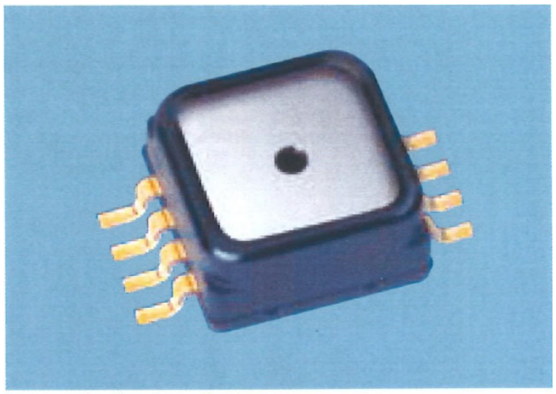
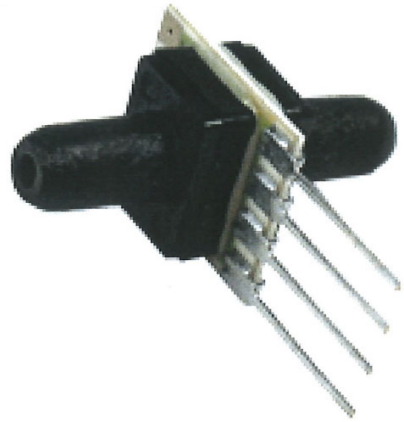
Lecture 10/21/22

Pressure Sensors (Continued)

1) Some examples of commercially available MEMS pressure sensors

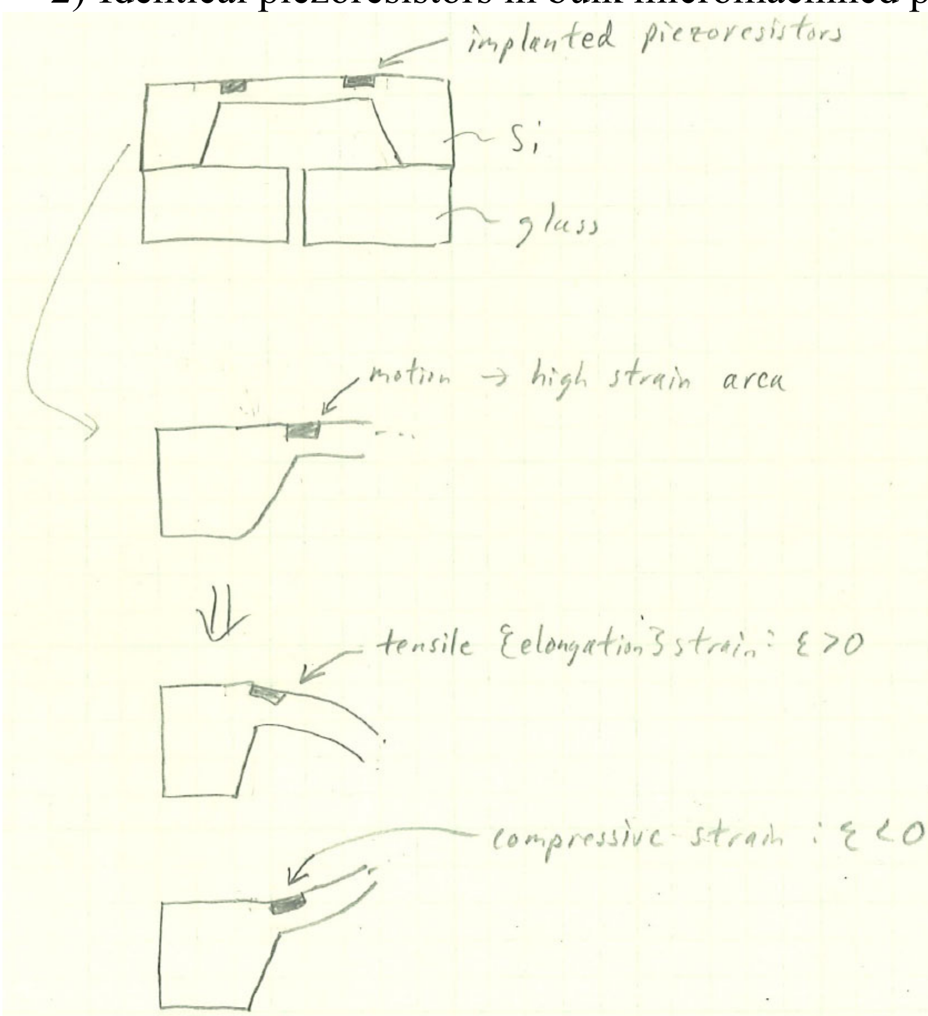


Freescale Semiconductor



AllSensors.com

2) Identical piezoresistors in bulk micromachined pressure sensors



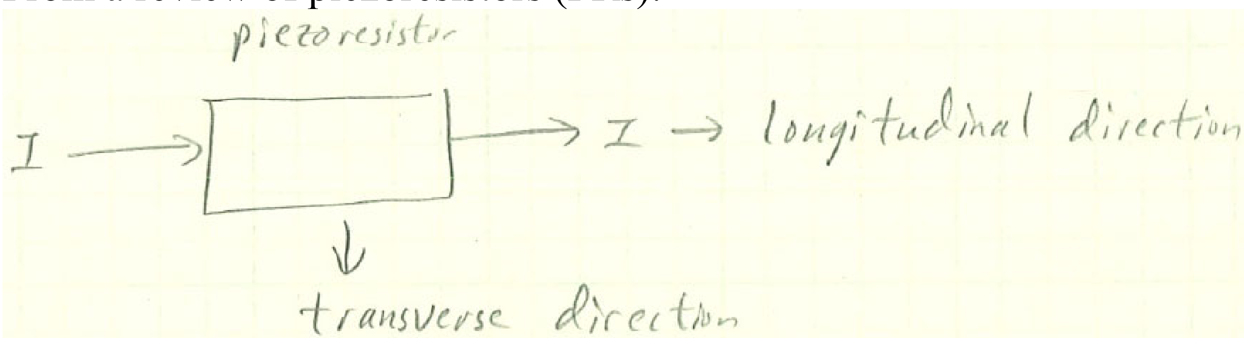
Since $GF = \frac{dR/R}{\varepsilon_1}$ and $\Delta R = R\varepsilon_1 GF$,

If GF = +200 (single crystal Si, p-doped)

For tensile strain: R_{new} increases because $\Delta R > 0 \rightarrow \varepsilon > 0$

For compressive strain: R_{new} decreases because $\Delta R < 0 \rightarrow \varepsilon < 0$

From a review of piezoresistors (PRs):



$$\frac{d\rho}{\rho} = \pi_l \sigma_l + \pi_t \sigma_t$$

Where: $\pi_l = longitudinal\ piezoresistive\ coefficient$
$\pi_t = transverse\ piezoresistive\ coefficient$
$\sigma_l = longitudinal\ stress$
$\sigma_t = transverse\ stress$

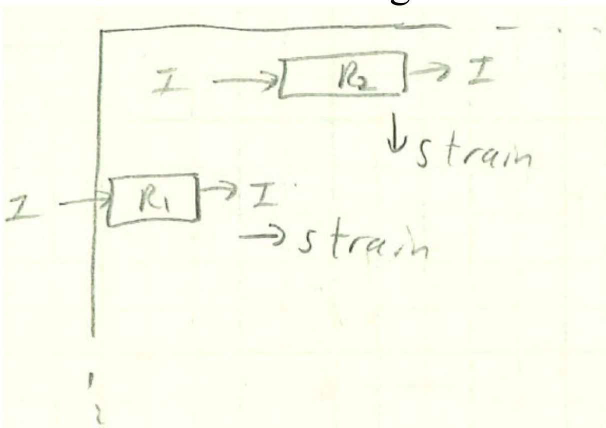
For a p-type (100) Si wafer, reasonable values for π_l and π_t:

π_l: +69 m^2/N and π_t: -69 m^2/N are reasonable values.

However, π_l and π_t are a function of crystal orientation, doping, and temperature. So obtaining exact values is challenging.

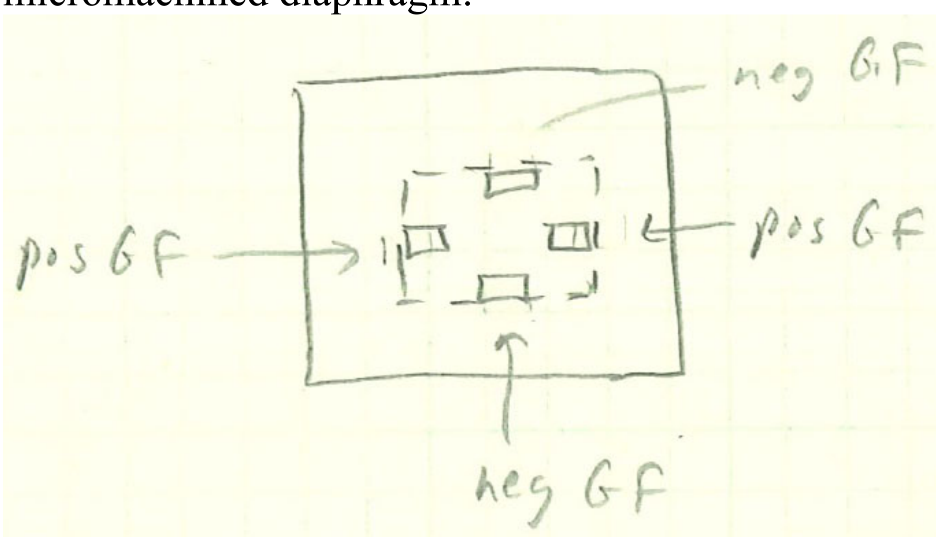
Observe that π_l and π_t have the same magnitude but opposite sign. This can be used to realize a Wheatstone bridge on the pressure sensor.

Consider this PR configuration:



Here, there are two PRs of the same size and shape (sorry for the poor artwork!), and same doping: the bulk single crystal Si is doped to realize the PRs. However, the stress is different for the PRs: one PR will experience longitudinal stress, while the other PR experiences transverse stress.

So with this technique, it is possible to make 2 identically doped PRs where one has +GF and the other one has –GF, where they are closely matched in magnitude. Expanding this to 4 PRs in a bulk micromachined diaphragm:



All 4 PRs have the same doping, so that this configuration can realize a Wheatstone bridge.

3) Temperature dependence

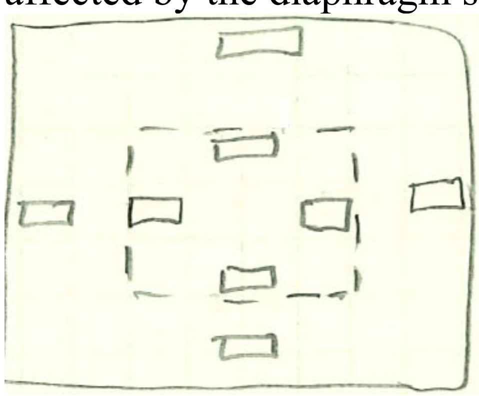
Piezoresistors → R = f(temperature)

The Wheatstone bridge reduces temperature sensitivity (all PRs should change the same way due to temperature changes), but temperature sensitivity is not completely eliminated, due to fabrication tolerances.

So, a couple of things can be done to improve temperature insensitivity:

a. Add a temperature sensor to the MEMS pressure sensor and calibrate the pressure sensor over P and T. This results in a table of correction values for each P and T combination that can be used to remove temperature induced biases (as well as nonlinearities in P measurement). However, this is a time consuming and therefore expensive process, and the resulting correction table must be stored in computer memory.

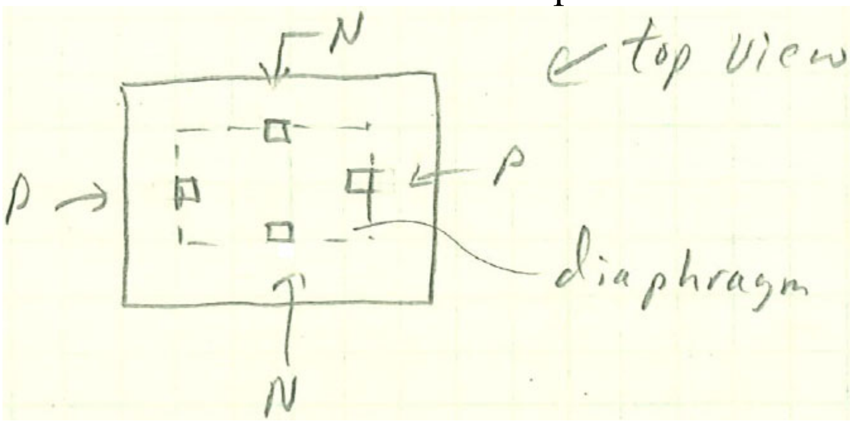
b. Add a dummy set of PRs to the pressure sensor chip that are not affected by the diaphragm strain:



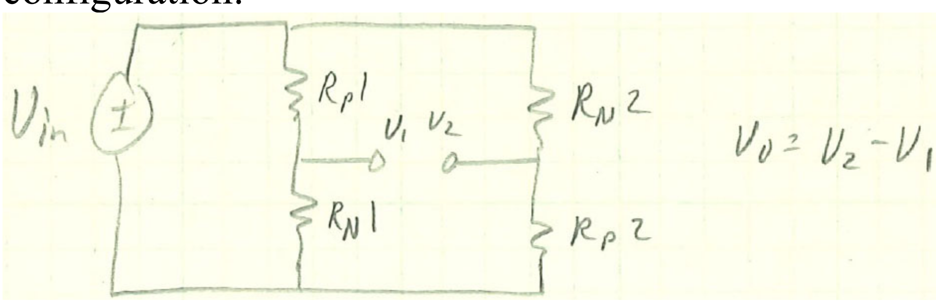
Use a 2nd Wheatstone bridge with the dummy PRs and subtract its output voltage from the pressure sensor output voltage.

4) p- and n-type PRs in bulk micromachined pressure sensors

Consider this bulk micromachined pressure sensor configuration:



Two of the PRs are p-type (GF ~ +200), while the other two are n-type (GF ~ -125). They could be connected in a Wheatstone bridge configuration:



However, for a given strain, ε, that all PRs experience, the p-type PRs will increase more in resistance than the n-type PRs decrease → undesirable.

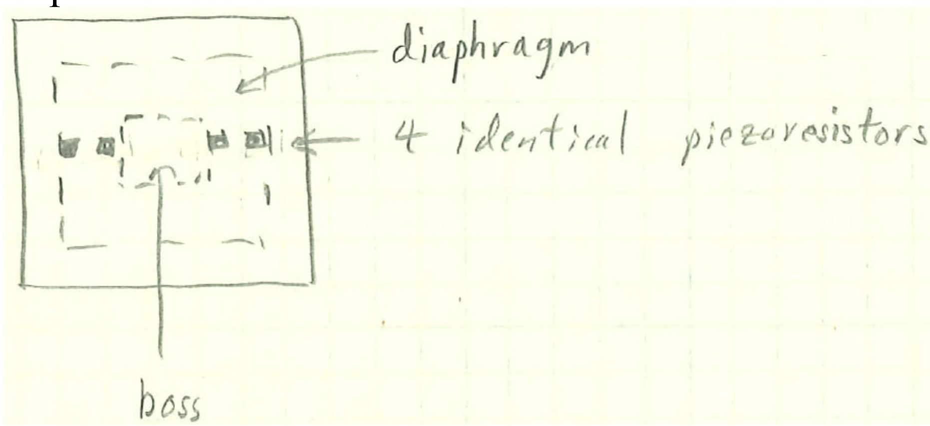
So, instead of doping regions of the Si diaphragm to realize PRs, consider depositing and patterning a thin layer of polysilicon on top of the diaphragm, and doping regions of it to realize polysilicon PRs:

Advantage: p-type GF ~ +30, n-type GF ~ -30: nearly matched

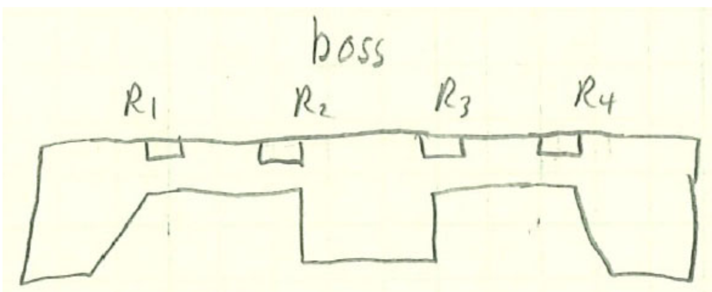
Disadvantage: more processing steps: lower yield, more expensive

5) Bossed diaphragm with PRs

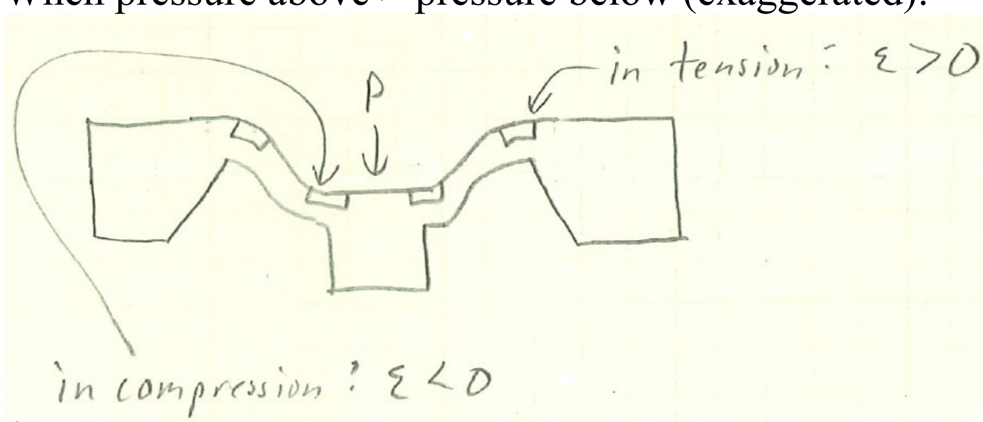
Top view:



Cross sectional view:



When pressure above > pressure below (exaggerated):



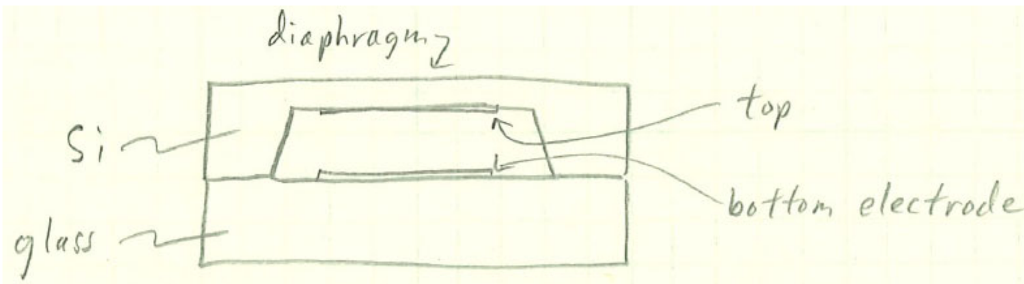
As a result:

$R_1 \rightarrow R\uparrow$
$R_2 \rightarrow R\downarrow$
$R_3 \rightarrow R\downarrow$
$R_4 \rightarrow R\uparrow$

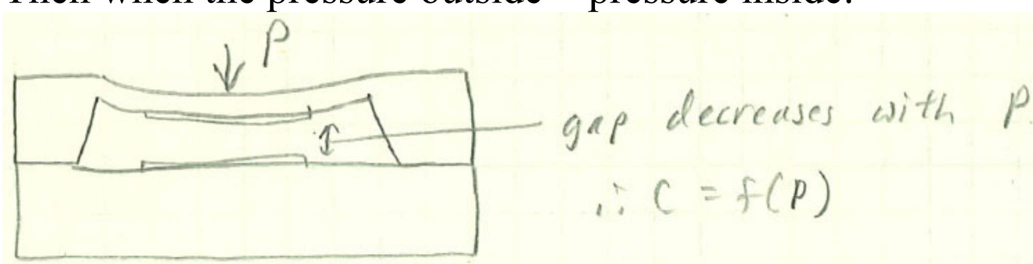
Then connect the four PRs on-chip with metal traces (another photolithography mask), and we have a Wheatstone bridge.

6) Capacitive pressure sensors

Often, a parallel plate capacitor is used where pressure changes the distance between the electrodes:



Then when the pressure outside > pressure inside:



Usually, capacitance is a nonlinear function of P: 1/x relationship.

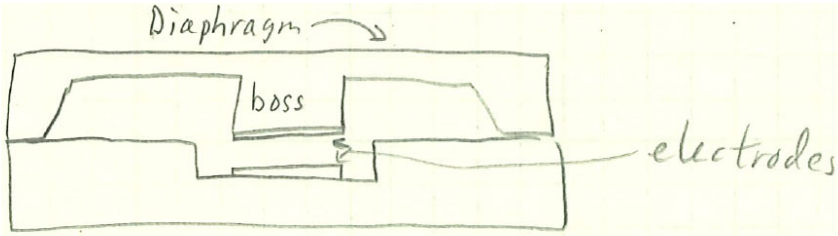
Fabrication is simpler (less expensive, higher yield) than with PRs; however, the interface electronics is more complicated than with PRs.

Capacitive detection is usually less sensitive to temperature than with PRs.

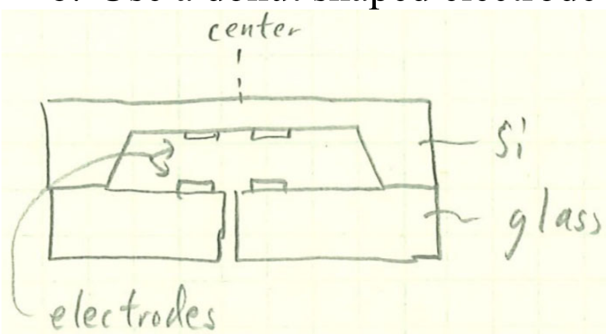
Also, the diaphragm deflects the greatest amount at the center, which has an additional nonlinearity.

a. Capacitive detection with the bossed diaphragm

The boss has a flat, nearly rigid bottom, which can be used as the movable electrode:



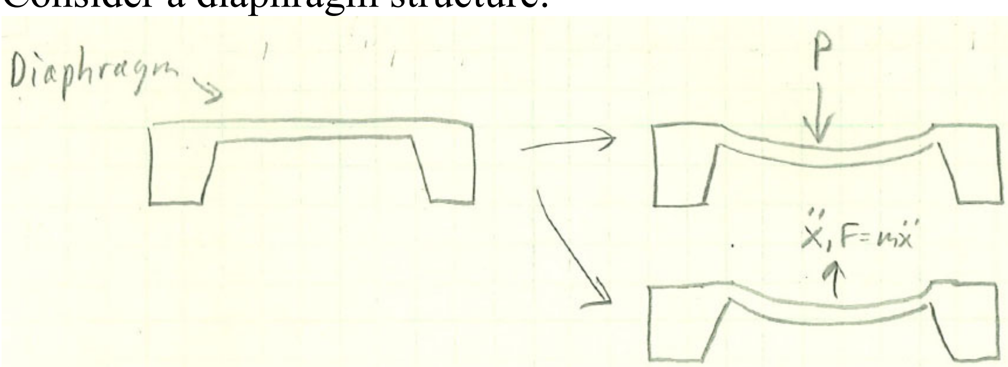
b. Use a donut shaped electrode around the center of the diaphragm



Advantages: smaller nonlinearity
Disadvantages: lower sensitivity and more complicated to fabricate

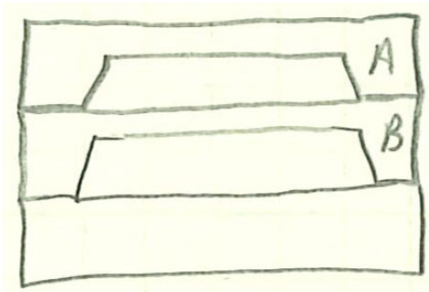
7) Acceleration effects

Consider a diaphragm structure:



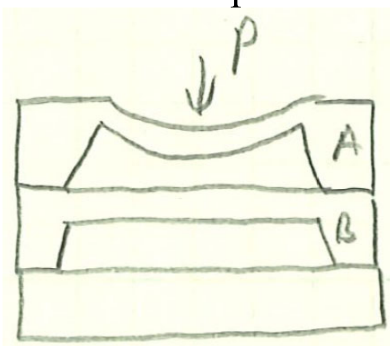
Is the diaphragm deflection due to pressure or to acceleration (or both)?

Consider this structure with two identical Si diaphragms bonded together:



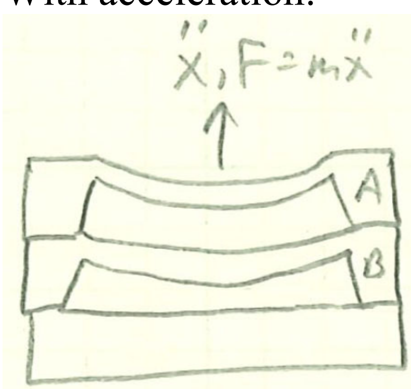
Diaphragms A and B with identical volumes in their sealed cavities.

Once external pressure is applied:



Observe that diaphragm A deflects but B does not (assuming high vacuum in both sealed chambers). Measure capacitance between A and B to determine pressure.

With acceleration:



A and B deflect together: capacitance is mostly not a function of acceleration.

Note: instead of capacitive detection, PRs could be used for detection here.