ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

VII Semester

AU3008 Sensors and Actuators

UNIT – 2 - Variable Resistance and Inductance Sensors

2.5 Piezo Resistive Sensor

❖ Piezoresistive sensors are devices that are fabricated by diffusion resistance on a substrate of a semiconductor material in accordance with the piezoresistive effect of the semiconductor material.

❖ The substrate can be directly used as a measuring sensor element, and the diffusion resistor is connected in the form of a bridge in the substrate.

❖ The sensor uses the integrated technology to integrate the resistance strip on the monocrystalline silicon membrane to make the silicon piezoresistive chip, and the peripheral of the chip is fixed in the shell, and the electrode lead is drawn.

❖ Piezoresistive pressure sensor is also called **_solid state pressure sensor_**, which is different from the adhesive strain gauge that needs to feel the external force indirectly through the elastic sensitive element, but directly through the silicon diaphragm to feel the measured pressure.

❖ When the substrate is deformed by an external force, the resistance values will change, and the bridge will produce a corresponding unbalanced output. The substrate (or diaphragm) used as a piezoresistive sensor is mainly a silicon wafer and a silicon wafer, and the silicon piezoresistive sensor made of a sensitive material is more and more popular, especially in measuring pressure. And speed solid state piezoresistive sensors are most commonly used.

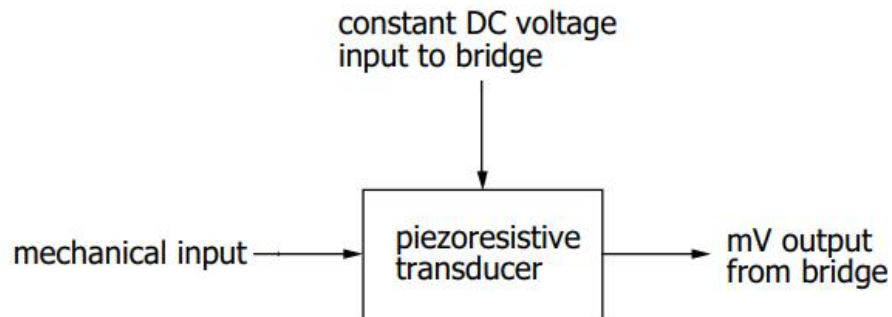❖ The working principle diagram of the piezoresistive pressure sensor is as follows:

Fig. 2.5.1 System inputs and outputs for a piezoresistive transducer

Materials for Piezoresistive Sensors:

❖ Piezoresistive sensors utilize materials that exhibit a change in electrical resistance when subjected to mechanical strain. These materials are typically semiconductors or alloys. Here are some common materials used in piezoresistive sensors:

Semiconductors:

✓ **Silicon:** The most widely used material due to its excellent piezoresistive properties

✓ **Germanium:** Similar to silicon, but generally less sensitive and more temperature-dependent.

✓ **Gallium Arsenide (GaAs):** Offers higher sensitivity and faster response times than silicon, but is more expensive to produce.

✓ **Silicon Carbide (SiC):** Known for its high temperature stability and durability, making it suitable for harsh environments.

 Alloys:

✓ **Nickel-Chromium (NiCr)**
✓ **Constantan**

The choice of material for a piezoresistive sensor depends on factors such as:

➢ **Sensitivity:** The desired level of resistance changes per unit strain.
➢ **Temperature Stability:** The ability to maintain consistent performance over a wide temperature range.
➢ **Cost:** The cost of the material and the fabrication process.
➢ **Compatibility:** The compatibility of the material with other components in the sensor or system.
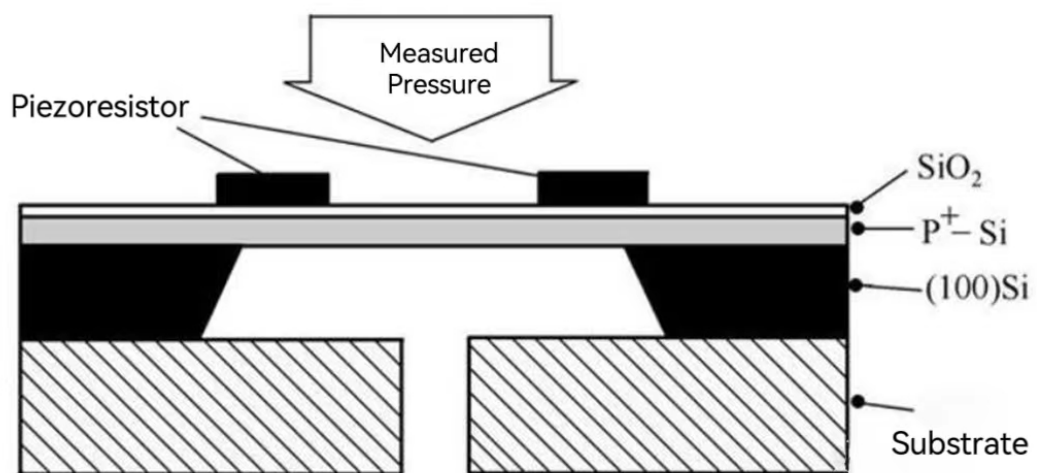

Fig. 2.5.2 Piezoresistive Pressure sensor

The working principle of piezoresistive sensors

❖ A strain gage is a sensitive device that converts the strain change on the device under test into an electrical signal. It is one of the main components of a piezoresistive strain sensor. The most widely used resistance strain gauges are metal resistance strain gauges and semiconductor strain gauges.

❖ The working principle of the metal resistance strain gauge is a phenomenon in which the strain resistance adsorbed on the base material changes with the mechanical deformation, which is commonly called the resistance strain effect.

❖ When the strain gauge substrate is subjected to stress changes, the strain gauge is deformed, and the resistance of the strain gauge is changed, resulting in a voltage change applied to the resistor. Such strain gauges typically have a small change in resistance when subjected to force.

❖ Generally, such strain gauges are formed into strain bridges and amplified by subsequent instrumentation amplifiers, and then transmitted to a processing circuit display or actuator for operation. One step of processing.

The relationship between piezoresistive pressure sensor and outputs:

❖ Piezoresistive pressure sensors are a type of pressure sensor that uses the piezoresistive effect to measure pressure. The piezoresistive effect refers to the change in electrical resistance of a material when it is subjected to mechanical strain or deformation. In piezoresistive pressure sensors, a diaphragm or membrane is typically used to convert the applied pressure into mechanical deformation, which in turn causes changes in the resistance of piezoresistive elements.

❖ In most piezoresistive pressure sensors, there is a direct and linear relationship between the applied pressure and the change in electrical resistance. As pressure increases, the diaphragm or membrane of the sensor undergoes deformation, causing the piezoresistive elements to experience strain. This strain leads to a change in resistance, and this change is proportional to the applied pressure. The change in resistance can be measured using a Wheatstone bridge circuit or other signal conditioning methods.
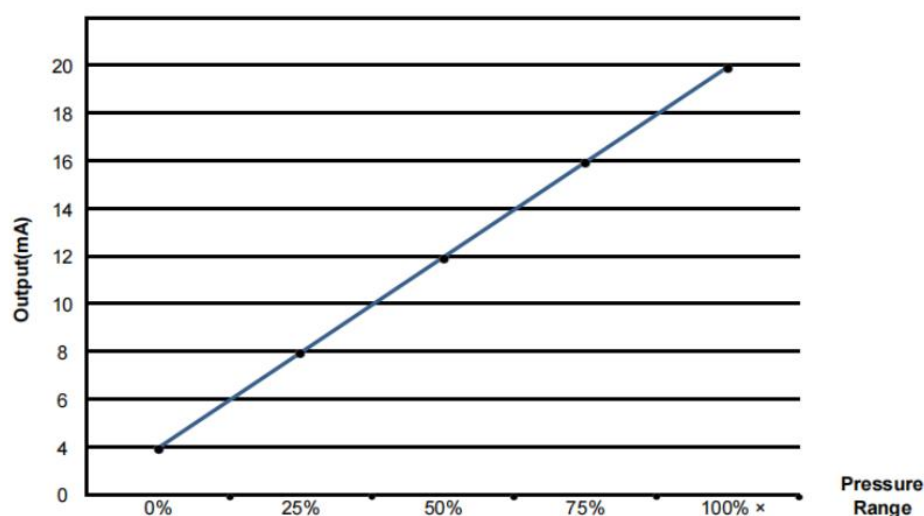

Fig 2.5.3 Input output characteristics of Piezo resistive pressure sensor

Wheatstone Bridge Configuration:

❖ Piezoresistive pressure sensors often utilize a Wheatstone bridge circuit to measure the change in resistance accurately. The bridge circuit consists of multiple piezoresistive elements, some of which are subjected to pressure-induced strain, while others are not. The differential change in resistance between the strained and unstrained elements is used to generate an output voltage that is proportional to the applied pressure.
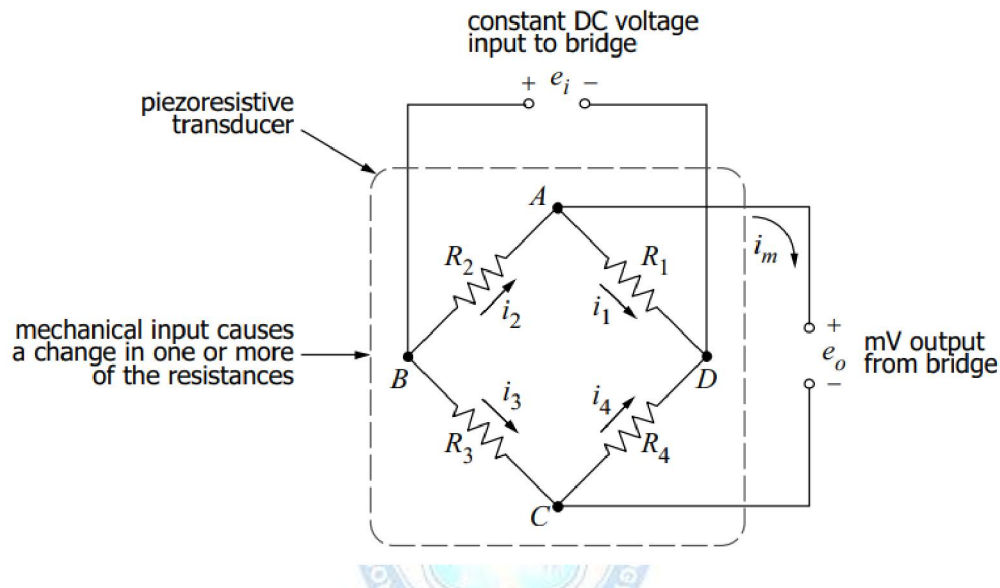

Fig. 2.5.4 Wheatstone Bridge Circuit

❖ Figure shows the Wheatstone bridge circuit, a Wheatstone bridge consists of a four piezoresistive material labeled as R1, R2, R3 and R4 respectively.

❖ The input voltage e_i is supplied by a constant DC source. The four arms of the bridge each contain a resistor, R1 through R4 (at least one of which is made of a piezoresistive material). The output voltage e_o is the difference between the voltages at nodes A and C, that is,

$$e_o = e_A - e_C.$$

$$e_o = \left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) e_i.$$

❖ If there is no mechanical input to the sensor, we would like to have zero voltage output,

$$\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} = 0$$

❖ We can rearrange this relationship

$$R_1 R_3 = R_2 R_4 .$$

Output Signal Conditioning:

❖ The output of a piezoresistive pressure sensor is typically an analog voltage signal. The voltage output corresponds to the change in resistance and, consequently, the applied pressure. Signal conditioning circuitry might be used to amplify, filter, and calibrate the output signal to obtain accurate pressure readings.

Applications of piezoresistive sensors:

❖ Piezoresistive sensors are widely used in various industries due to their ability to accurately measure pressure and force. Here are some common applications:

Automotive:

❖ **Tire Pressure Monitoring Systems (TPMS):** Measure tire pressure to ensure optimal performance and safety.
❖ **Engine Control Systems:** Monitor engine pressure parameters such as intake manifold pressure and oil pressure.
❖ **Transmission Control Systems:** Measure transmission fluid pressure for gear shifting and torque control.
❖ **Suspension Systems:** Detect load on the suspension to adjust damping and stiffness.

Industrial:

❖ **Process Control:** Monitor pressure in pipelines, tanks, and reactors for efficient process control.

❖ **Hydraulic Systems:** Measure pressure in hydraulic cylinders and pumps for machinery operation.

❖ **Pneumatic Systems:** Monitor pressure in pneumatic cylinders and valves for automated systems.

❖ **Force Measurement:** Measure forces applied to structures, machines, and tools.

Medical:

❖ **Blood Pressure Monitors:** Measure blood pressure using a cuff and a piezoresistive sensor.

❖ **Intracranial Pressure Monitoring:** Measure pressure within the skull to monitor brain health.

❖ **Force Sensors in Prosthetic Devices:** Measure forces applied to prosthetic limbs for more natural movement.

❖ **Aerospace:**

❖ **Aircraft Instrumentation:** Measure pressure in various systems such as fuel tanks, hydraulic lines, and air conditioning.

❖ **Engine Control:** Monitor engine pressure parameters for optimal performance and efficiency.

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