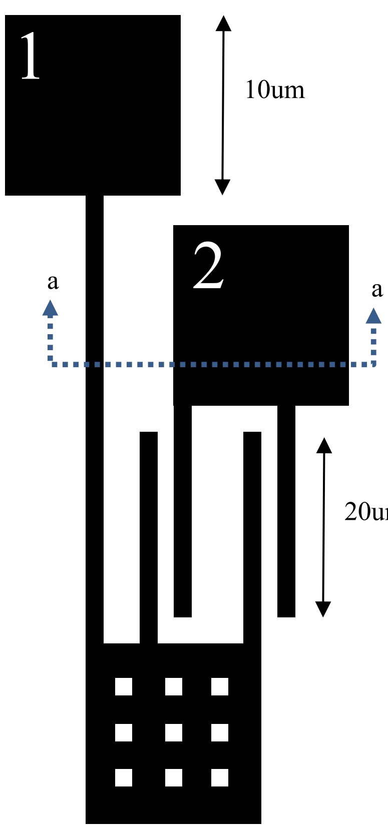
EE 147/247A
Fall 2021

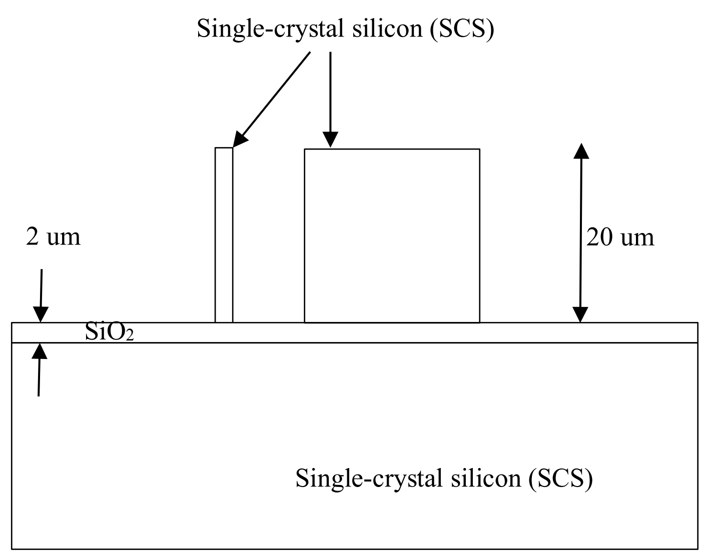
Prof. Pister

Homework Assignment #1

Due on bcourses Wednesday 9/7/2021 (late 9 AM Thursday)

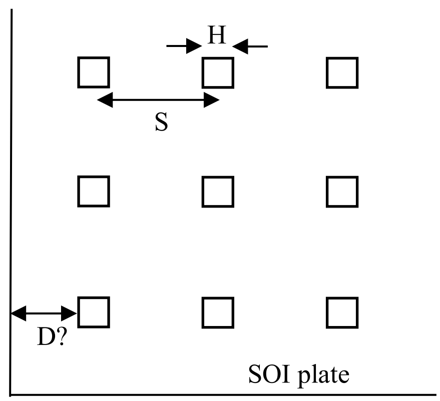
1. Search for MEMS images on the web. Find one picture of a sensor, and one picture of an actuator. Include the URL for each image, and a one sentence description of what kind of sensor/actuator (e.g. thermal, capacitive, etc.) it is, and how you think it was made (e.g. surface micromachining, bulk micromachinging, DRIE).
2. What is the cheapest MEMS accelerometer that you can find on digikey.com, and how much does it cost? What is the range of acceleration that it can sense (minimum detectable acceleration, and maximum detectable)?
3. In the figure below, the structure on the left is the pattern on a mask. The beam and fingers are 2μm wide. All plates are 20x20μm^2. The holes in the lower plate are 2μm square on 5μm centers. The gap between the fingers is 2 um.
   The mask is used for a Deep Reactive Ion Etch (DRIE) into a Silicon-on-insulator (SOI) wafer with a top-layer thickness of 20μm, and an oxide thickness of 2μm. A cross-section of the device is shown after the DRIE etch and subsequent photoresist removal. The device is then dropped into a hydrofluoric (HF) acid solution with an SiO_2 etch rate of 1um/minute, and a silicon etch rate of 0.
   a. Draw the process cross-section after 15 seconds of SiO_2 etching.
   b. Draw the cross-section after 1 minute of SiO2 etching.
   c. On a top-down view of the structures, sketch where you think there would still be oxide after a 1 minute etch, assuming that the numbers 1 and 2 really are etched into the SCS. Think carefully about the perforated plate!
   d. Estimate the minimum etch time to release the perforated plate, and the maximum etch time before the anchors are released and the whole thing floats away.
   e. Estimate the capacitance between the fingers of structure 1 and the fingers of structure 2.





Cross section a-a

f. Estimate
   i. the lateral spring constant of the spring supporting the perforated plate.
   ii. the mass of the perforated plate and fingers
   iii. the resonant frequency of the spring/mass
   iv. the lateral deflection of the mass in a 1 gravity field (e.g., on earth)
   v. the change in total capacitance (2 pairs of fingers) due to a 1 gravity field
g. If you have a circuit that can detect capacitance changes of 1 zeptofarad (10^{-21} F), what is the minimum detectable acceleration?
h. [ee247 only] Calculate the capacitance between structure 2 and the substrate. How small does the gap between the fingers need to be before the capacitance between structures 1 and 2 is larger than the capacitance of structure 2 to the substrate?



4. The corner of a large SOI plate is shown above. The plate has an array of square etch holes of size HxH, and their centers are on a square grid of separation S.
   a. Draw a top view (layout view) of where the SiO_2 will be under the plate after an isotropic etch for a distance H. You can just draw the etch front around one etch hole, and near the corner of the plate.
   b. What is the etch distance at which there is a path through the HF under the plate which connects all of the etch holes?
   c. What is the minimum isotropic etch distance E necessary to free the center of the plate (inside the etch hole array)?
   d. If the goal is to free the plate with the minimum etch time, what is the maximum distance from the edge of the plate to the edge of the etch holes? Write your answer in terms of E.
5. Ants can lift as much as 50 times their own weight. It turns out that scaling has something to do with this. To explore this, suppose some atomic tests in New Mexico caused some common ants to mutate into giant ones about the same size as humans, which for this problem we assume means 500× larger in all dimensions. If the lifting strength of the ant *goes as the cross-sectional area of its muscle*, can such a giant ant still lift something as much as 50 times its weight? If not, how much can it lift in terms of its own weight?

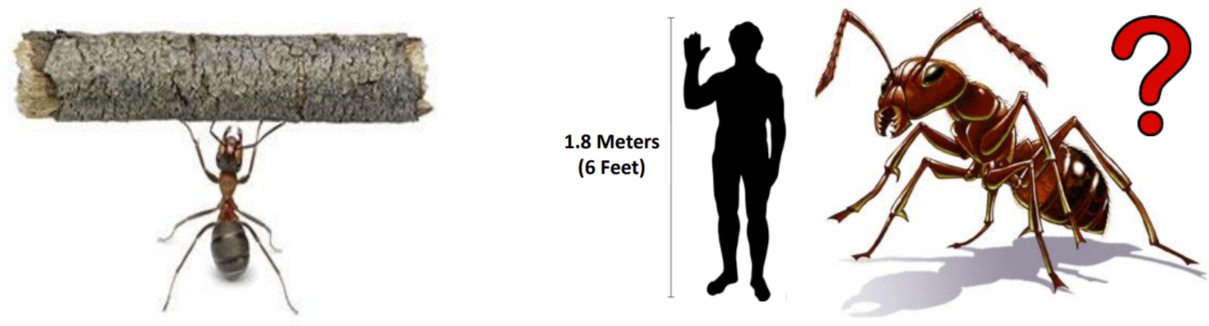


Figure PS1-1

Problem from Professor Clarke UCB

6. [ee247 only] Take a look at Liu et al. [1] and their modeling of HF etching of phosphorous-doped SiO2.
   a. Based on the data in Figure 5, what's an estimate of the undercut distance for which a constant-etch-rate model is reasonably accurate? If you assume that the etch rate of PSG in 49% HF is at least 25um/min, how far do you have to etch before you have overestimated the etch rate?
   b. The HF etch rate of thermal SiO2 is about 25 times slower. How will that affect the linear regions of these curves? Can you do the math or find a paper to support your assertion?

[1] J. Liu, Y-C Tai, J. Lee, K. Pong, Y. Zohar, C. Ho, "In situ monitoring and universal modelling of sacrificial etching using hydrofluoric acid", MEMS 1993.