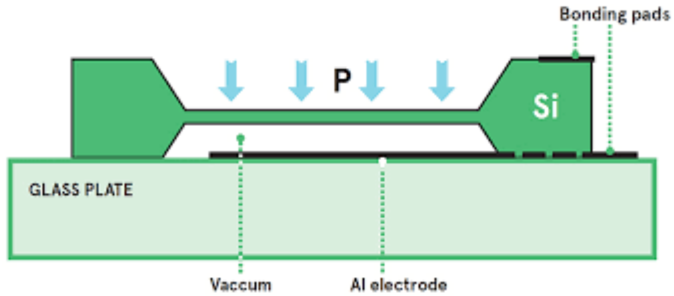
Hw#1 Rubric: 45 points

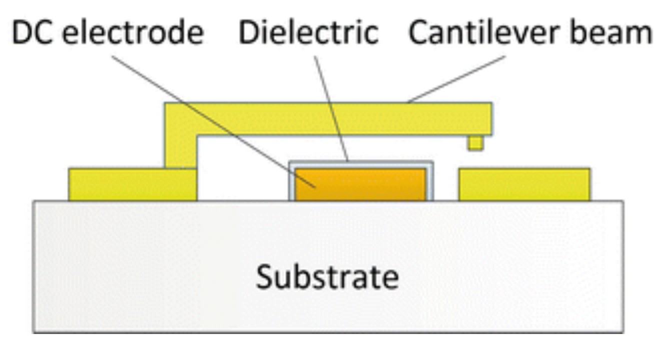
1. 6 points for effort: for both sensor and actuator, did you: include URL (1 pt), 1 sentence description of what it is (1 pt) and how it was made (1pt)

For example, below is an image of a pressure sensor and actuator. The change in pressure P causes the film to bow; this change in shape causes strain in the film, which can be measured with piezoresistors: piece of material (like Si) who's resistance changes when you stretch it. We'll learn how to make this using bulk micromaching later in the course.



https://www.avnet.com/wps/portal/abacus/solutions/technologies/sensors/pressure-sensors/core-technologies/mems/

The orange DC electrode pulls the cantilever beam down with an electrostatic force, but the beam is physically stopped by the yellow block on the right where it makes electrical contact.



https://link.springer.com/referenceworkentry/10.1007%2F978-981-10-2798-7_34-1

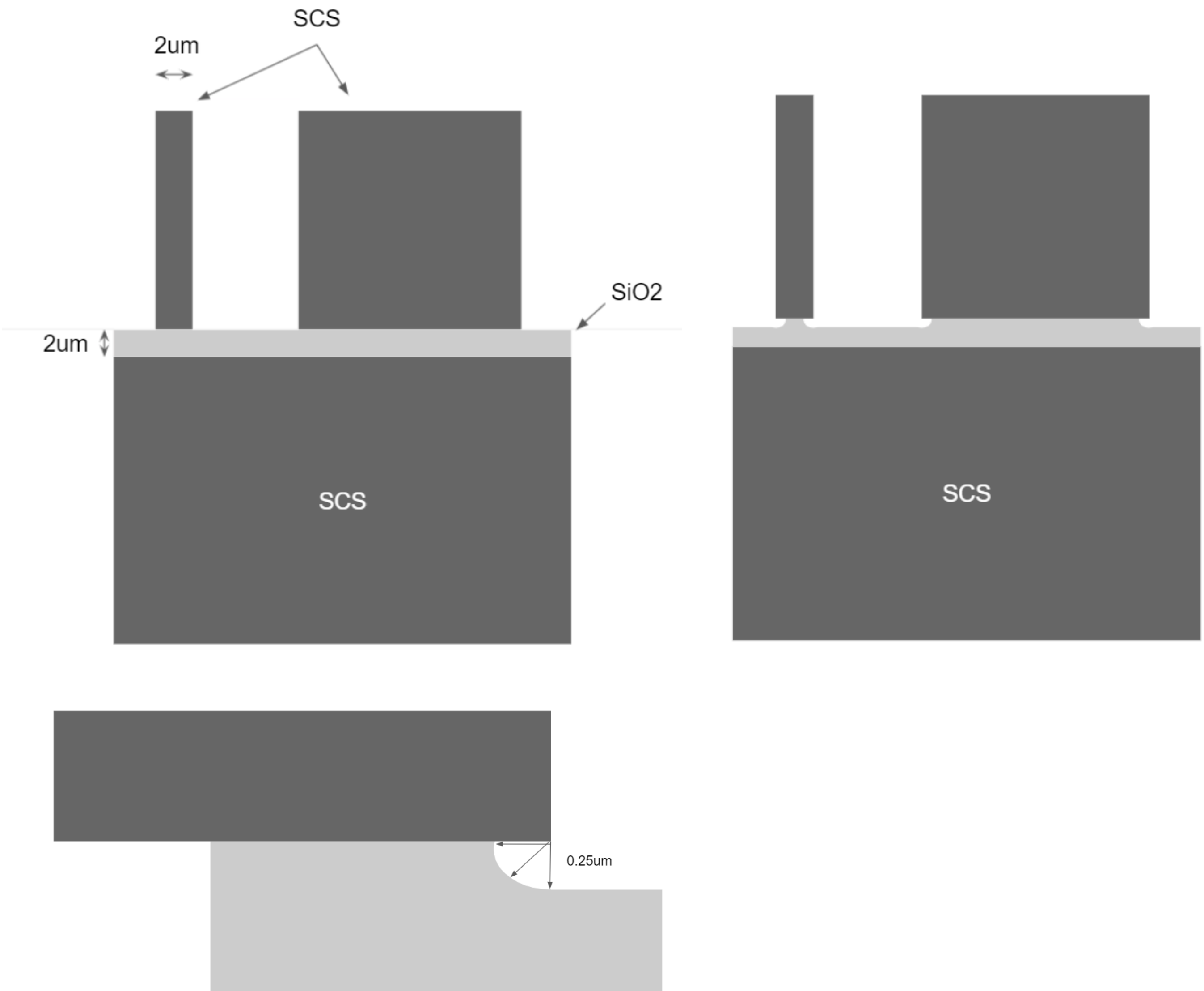
2. 4 points for effort: finding one, cost, min accel, max accel

$0.42 https://www.digikey.com/en/products/detail/rohm-semiconductor/KX003-1077/9679233

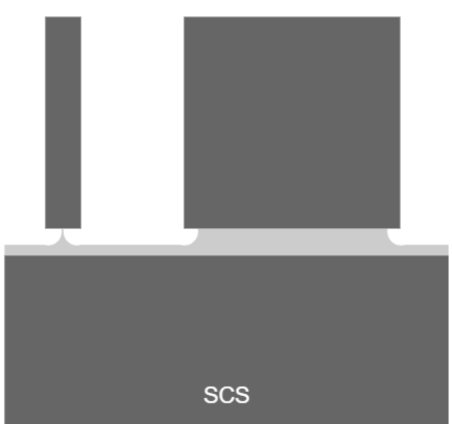
Senses 2g up to 16g

3. 28 Points

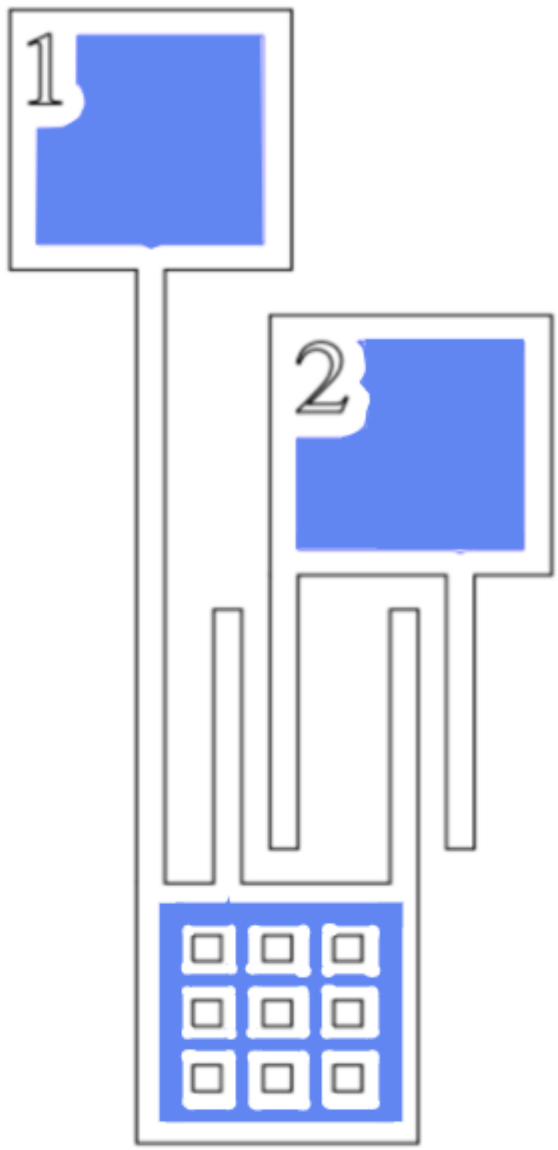
a. 1 point for undercut, 1 point for 0.25um



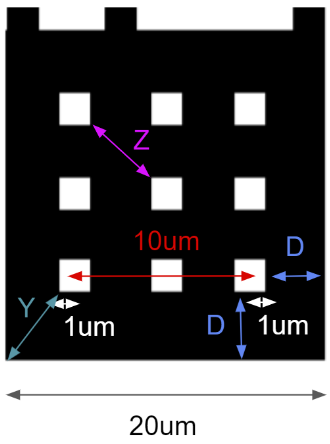
b. 1 point for undercut, 1 point for 1um



c. 1 point for correct shape around numbers, 1 point for no oxide under fingers, 1 point for perforated plate shape



d. 2 points for effort, 1 point for answer



D=4um: 2D=20um-10um etch hole spacing-2(half etch hole width)

Y=$D\sqrt{2}$

Z=3$\sqrt{2}$

The Etch distance E must satisfy two conditions to release the plate.

1. E>$\frac{Z}{2}$ $to\ release\ the\ plate\ between\ etch\ holes$
2. E>$\frac{Y}{1+\sqrt{2}}$ $to\ release\ the\ corners\ of\ the\ plate$

In this problem the second requirement requires more etching so we'll use that distance to determine out etch time.

E>$\frac{4um\sqrt{2}}{1+\sqrt{2}}$. At $\frac{1um}{min}$ this takes about 2 minutes and 20 seconds.

The time it takes to release the anchors is 10 minutes because the plate is 20umx20um.

e. 1 point for effort, 1 point for answer

$$C = \frac{\varepsilon_0 A}{g} = \frac{\varepsilon_0 L_{overlap} t}{g} = \frac{8.85 * 10^{-12}\frac{F}{m}(20um)(20um)}{2um} = 18 * 10^{-15}F$$

But! There are two capacitors so the total capacitance between the structures is 32$* \ 10^{-15}F$

f.

i. 1 point for effort, 1 point for answer

Any number close to this is fine as long as you stated your assumption.

k_lateral=$\frac{Etw^3}{4L^3} = \frac{170gPa(20um)(2um)^3}{4(50um)^3} = 54\frac{N}{m}$

ii. 1 point for effort, 1 point for answer

SA of fingers=2fingers*width*length=$100um^2$

SA of perforated plate=SA of plate-SA of etch holes=20um*20um-9($4um^2$)=364um^2

Total SA=464

Mass=2329$\frac{kg}{m^3} * 20um * 364um^2$=1.5$* \ 10^{-11} \ kg$

iii. 1 point for effort, 1 point for answer

Mass needs to be in kg.

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{54\frac{N}{m}}{1.5*10^{-11} \ kg}} = 6* \ 10^6 \ \frac{rad}{sec} = 1\text{MHz}$$

iv. 1 point for effort, 1 point for answer

F=ma=kΔx

$$1.5* \ 10^{-11} \ kg*10\frac{m}{s^2} = 54 \frac{N}{m}*\Delta x$$

$$\Delta x = 3* \ 10^{-12} m = 3pm$$

v. 1 point for effort, 1 point for answer

from 3c, C_0=18 $* \ 10^{-15} F$

At 1g, the perforated plate, and fingers have moved 3pm

$$\Delta C = \frac{C_0}{g_0}\Delta x = \frac{18 * 10^{-15}F}{2um} * 3pm = 27 * 10^{-21}F$$

g. 1 point for effort, 1 point for equation, 1 point for answer

$$\Delta x = \frac{ma}{k}$$

$$\Delta C_{min} = 10^{-21}F = \frac{C_0}{g_0}\Delta x = \frac{C_0}{g_0}\frac{ma_{min}}{k} \rightarrow a_{min} = \frac{\Delta C_{min} k g_0}{mC_0} = \frac{10^{-21}F * 54\frac{N}{m} * 2um}{1.5 * 10^{-11} \ kg * 18 * 10^{-15}F} =$$

$$0.5\frac{N}{s^2} = 50m\,'g'$$

h. 1 point for effort, 1 point for equation, 1 point for answer

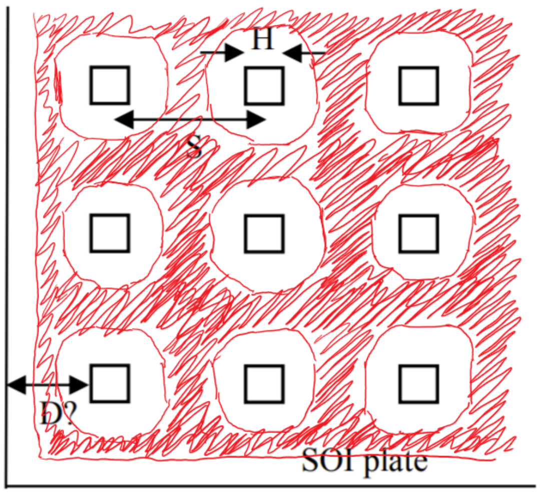
g here is the thickness of the SiO2

C_2-sub=C_plate+C_fingers=$\frac{\varepsilon_{SiO2}\varepsilon_0}{g}(400um^2 + 2 * 100um^2) = \frac{4*8.85*10^{-12}\frac{F}{m}}{2um}(600um^2) = 10^{-14}F$

C_1-2=C_2-sub→ $\frac{\varepsilon_0 A_{fingers}}{g_{fingers}} = \frac{\varepsilon_{SiO2}\varepsilon_0 * A\_2}{g_{SiO2}} \rightarrow \frac{A_{fingers}}{g_{fingers}} = \frac{\varepsilon_{SiO2} * A\_2}{g_{SiO2}} \rightarrow g_{fingers} = \frac{A_{fingers} * g_{SiO2}}{\varepsilon_{SiO2} * A\_2} = \frac{(20um)(20um)(2um)}{4*600um^2} = 0.33um$

4. 10 points:

a. Red is remaining SiO2 1 point for effort, 1 point for curved SiO2 on corner, 1 point for straight edges



b. 1 point for effort, 1 point for answer

Shortest distance between etch holes is 0.5(S-H).

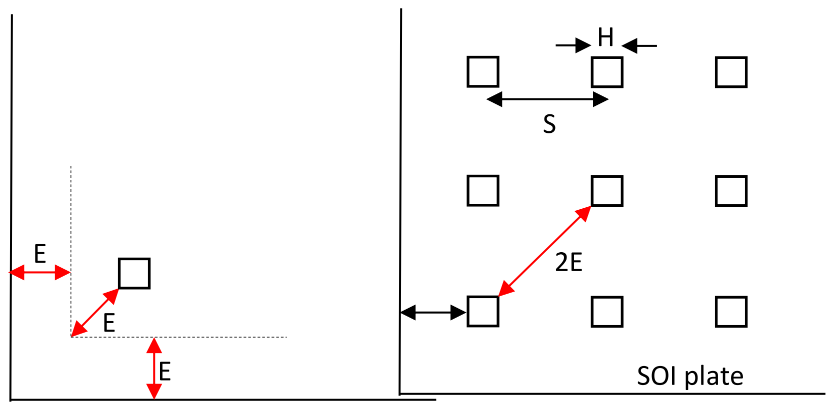
c. 1 point for effort, 1 point for $\sqrt{2}$(S-H), 1 point for answer

Distance between etch hole diagonals is $\sqrt{2}$(S-H). Since HF is isotropic, the etch distance is half of that. Isotropic etch distance E= $\frac{\sqrt{2}}{2}(S - H)$.

d. 1 point for effort, 1 point for answer

Total diagonal distance etched is E+$\sqrt{2}$E=$\sqrt{2}$D

D< $\frac{E(1+\sqrt{2})}{\sqrt{2}}$



5. 3 points: 1 point for SA scaling, 1 point for Volume scaling, 1 point for answer

At normal size, an ant's $\frac{Muscle\ Cross\ Sectional\ Area}{Weight}$ = 50. To find the atomic ant's strength:weight ratio we need to find out how much stronger the ant is, and how much more it weights.

Area scales as s^2 so the ant becomes $500^2 = 25 * 10^4$ times as strong.

However, mass scales as s^3 so the ant is now $500^3 = 125 * 10^6$ times as heavy.

It's $\frac{Muscle\ Cross\ Sectional\ Area * s^2}{Weight * s^3} = 50 * \frac{25*10^4}{125*10^6}\ or\ 50 * \frac{500^2}{500^3} = \frac{50}{500}$

See that the atomic ant can only lift $= \frac{1}{10}$ of its weight.