Transducers & Instrumentation

Module 05

Measuring Pressure, Flow and Volume

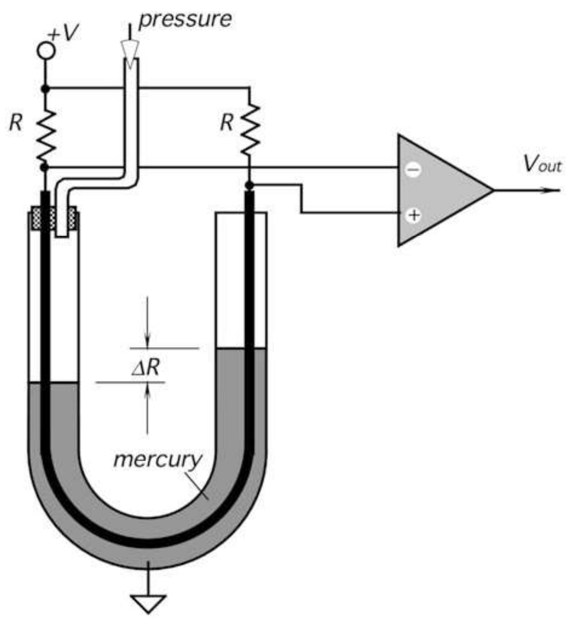
Pressure

- Force is applied from one body to another over a finite area.
- Pressure is defined as the force applied per unit area.
- Unit:N/m^2 or Pascal
- Various other units are employed:
  - mm of Water level (mmWater)
  - Mm of Hg level (mmHg or Torr)
  - Pounds per square inch (PSI)
  - …

$$\begin{aligned} 1\mathrm{N}\cdot\mathrm{m}^{-2} &= 1\ \mathrm{Pa} \\ &= 1.45\times10^{-4}\mathrm{psi} \\ &= 7.5\times10^{-4}\mathrm{cmHg} \end{aligned}$$

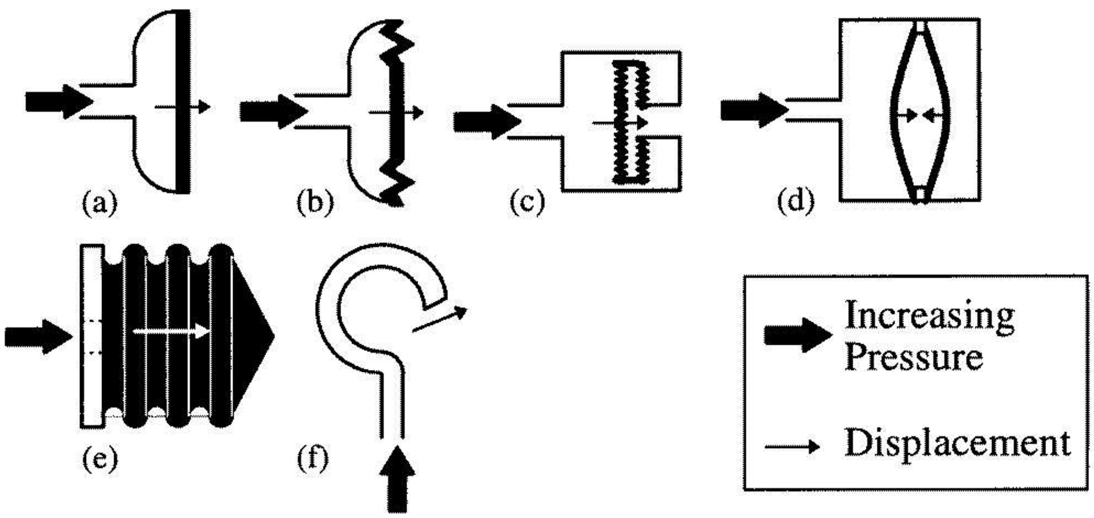
- Measured with respect to a reference.
  - Absolute pressure: with respect to vacuum
  - Gauge pressure: with respect to atmospheric pressure
  - Different pressure: with respect to an arbitrary reference

Mercury pressure sensor



Source: Fraden, Jacob, and Jacob Fraden. *Handbook of modern sensors: physics, designs, and applications*. Vol. 3. New York: Springer, 2004.

Elastic pressure sensors

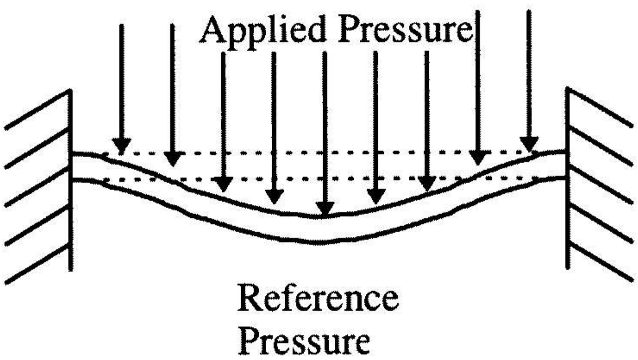


Eaton, William P., and James H. Smith. "Micromachined pressure sensors: review and recent developments." *Smart Materials and Structures* 6.5 (1997): 530.

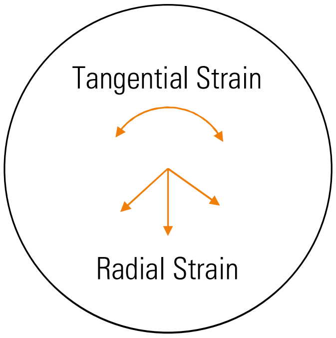
Bellow based pressure sensors

Source: Fraden, Jacob, and Jacob Fraden. *Handbook of modern sensors: physics, designs, and applications*. Vol. 3. New York: Springer, 2004.

Diaphragm-based pressure sensors

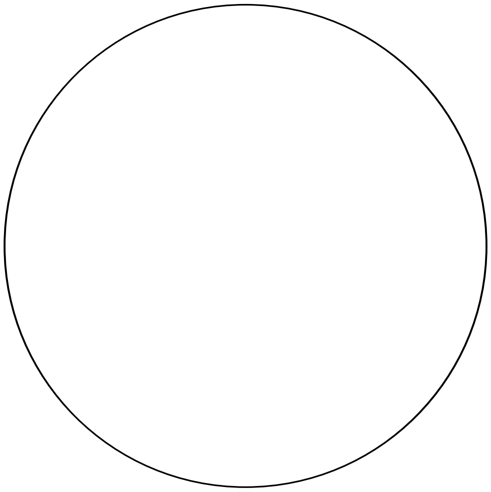


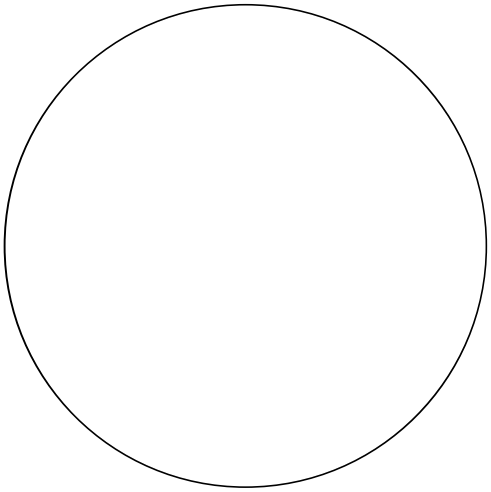
$$w(r) = \frac{3Pa^4}{16Eh^2}(1-\nu^2)\left[1-\left(\frac{r}{a}\right)^2\right]^2$$



Source: Fraden, Jacob, and Jacob Fraden. *Handbook of modern sensors: physics, designs, and applications*. Vol. 3. New York: Springer, 2004.

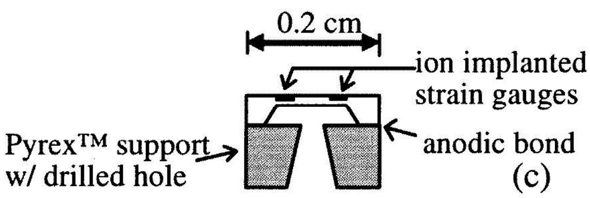
Diaphragm-based pressure sensors



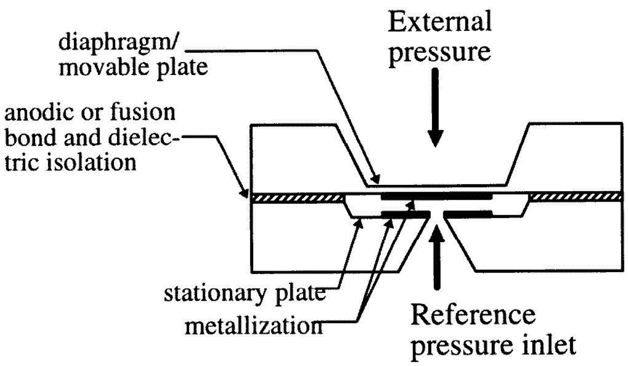


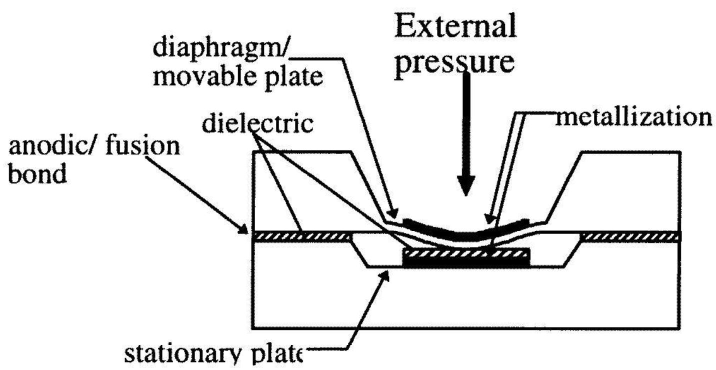
Diaphragm-based pressure sensors

Micromachined diaphragms and piezoresistive strain gauges



Diaphragm-based pressure sensors

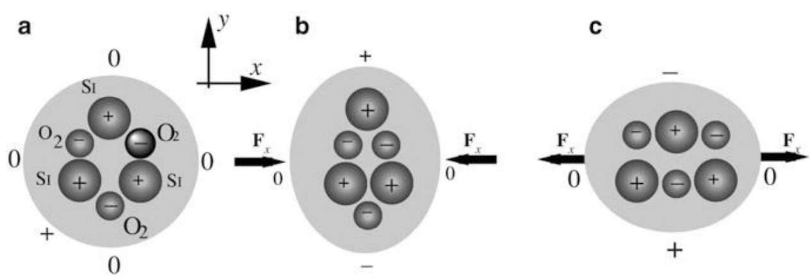




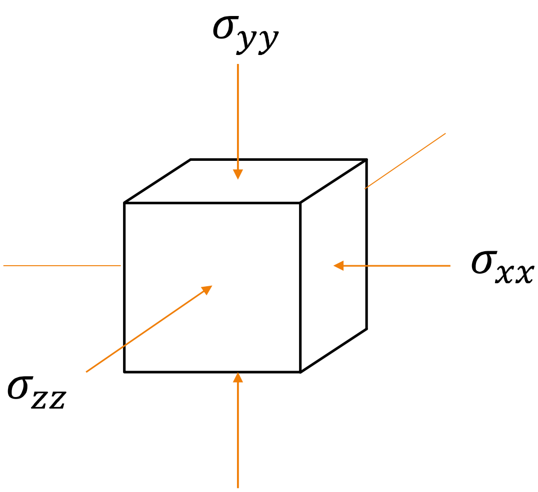
Have better sensitivity than piezoresistive sensors.
Can be affected by stray capacitances.
Requires complex signal conditioning circuity.

Piezoelectric Effect

- Generation of electric charge by a crystalline material when subjected to a stress.
- Examples of materials: quartz (SiO_2), poled man-made ceramics, and some polymers (PVDF).



Piezoelectric effect



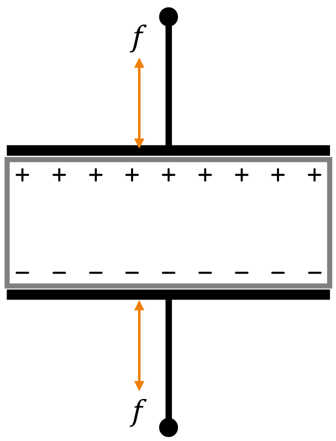
Polarization of the crystal due to stresses acting in different directions

$$\mathbf{P} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \end{bmatrix}$$

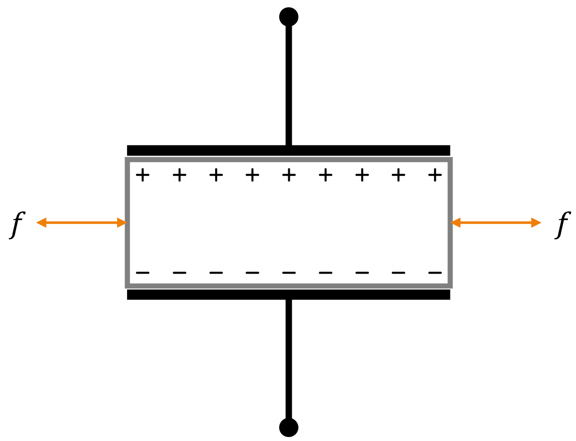
d_{mn}: Piezoelectric coefficient (Coulumb / Newton)

In practice crystals are used in the directions where the coefficient is the largest.

Piezoelectric effect

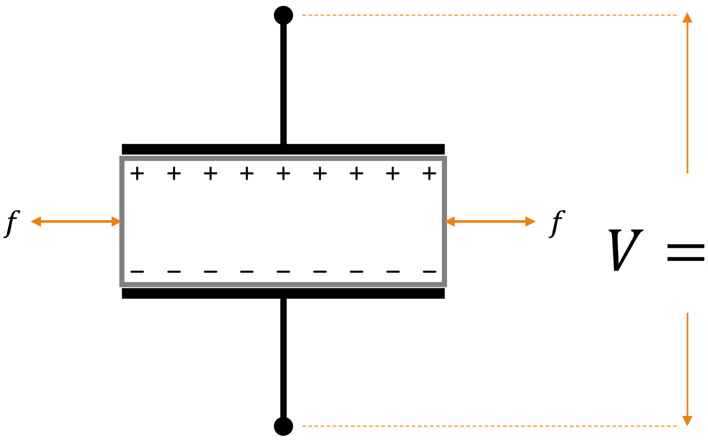


Longitudinal effect



Transverse effect

Piezoelectric effect

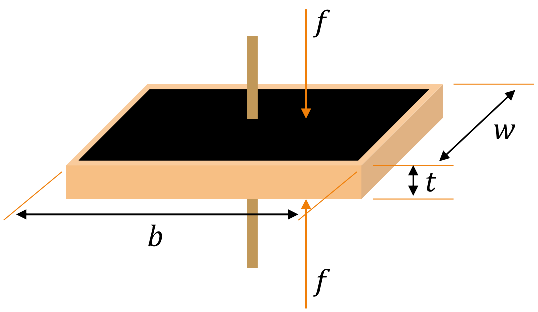


$$V = \frac{Q}{C}$$

$$Q = d \cdot f \qquad C = \epsilon \frac{A}{l} = QV$$

$$V = \frac{Q}{C} = \frac{d}{C} f = \frac{dl}{\epsilon A} f$$

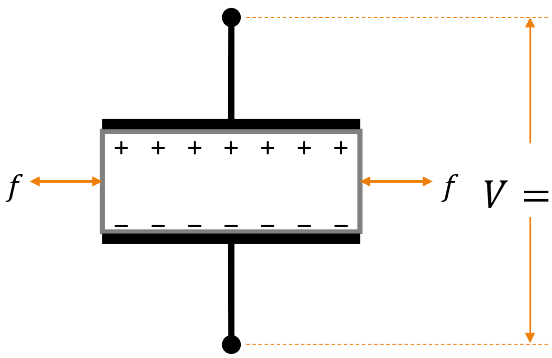
$$f = \epsilon \frac{A}{d \cdot l} V$$



What is the output charge and voltage generated by this piezoelectric sensors if a force of 3N is applied on the sensor?

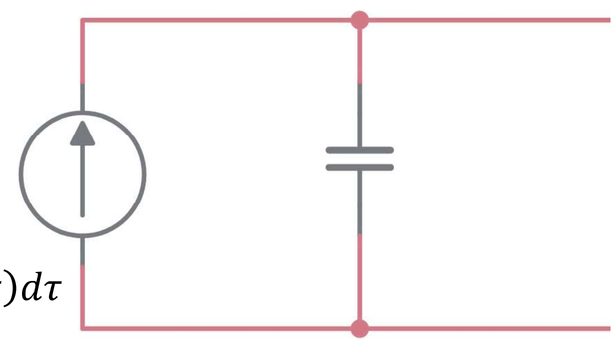
$$b = w = 1cm \quad t = 0.5cm$$
$$\epsilon = 2 \times 10^{-10} F \cdot m^{-1}$$
$$d = 1.8\, pC \cdot N^{-1}$$

Piezoelectric sensor equivalent circuit

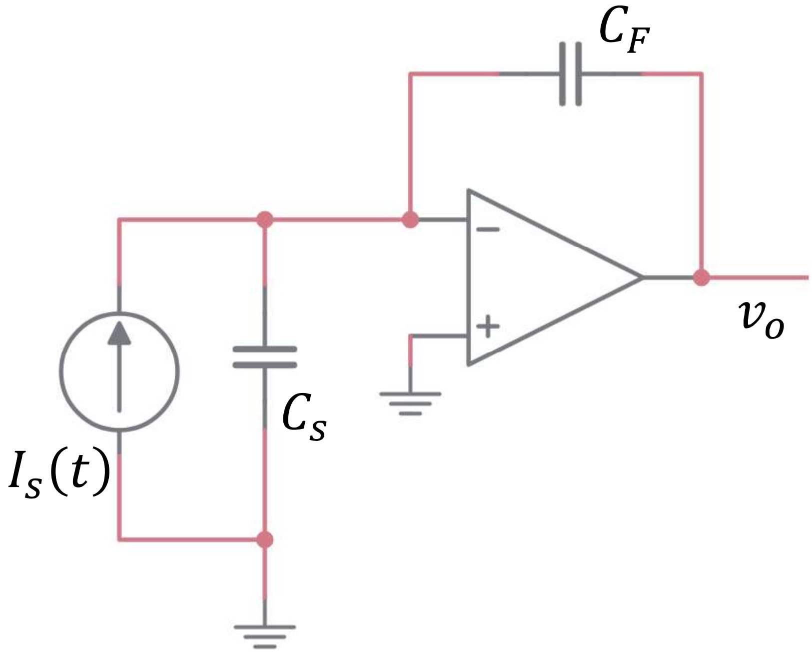


$$V = \frac{Q}{C}$$

$$Q = \int_{-\infty}^{t} I(\tau)d\tau$$

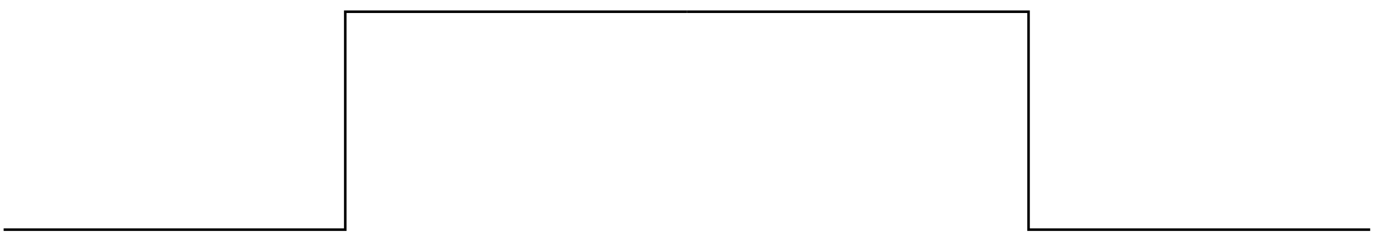


Charge amplifier



$$v_o = -\frac{1}{C_F}\int_{-\infty}^{t} I_s(\tau)d\tau$$

Piezoelectric sensors are not good for DC measurements



Piezoelectric pressure sensor