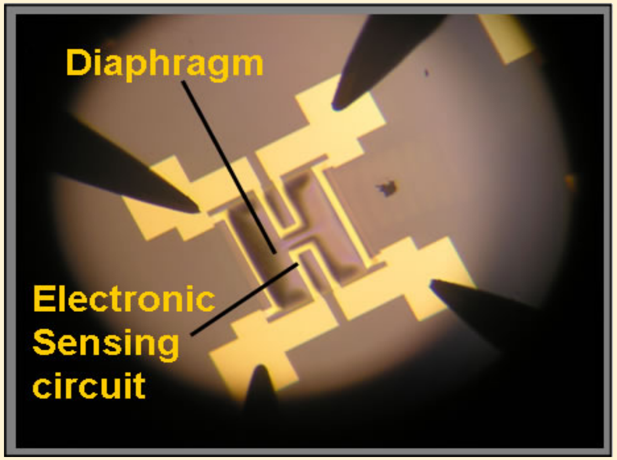
A Micro Pressure Sensor

- Many micro pressure sensors use a Wheatstone bridge (WB) configuration *(below)* as the sensing circuit.
- The WB circuit is mounted on a membrane or diaphragm.
- Resistors in the WB are made of a piezoresistive material.



A Micro Pressure Sensor

- In the circuit below, gold is used for the bridge circuit.
- The pressure sensor diaphragm is a thin film of material of silicon nitride.
- 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.

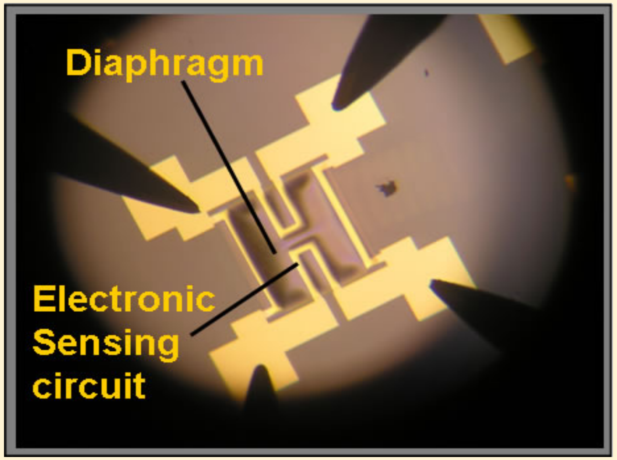


Pressure Sensor illustrating the Wheatstone bridge and the Silicon Nitride Membrane (Diaphragm)

[Image of a pressure sensor built at the Manufacturing Technology Training Center (MTTC) at the University of New Mexico (UNM)]

A Micro 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.



Pressure Sensor illustrating the Wheatstone bridge and the Silicon Nitride Membrane (Diaphragm)

[Image of a pressure sensor built at the Manufacturing Technology Training Center (MTTC) at the University of New Mexico (UNM)]

Resistivity

- All materials have electrical resistance.
- Resistance to electrical current flow is related to a material property called resistivity (ρ), and the object's geometry - length, width, thickness.
- The combination of the geometry (shape) and material property (resistivity) determines the overall electrical characteristic (resistance).

$$R = \rho \frac{L}{A}$$

Resistivity

- Resistivity is constant under constant temperature and stress (e.g., pressure).
- Resistivity of a material, ρ, is inversely proportional to its conductivity, σ:

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

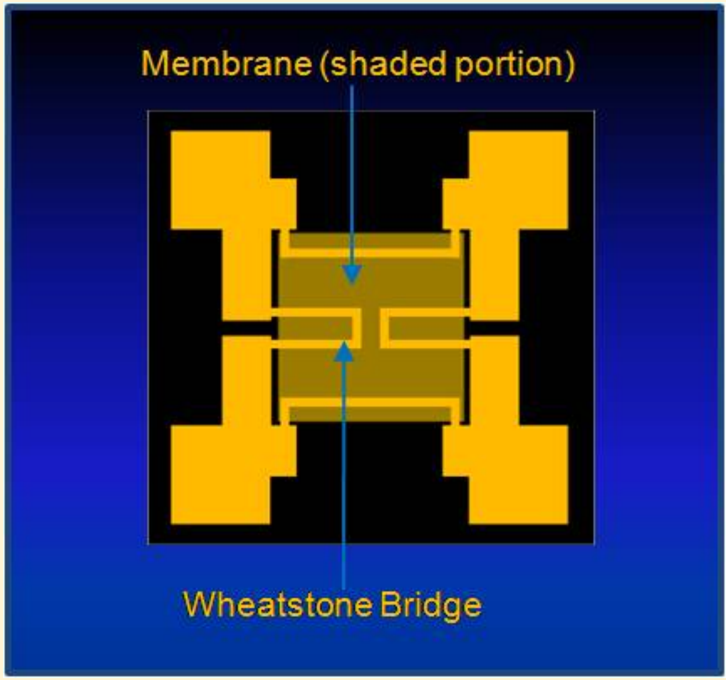
As the conductive (resistive) material stretches, the length increases while the cross-sectional area decreases. This increase in length and decrease in cross-sectional area results in an increase in overall resistance.

Micro Pressure Sensor Fabrication

In this activity you build a macro-size pressure sensor that is modeled after micro 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 micro pressure sensor is fabricated.

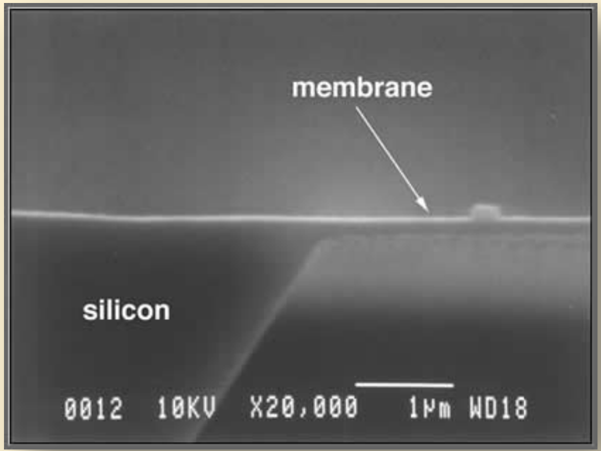
MTTC Pressure Sensor

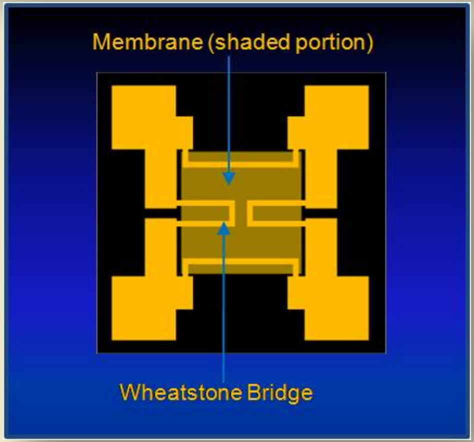
- Process developed at the UNM MTTC/CNM
- Design incorporates a Wheatstone bridge (WB) as an electronic sensing circuit
- 4 Resistors (2 fixed, 2 variable)
- Conducting metal is gold
- 4 pads as leads



Determining Change in Pressure

- Thin film of silicon nitride is the sensing membrane or diaphragm.
- WB is fabricated on the membrane and a constant voltage is applied to the bridge.
- Cavity underneath the membrane is a reference pressure.
- Membrane deflects when pressures on opposite sides of the membrane are different.
- As the membrane deflects, resistance changes in the variable resistors of the bridge circuit.
- Amount of change in resistance is correlated to the change in pressure.
- Calibration curves are created using known pressure differences.





Pressure Sensor Physical Features

- Sensing Membrane
- Wheatstone bridge electronic sensing circuit
- Reference chamber

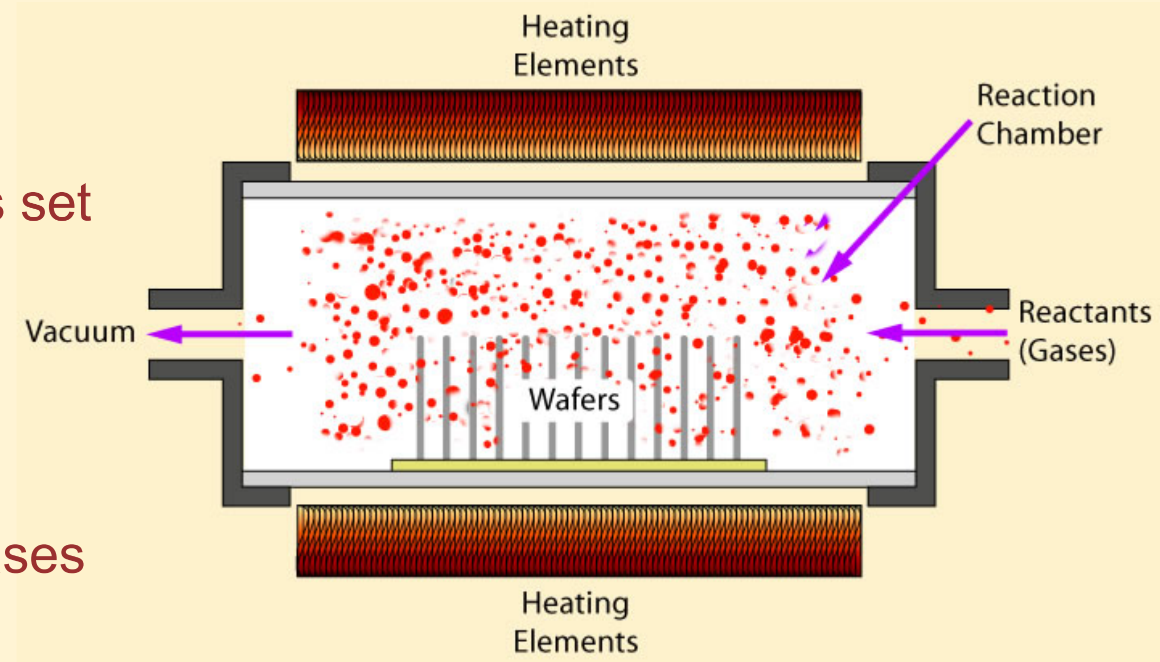
Pressure Sensor Fabrication Process

- 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.

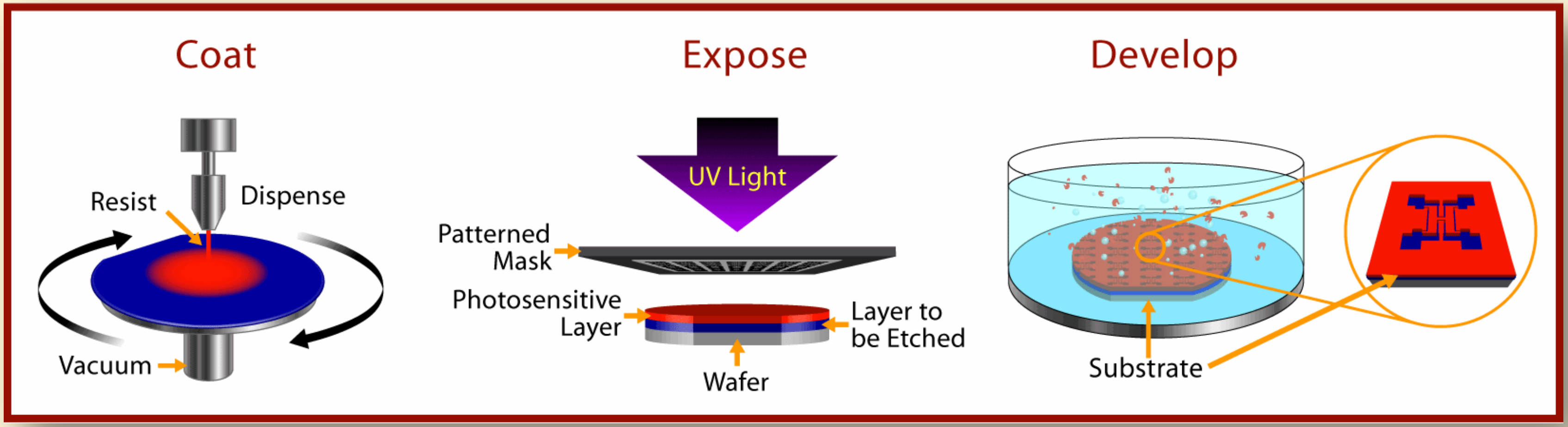
Wheatstone Bridge Fabrication

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.

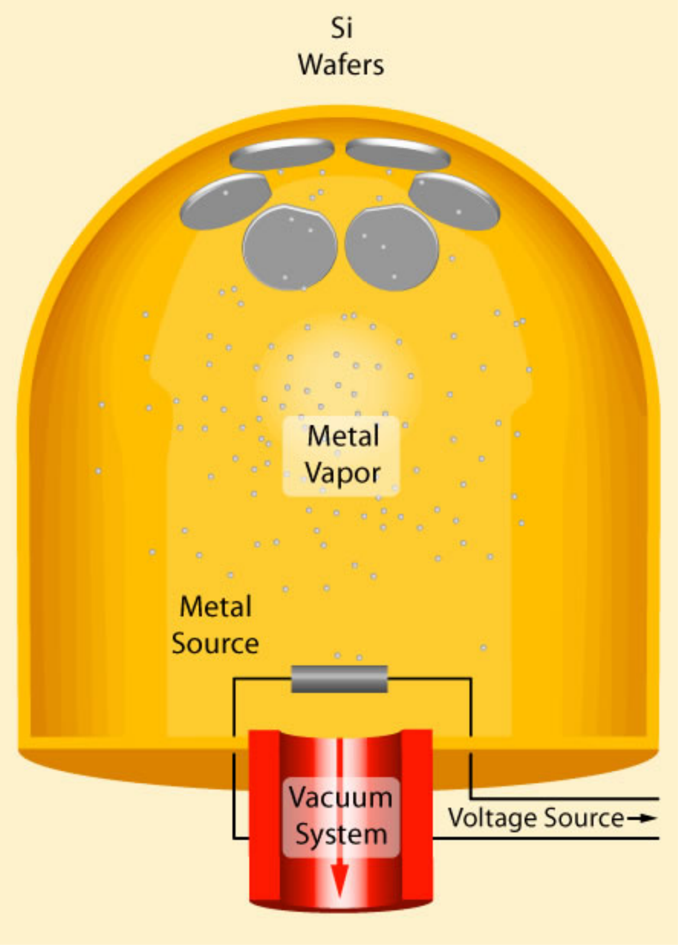
Photolithography – 3 Step process

- 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

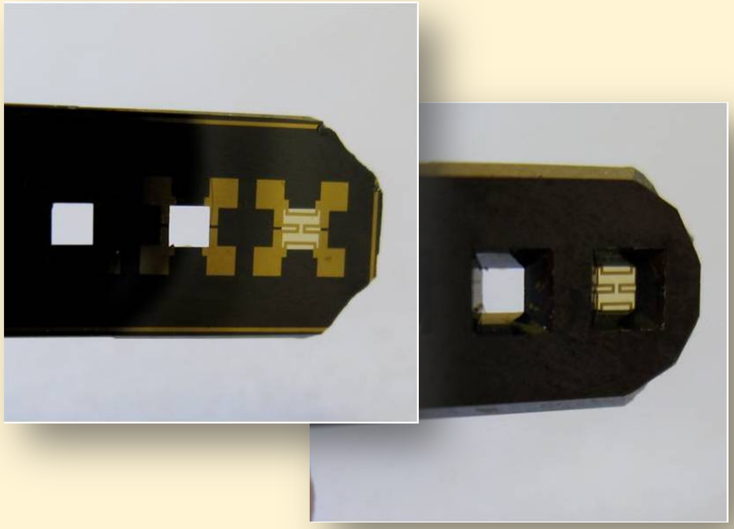
- ❖ Bulk micromachining defines structures by selectively etching inside a substrate, usually by removing the “bulk” of a material.
- ❖ This is a subtractive process.
- ❖ Example: Cliff dwellings at Mesa Verde, Colorado, were “bulked etched” below the surface of the flat topped mesa by man and nature.
- ❖ The chamber of the pressure sensor is formed in the same manner.

[Image printed with permission from Barb Lopez]

Bulk Etch – Reference Chamber

- ❖ 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.

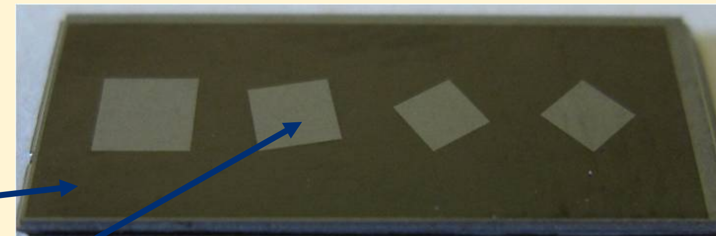
Front side and Backside of MTTC Pressure Sensor [Images courtesy of MTTC/ UNM]



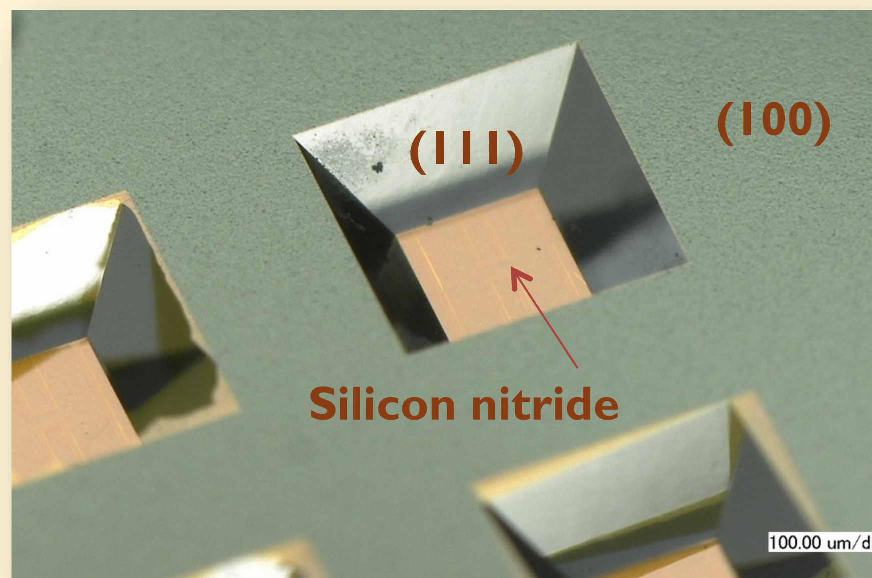
Bulk Micromachining - Backside

Bulk Micromachining involves deposition, photolithography and etch.

- ❖ Silicon nitride film is deposited on the backside of the wafer.
- ❖ 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



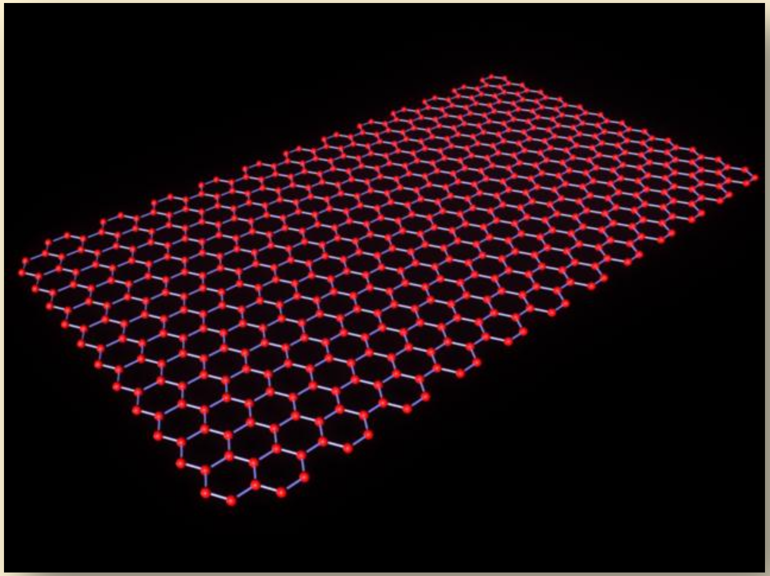
Modeling a Micro Pressure Sensor

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.

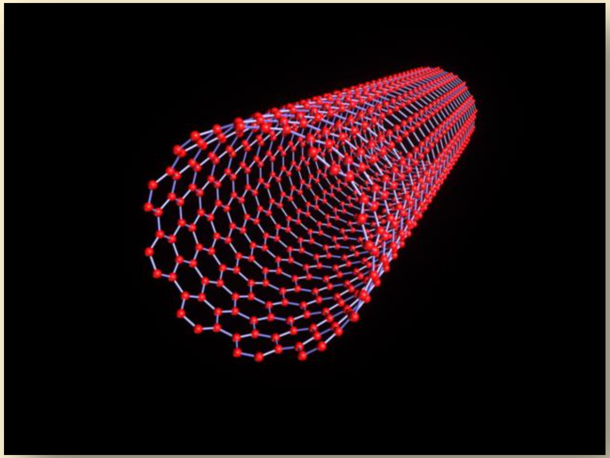
What is Graphene?

- Graphite is used to construct the WB circuit.
- Graphite consists of stacks of graphene sheets.
- 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 right)*.



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 WB contains sheets of graphene.
- These sheets are thought to maintain contact as they slide on top of each other when the conductive material stretches.
- The material stretches as pressure is applied to the membrane.

Summary

Now you know how micro 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.

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