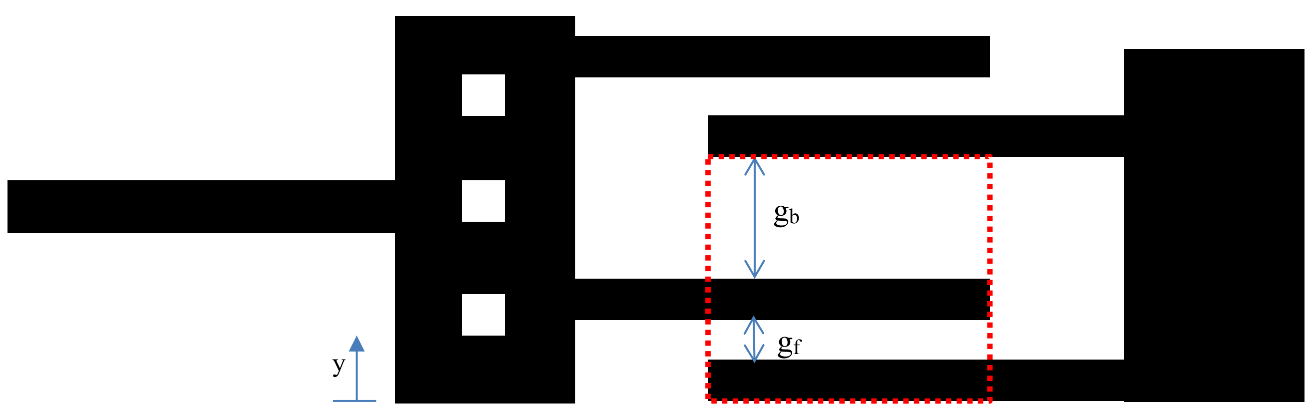
EE 147/247A Prof. Pister
Fall 2021

Homework Assignment #2

Due on bcourses Wednesday 9/15/2021 (late 9 AM thursday)

1. You have a solid cube of silicon of side length *S* sitting a distance *d* beneath a large flat conductive plate, creating a parallel plate gap between them. You apply a voltage *V* between the cube and the plate, which generates an upwards force on the cube. If $d=S/100$
   a. Does the magnitude of the force depend upon S?
   b. Using the approximation that $\frac{1}{2}\varepsilon_0(15V)^2=1nN$, what is the force on the cube if V=1.5V, 15V, and 150V?
   c. For the three voltages above, calculate the range of values of *S* for which the mass of the cube is less than the electrostatic force lifting it up
2. In a single-mask SOI process in which your minimum lithography line and space is λ, you wish to make an accelerometer with a variable capacitor readout, like our simplest accelerometer (e.g. in lecture W2L2 at around 34 minutes). Two of the many capacitor finger pairs are shown below, showing the desired front gap g_f, and the undesired back gap g_b.
   a. For a displacement of the proof mass over the range $y = [-g_f, g_b]$, sketch the front gap capacitance, back gap capacitance, and total capacitance assuming $g_b = 2\ g_f$. You should have some asymptotes! Show clearly the relative front and back capacitance values when y=0.
   b. What is the impact of the back gap on dC/dy near y=0?
   c. Repeat parts a and b, assuming $g_b = g_f$.

   Making gb too big means we don't get very many fingers, so we don't have much capacitance per layout area, and there is an upper limit on how much area we can use. Making gb too small means that we can put in a lot of fingers, but the change in capacitance per finger gets smaller. Somewhere there is an optimum.
   d. Assuming that the width of the capacitor fingers and the front gap is λ, what is the value of the back gap that maximizes dC/dy at y=0 per unit layout area? I've drawn a representative tile-able layout area in red below.



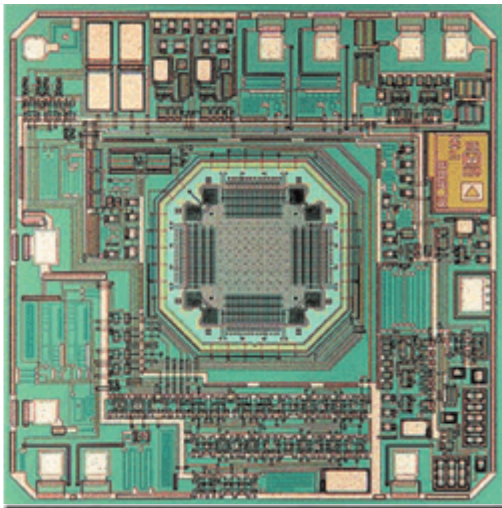
3. For this problem, assume that the fracture strain of silicon is 1%. You may use 50 kg as your mass if you'd rather not disclose personal information.
   a. What is the minimum cross-sectional area of a silicon wire that will hold your weight without breaking?
   b. If we etched a long straight piece of the device layer on a 40/2/550 SOI wafer and supported you by it, how wide would it need to be?
4. Look at the video on the link "single-mask SOI motor" on the class webpage.

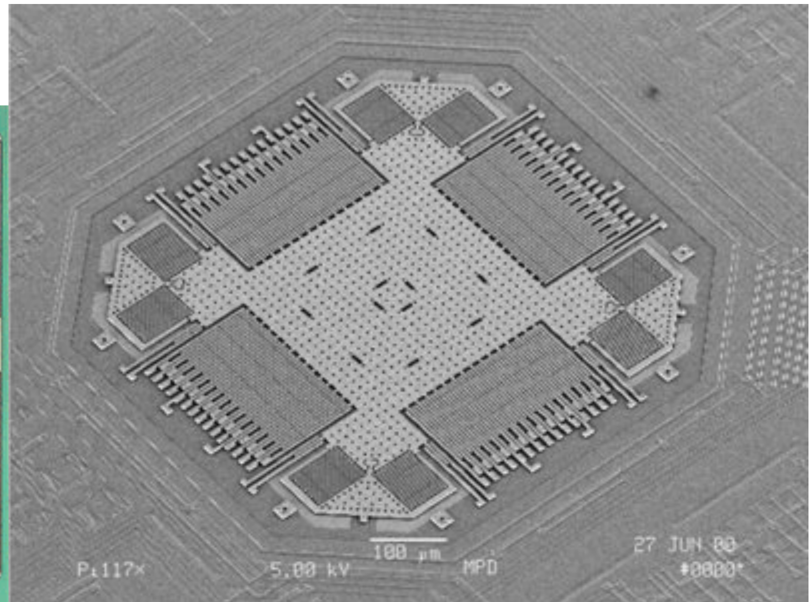
a. There's a scale bar at 0:05. How big is the overall structure, from bond wire to bond wire? (the bond wires are in 400x400 um2 holes in the SOI layer, and connect to the substrate, most likely to ground it)
b. Estimate the change in sense capacitance over the range of travel (shown 0:20 to 0:35), and the distance traveled. With a sensor able to resolve 4 aF, what position resolution would this give?
c. Estimate the change in capacitance for one of the three poles, over a single step (0:44 to 0:57). You'll need to do some counting of crenelations.
d. At 1:06 it gives a peak angular velocity. Estimate the corresponding velocity of the pointer tip in m/s.
e. What is the approximate frequency of the electrical excitation signal at the peak angular velocity?

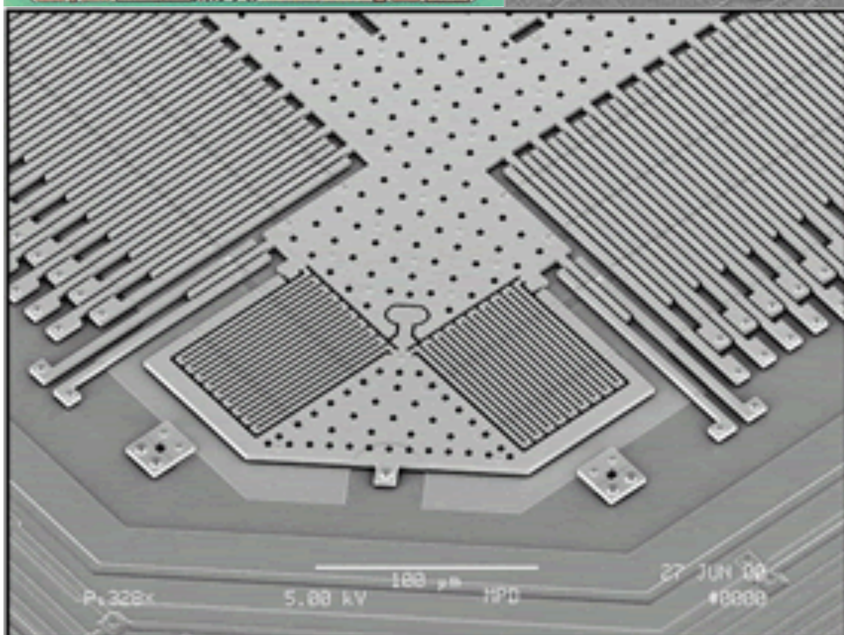
5. The pictures below are of the ADXL202, which is now obsolete but looks a lot like the newer parts that replaced it. Die photo (CMOS+MEMS), SEM of the MEMS device, detail SEM, and simulation of response to a vertical acceleration.
   a. Using the scale bar, estimate the mass of the proof mass, assuming a 3um thick polysilicon film.
   b. Using the sensor resonant frequency quoted on the datasheet, estimate the combined spring constant of all of the support springs.

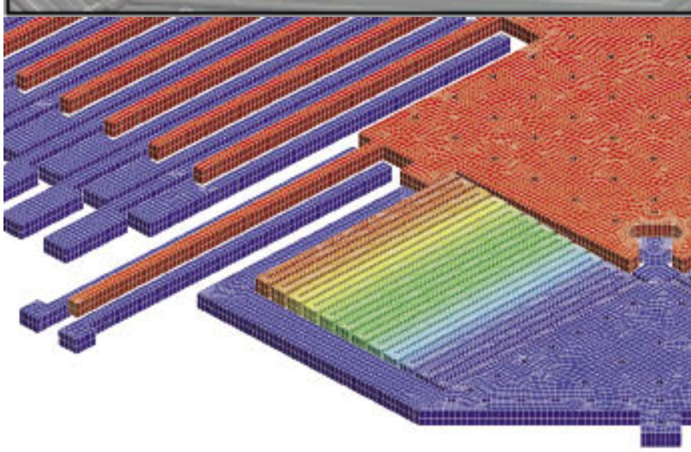
http://www.analog.com/media/en/technical-documentation/obsolete-data-sheets/ADXL202_210.pdf

   c. In the detailed SEM, identify the proof mass, support springs, proof mass anchor, over-acceleration mechanical stops, differential sense capacitors (big), actuation capacitors (small).
   d. Assuming a 3um thick film with 1um gaps, estimate the voltage needed across the actuator gap to support the weight of the proof mass (at 1 gravity).









6. [EE247A] In a three mask process (POLY0, C1S, POLY1) with only one structural polysilicon (POLY0 for wiring, and POLY1 for structures), design a 3 axis capacitive accelerometer. Can you do it with a single proof mass? Will the response be linear in all directions?