EE147 / 247A Midterm Fall 2021

The exam is open book, open notes.

Name_____

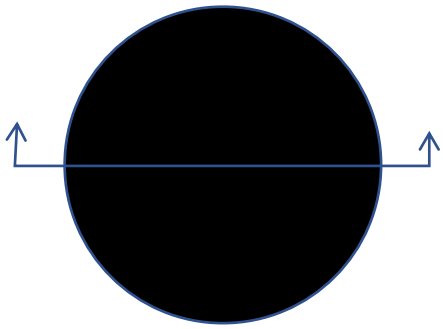
SID_____

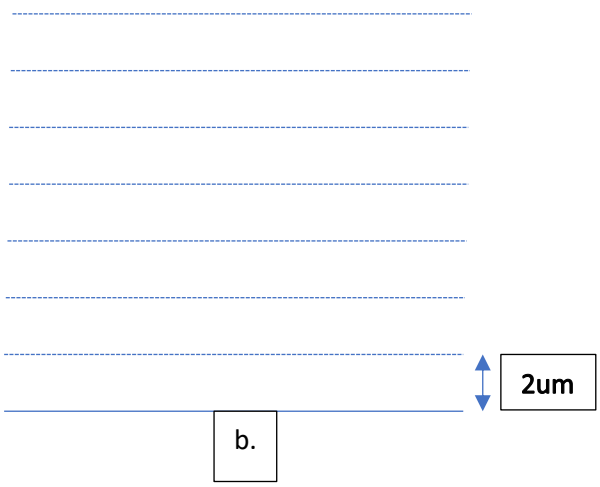
Problem	Score	Points Possible
1		10
2		10
3		8
4		8
5		10
6		6
7		10
8		8
Total		70

Show your work ***Use proper units in all answers.***

1. The figure below shows a 10um diameter circle. This mask is used to pattern a 10 um thick SOI layer on a 2 um thick silicon dioxide layer. The structure is etched using DRIE. The device is then dropped into a hydrofluoric (HF) acid solution with an SiO2 etch rate of 1um/minute, and a silicon etch rate of 0.
    a. What is the minimum etch time needed to release the structure from the substrate?

    b. Draw the process cross-section after 1 minute of SiO2 etching.
    c. Draw the cross-section after 3 minutes of SiO2 etching.





2. You have a cantilever beam of length L, thickness b, and width a. A force F is applied at the tip in the transverse ("a") direction.
    a. What is the resulting moment at the base of the beam, M(0)?

    b. What is the maximum strain in the beam, and where does it occur?

    c. What is the deflection y at the tip of the beam?

    d. Write a simple expression for the strain at the surface of the beam at x=0, in terms of L, a, b, and y (and not F)

3. The accelerometer below is etched into the same 10 um thick SOI film. There are 3 squares labeled ABC which are each 100 um on a side. Square B has a single etch hole in the center that is 20 um on a side. All of the beams and capacitor fingers are 2 um wide. The overlap of the capacitor fingers is 100 um, and the small gap between them is 1 um.
    a. Estimate the etch time required to free the moving mass.

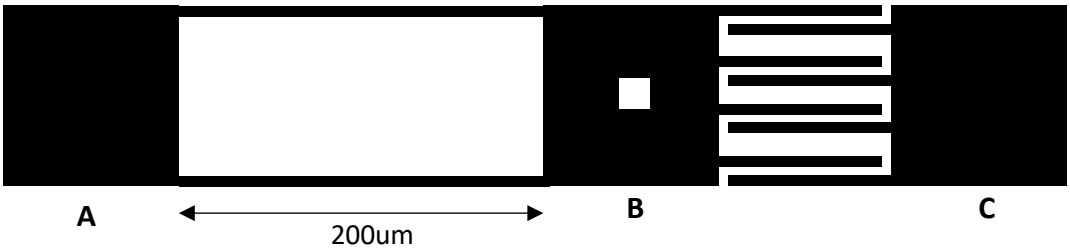
    b. Assuming that etch time, describe the shape of the oxide remaining beneath A and C? (for example, "a 10 um diameter circle")

    c. Estimate the mass in kg

    d. Calculate the spring constant of the support. Assume E=170 GPa

    e. Calculate the capacitance of the accelerometer (between electrodes A and C) at rest.

    f. To maximize the change in capacitance per change in the position, how big should the back gap be, and how many capacitor fingers should there be on each side? (The size of the squares B and C should not change.)



4. In a similar accelerometer, the mass is 10^-9 kg, and the spring constant is 0.1 N/m, and a capacitance at rest of 1 pF
    a. What is the resonant frequency (in radians/sec)?

    b. What is the deflection of the mass in a 1 gravity field?

    c. Estimate the change in capacitance in a 1 gravity field.

    d. If you have electronics which can detect a capacitance change of 0.001 pF, what is the minimum detectable acceleration?

5. For this same accelerometer, if all dimensions are scaled by a factor S, how does that affect, the mass, spring constant, resonant frequency, deflection due to 1 gravity, rest capacitance, and capacitance change due to 1 gravity

6. A piezoresistive sensor is used with a digital voltmeter with +/-10V range and 1 mV accuracy. The gauge factor is 100, and the temperature coefficient of resistance is 0.1%/K.
    a. The piezoresistor is used in a half bridge (voltage divider) with 10V excitation. What is the voltage output of the bridge as a function of strain?

    b. What is the resolvable strain?

    c. If there is 1 mV of noise on the power supply (excitation voltage), what is the noise-equivalent strain?

    The sensor is now put into a Wheatstone bridge with the same 10V excitation, and is the only active resistor. An amplifier with a gain of 100 is used between the bridge output and the voltmeter.

    d. What is the resolvable strain?

    e. If one resistor is heated slightly more than the other resistors, what is the temperature change necessary to give a 1mV change on the digital voltmeter?

7. In the PolyMUMPS process, list the thin film layers that will be present on the substrate (starting at the substrate and working up, in order) before the release etch, in regions with the following masking layers
    a. POLY0, POLY1, POLY2, METAL

    b. METAL

    c. ANCHOR1, POLY1, METAL

8. A comb-drive resonator with a spring constant of 1 N/m, a resonant frequency of 10,000 rad/s, and a quality factor of 200 is driven by a force of $f(t) = F_0 \sin(\omega t)$. What is the magnitude and phase of the displacement $x(t)=x_0 \sin(\omega t+\phi)$ at the frequencies below?

ω	x_0	ϕ
1 rad/s		
9,900 rad/s		
10,000 rad/s		
10,100 rad/s		
100,000 rad/s		

9. A comb-drive resonator in the PolyMUMPS process has 50 moving fingers on layer POLY1 with 2um gaps between moving and fixed fingers. A voltage of -150V is applied to the ground plane, and a voltage of 1.5V sin(wt) is applied to the fixed comb fingers. Find the total force on the moving structure. Give your answer in Newtons, with appropriate sines or cosines.