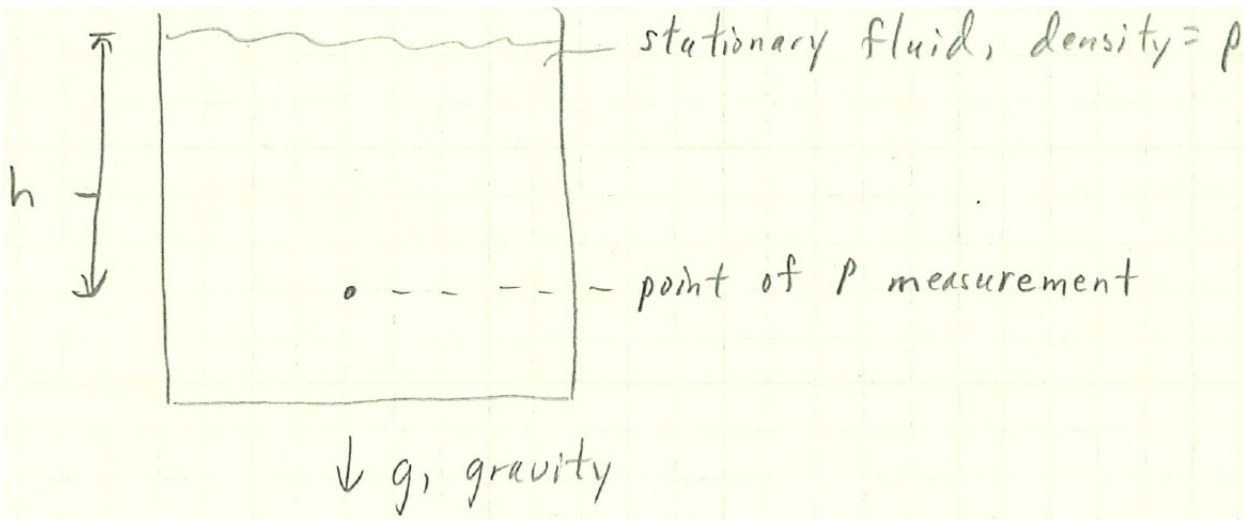
Lecture 10/17/22

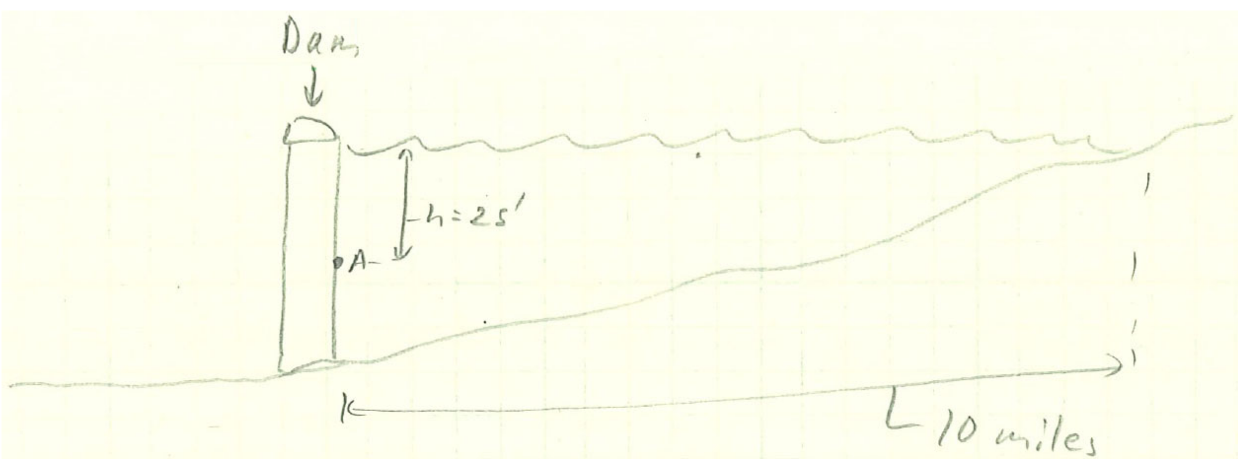
Pressure Sensors (Physics of Pressure)

1) Fluid Mechanics

a) Static Pressure



$P = \rho g h \rightarrow$ due to the weight of the fluid above the measurement point.



The pressure on the dam at any point is only due to the water above that point: P = ρgh (and the air pressure above the dam) and *not* due to the length of the lake behind the dam.

1) Buoyancy

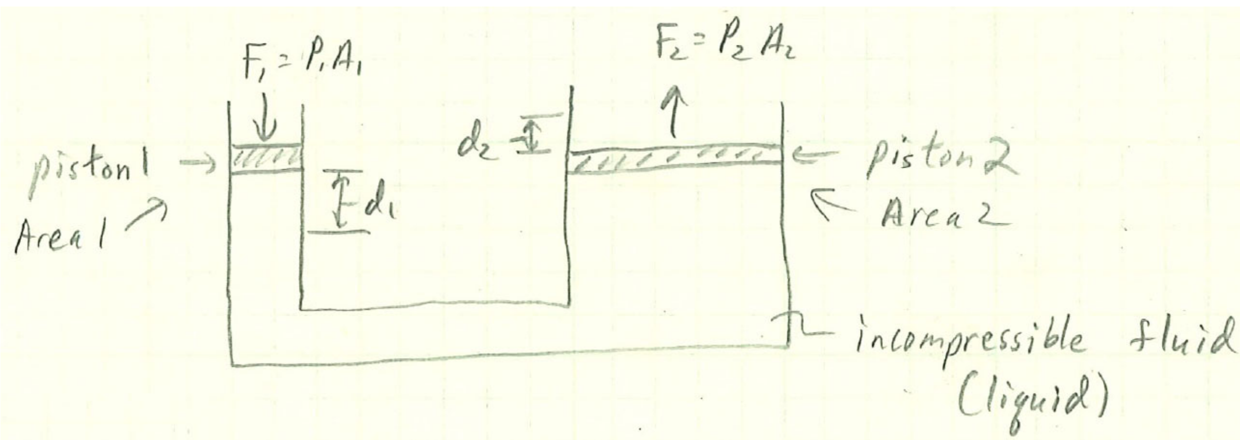
Also known as Archimedes' principle

A submerged object of volume, V, displaces an equal volume of fluid.

If the volume of displaced fluid weighs more than the submerged object, the object floats.

If the object weighs more than the volume of fluid displaced, it sinks.

2) Hydraulic Force



$$P_1 = P_2 = P$$

$$work = F_1 d_1 = F_2 d_2$$

$$PA_1 d_1 = PA_2 d_2$$

$$\therefore d_2 = \frac{d_1 A_1}{A_2}$$

b) Dynamic Pressure

Here, the fluid is in motion.

Bernoulli's equation: $P_t = P_s + \frac{\rho v^2}{2}$, where:

$P_t \equiv$ total pressure
$P_s \equiv$ static pressure
$\frac{\rho v^2}{2} \equiv$ dynamic pressure

This equation exactly holds for an incompressible fluid with zero viscosity. It's an approximation otherwise.

If you can measure the static pressure, the total pressure, and the fluid density, you can calculate the fluid velocity, v, be rearranging Bernoulli's equation:

$$v = \sqrt{\frac{2(P_t - P_s)}{\rho}}$$

An instrument for measuring P_t and P_s to determine airspeed of an aircraft by this technique is the Pitot tube:

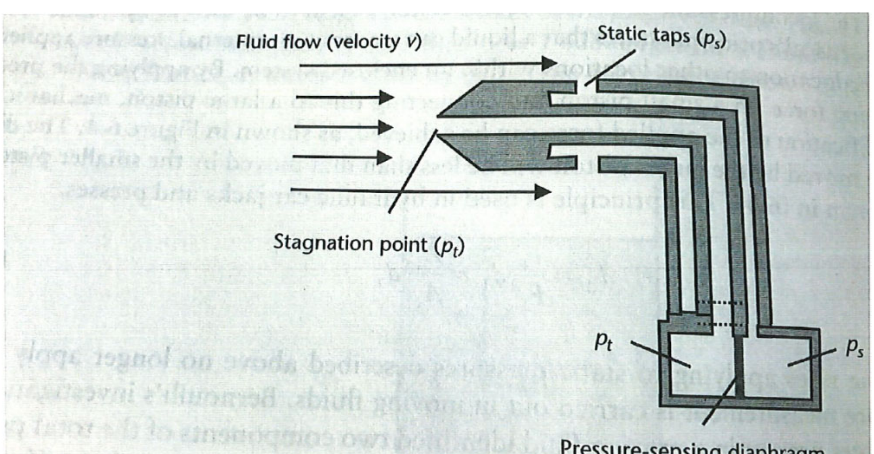


Figure 6.5 Pitot tube arrangement.

Pitot Tube photo, curtesy Wikipedia

c) Compressible Fluids (i.e. gasses)

Ideal gas law: PV = nRT, where:

P → pressure
V → volume
T → temperature (degrees Kelvin)
n → number of moles of gas
R → universal gas constant (8.314 J/mol·K)

<u>Pressure Sensing Structures</u>

1) Diaphragm

A diaphragm is a rigid, planar member clamped on all sides:

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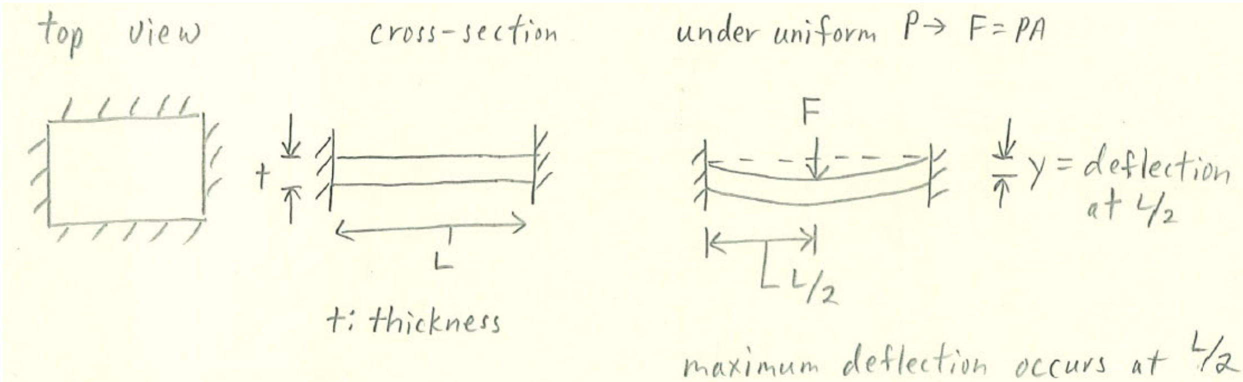


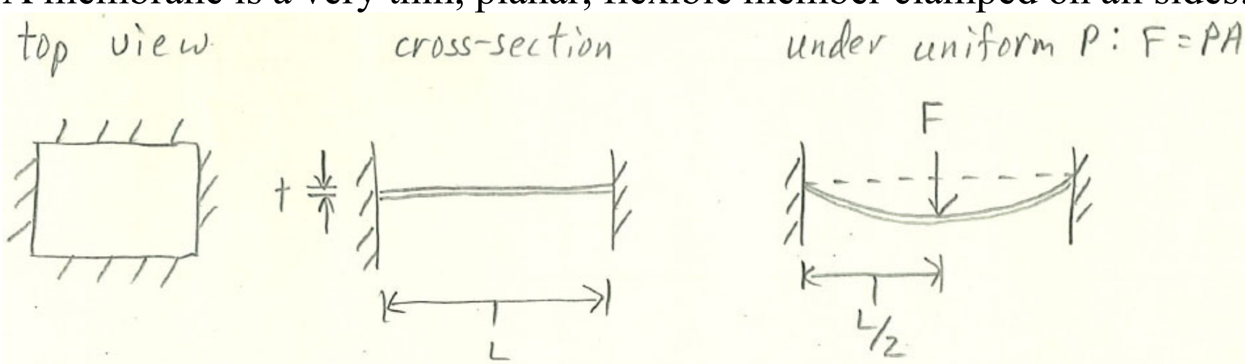
A diaphragm experiences bending stress *and* tensile stress.

For small deflections (y ≤ ~30% t) → $y \propto P$.

In this range of deflections, the deformations are elastic.

2) Membrane

A membrane is a very thin, planar, flexible member clamped on all sides:



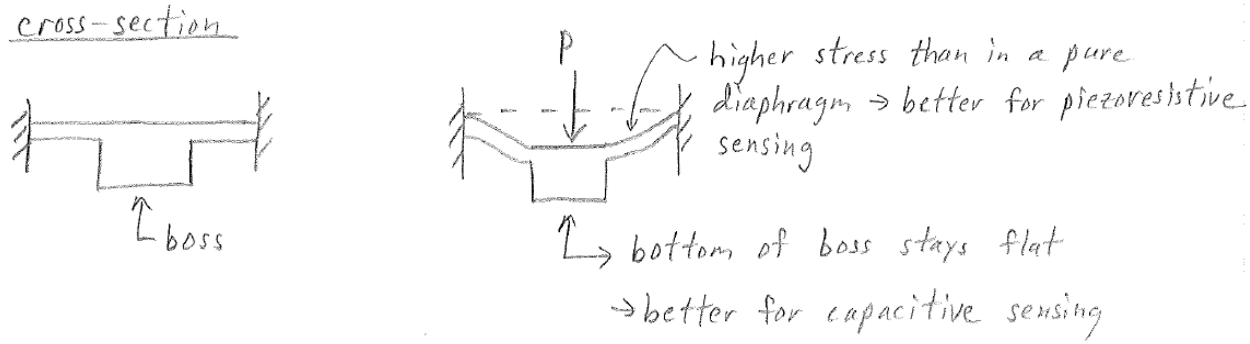
A membrane experiences *only* tensile stress, *not* bending stress.

Membranes can experience large deflections: y often > t.

A balloon is an example of a membrane: $P_{inside} > P_{outside}$ Why?
How would you measure pressure on/in a balloon?

3) Bossed Diaphragm

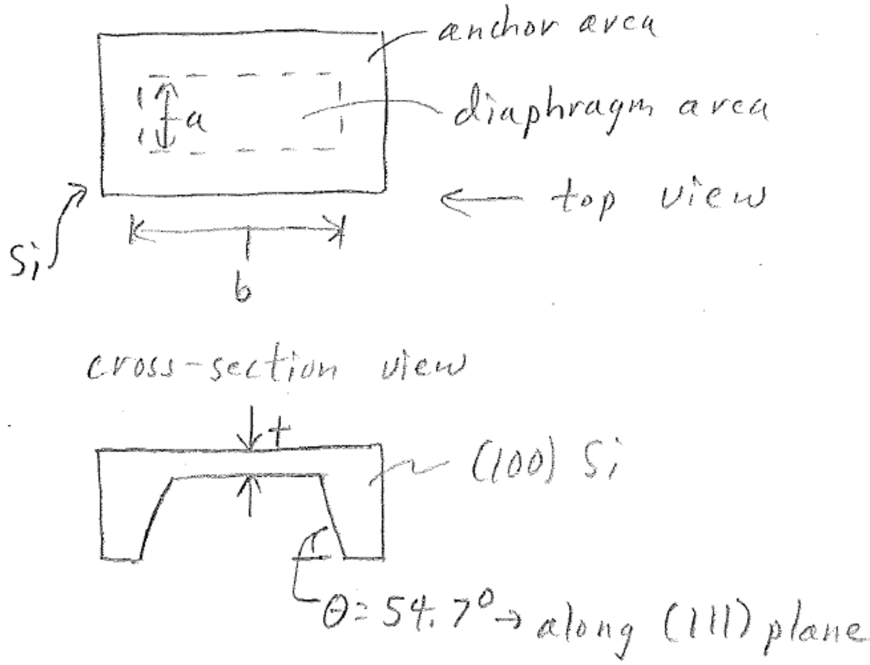
A "boss" is a thicker area in the center of a bossed diaphragm, far more rigid than the rest of the diaphragm:



The boss is at least six times thicker than the diaphragm.

4) Bulk Micromachining of a Diaphragm Pressure Sensor

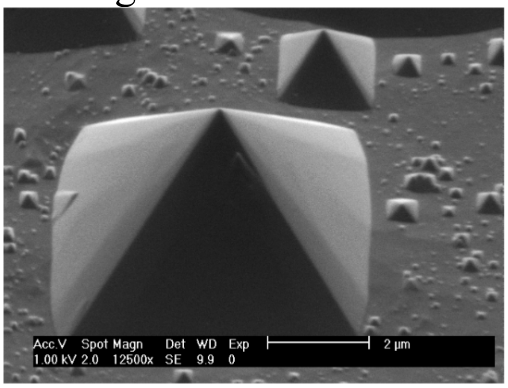
The diaphragm based pressure sensor is fabricated by etching bulk material out of the substrate:



In the example above, the backside etched volume was fabricated using an anisotropic (crystal plane dependent) wet etch of Si, example: KOH or TMAH etching solutions.

This timed etch "results" in a rectangular, uniform thickness diaphragm, where the time of etch determines the diaphragm thickness.

Etching defects sometimes occur, called hillocks:

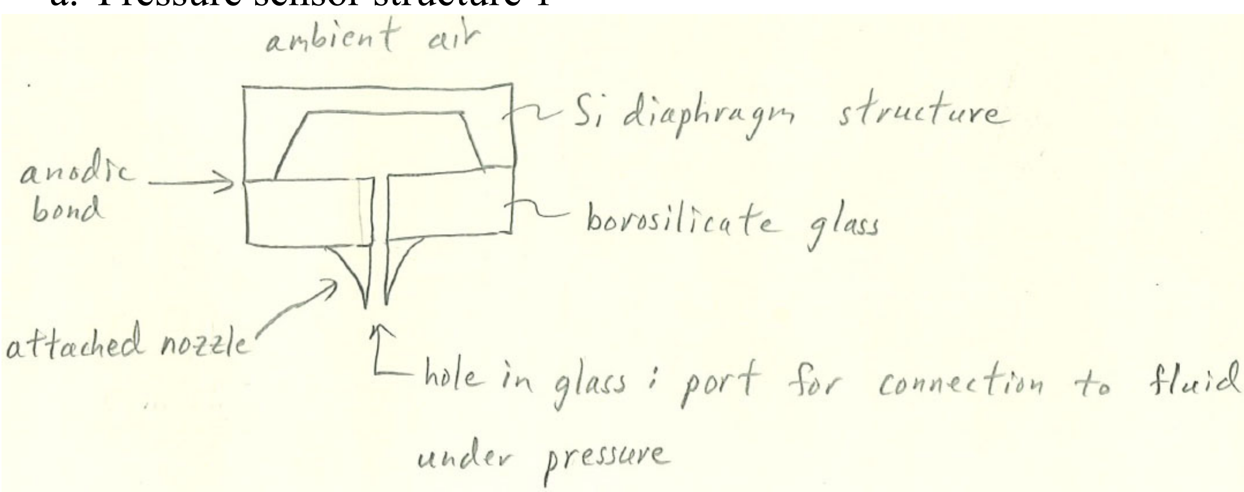


J. Thong et al., "Evolution of hillocks during silicon etching in TMAH," J.M.M. (11), 2001.

Kind of like fire ant mounds in your lawn…

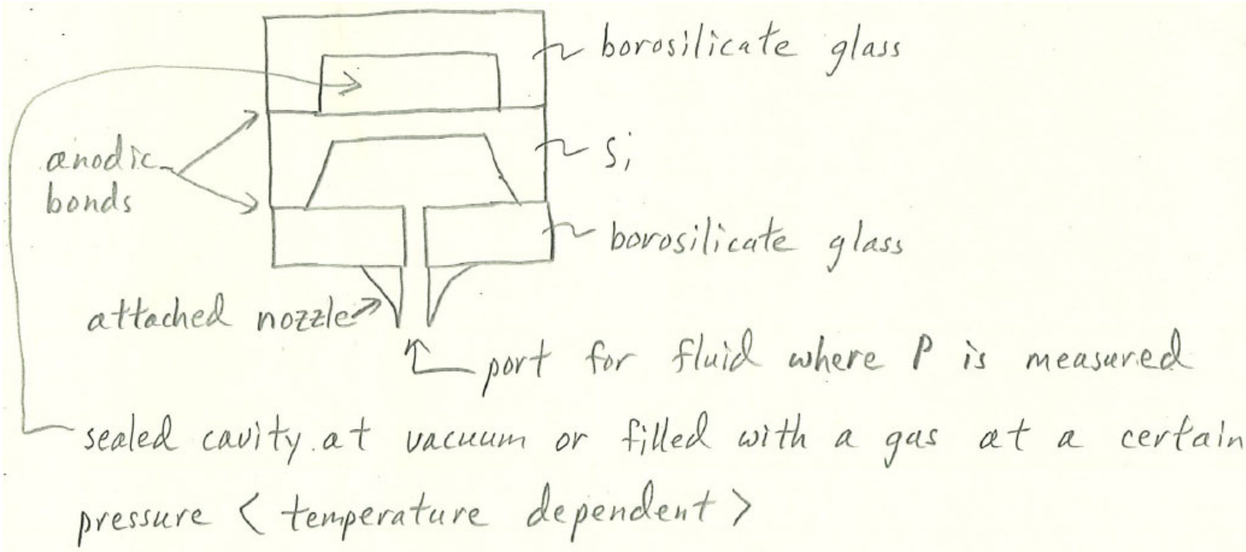
Typically, a micromachined diaphragm is designed to have a resonant frequency above the audio frequency range, to avoid microphone behavior if damping is low. 80 kHz or higher is typical for the resonant frequency.

a. Pressure sensor structure 1



This design would be for measuring pressure w.r.t. ambient air pressure.

b. Pressure sensor structure 2

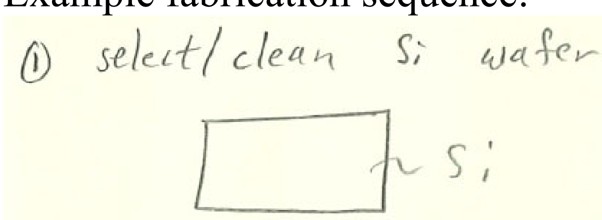


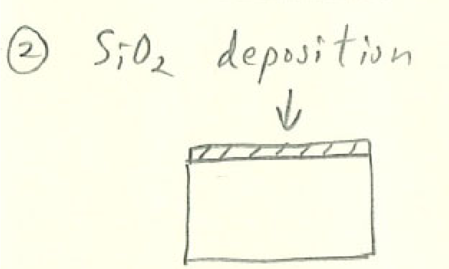
This structure could be an absolute P sensor (measure P w.r.t. a full vacuum).

5) Surface Micromachining of Pressure Sensors

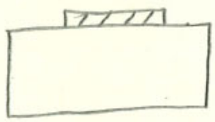
The diaphragm or membrane structure is fabricated on top of the Si substrate using additive or subtractive processes.

Example fabrication sequence:

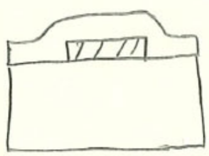




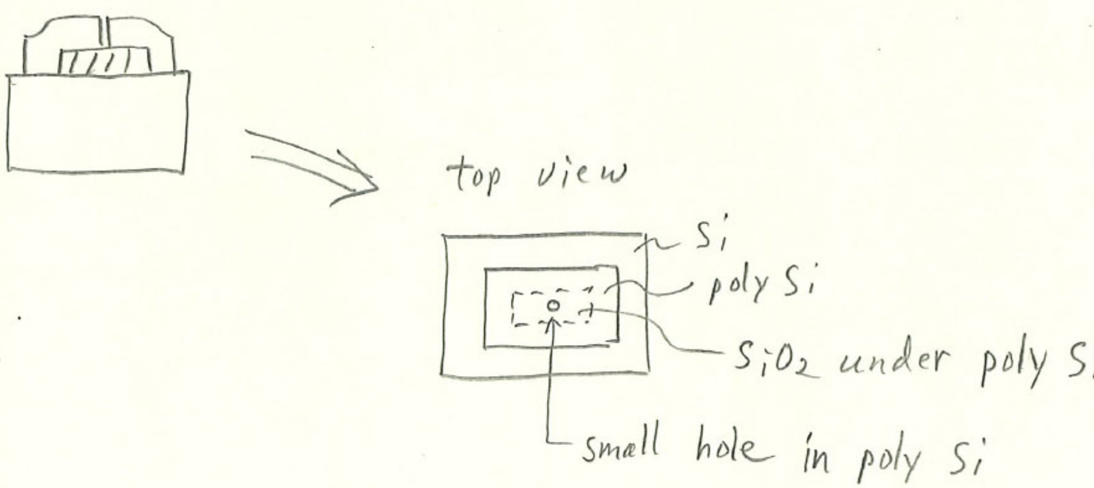
③ SiO_2 patterning <to be used as a sacrificial layer>



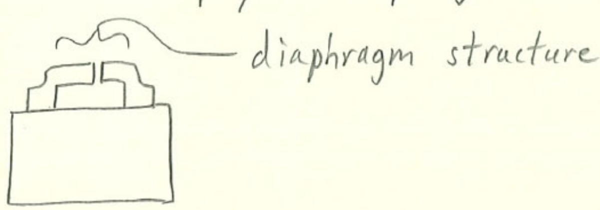
④ Poly Si deposited (using LPCVD) → conformal coating



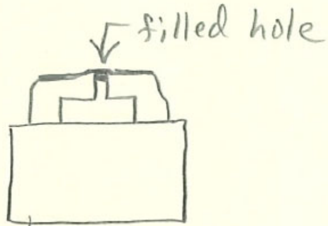
⑤ Poly Si patterning with small hole in diaphragm center



⑥ SiO_2 sacrificial layer is chemically removed (release etch), leaving the anchored poly Si diaphragm



(7) Fill the hole in the poly Si : <u>ex</u>: using silicon nitride (SiN)



low P process that leaves the void at a near vacuum

↳ ∴ an absolute P sensor

↳ various techniques can be used to measure diaphram or membrane deflection, y, where $y \propto P$

*Membranes can be made with this process (instead of a diaphragm) where other materials are used in place of polysilicon, such as silicon nitride.