Name **SID**

1. (30 points) For the following questions, write a sentence or equation or two supporting your answer.

   (a) Your friend from Stanford tells you that he has made a great accelerometer. Even though the sensitivity is only 1 nanoVolt per gravity, he says that he can amplify the signal as much as he wants to measure arbitrarily small accelerations. Do you believe him?

   (b) Your friend from MIT is using the Bosch process in the STS deep reactive ion etcher to make high-aspect-ratio silicon structures. She says that the deposition step for the Teflon-like film slows down the process too much, and she plans run her next wafers without it. Do you think she will get what she wants?

   (c) Your friend from Michigan says that his gap-closing electrostatic actuators can only operate over roughly 30 percent of the gap because they snap together if he increases the voltage. He says that next run he'll make his springs 3 times stiffer and it should solve the problem. Do you agree?

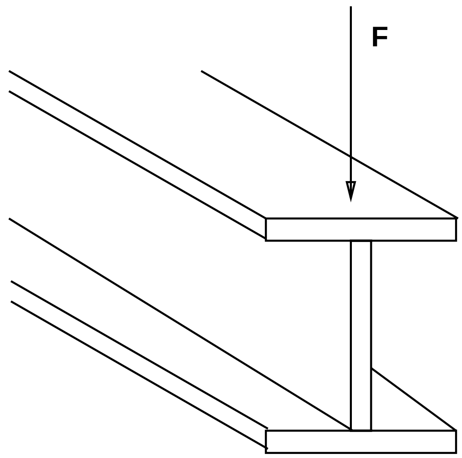
   (d) In a new double-sacrificial process, you want to etch away a layer of silicon dioxide and a layer of polysilicon. What structural materials could you use that would survive this processing?

   (e) To measure residual strain in MUMPS, you have a test array with clamped/clamped beams in poly1 with width 6 microns and length varying from 10 to 1000 microns in 2 micron increments (hey, you're thorough!). If the residual strain is 0.01 percent, which beams are buckled?

   (f) The same test array is used in a process with zero residual strain. You shove current through each of the beams and heat them uniformly to a temperature ΔT above the substrate temperature. For what values of ΔT will the longest beam buckle?

   (g) A simple spring/mass resonator has a resonant frequency of 2000 radians/second. What is the static deflection of the mass in a 1 gravity field? (I want an answer in microns!)

2. (10 points) Using a simple geometric model we showed that the reciprocal of the radius of curvature of a beam was equal to the moment over EI. For a square cross-section beam, we calculated that I was $a^3b/12$. Calculate I for an I-beam, where all three pieces of the cross-section have the same dimensions: width b, thickness a. I'm not as interested in the right answer as I am in seeing the integral that you write relating radius of curvature to moment.



3. (20 points) Given a particular design of a Tang-style resonator, we want to scale the size of the design up or down by a factor λ. All dimensions will be scaled simultaneously by this factor. For example, if I have a rectangular beam, the length scales as λ, the surface area scales as λ^2, the volume scales as λ^3, and the ratio of length to width remains constant.

   Independently, we would like to scale the thickness, t, of a particular design, while keeping the planar dimensions constant. In this case, the beam length remains constant, the volume scales as t, and the surface area scales as a constant (the top and bottom surface area) plus something proportional to t.

   How will the following properties of a particular Tang-style resonator change? Assume that the voltage applied to the actuators is constant.

property	λ scaling	t scaling
EX:		
beam length	λ	const
beam surface area	λ^2	t + const
beam volume	λ^3	t
mass (m)		
spring constant (k)		
Couette damping (b)		
resonant frequency (ω_n)		
Quality of resonance (Q)		
electrostatic force		
electrostatic deflection		
strain due to electrostatic force		
static deflection due to gravity		
strain due to gravity		

4. (20 points) A single crystal silicon cube of dimension 0.5 mm on a side is suspended from a cantilever beam 1cm long by 50 microns wide by 10 microns thick. A resistor is diffused into the beam near the anchor. Assuming a piezoresistive gauge factor of 100, a Wheatstone bridge with a single active element, and an excitation voltage of 1V, what is the sensitivity of this device in volts per g? If a capacitive sensor is created by putting an electrode 10 microns above the surface of the 0.5mm cube, what is the sensitivity under the same excitation assumptions?

5. (20 points) You have built a piezoresistive accelerometer with a sensitivity of 10 mV/g and a 1 kΩ resistance. Recall that $kT = 4 \times 10^{-21} J$.

   (a) What is the total voltage noise in the sense resistor from DC to 10kHz?

   (b) What is the noise-equivalent acceleration in the range from DC to 10kHz?

   (c) You add a low noise amplifier to the accelerometer. The amplifier has a gain of 5, and input referred noise of $10nV/\sqrt{Hz}$. What is the total noise voltage at the sensor in the range from DC to 100 Hz?

   (d) What is the noise-equivalent acceleration in the range from DC to 100 Hz?

   (e) You discover that the amplifier has 1/f noise with a corner frequency of 1 Hz. What is the total voltage noise in the range from 10^{-5} Hz to 100 Hz?