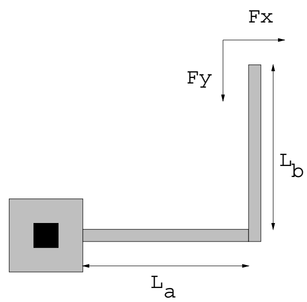
Name **SID**

1. (20 points) Using poly1 in the MCNC/MUMPS process:



$$\begin{bmatrix} \delta_x \\ \delta_y \end{bmatrix} = \begin{bmatrix} c_{xx} & c_{xy} \\ c_{yx} & c_{yy} \end{bmatrix} \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{1}$$

(a) Calculate c_{xy}, the constant relating the force in direction y, F_y, to the deflection in direction x, δ_x.

(b) Calculate c_{yx}, the constant relating the force in direction x, F_x, to the deflection in direction y, δ_y.

(c) Calculate c_{xx} and c_{yy}, the constants relating forces and deflections in the same directions.

(d) Assume that both beams are 2 μm wide and that E=100GPa. Calculate the values of L_a and L_b required to get a spring constant of 0.05N/m in both the x and y directions (i.e. $c_{xx} = c_{yy} = 0.05N/m$). Don't panic if you find that you need to solve a cubic polynomial. Assume small deflections.

2. (20 points) For the following questions, give a short answer and a quick layout sketch to justify your answer.

   (a) You need to design a very cheap impact sensor (accelerometer) in a standard process. Which do you choose: LIGA, CMOS, MUMPS?

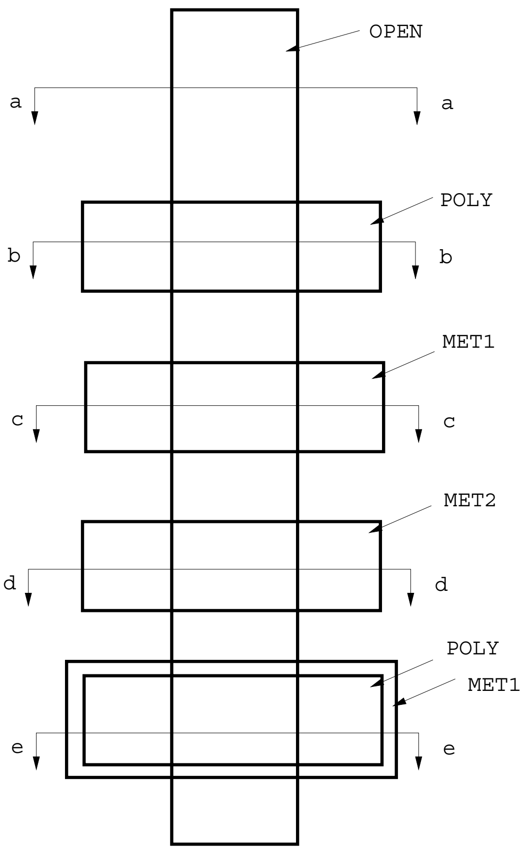
   (b) You need to design a motorized rotating disk in a standard process. Which do you choose: LIGA, CMOS, MUMPS?

   (c) You need to design a strong gear train in a standard process. Which do you choose: LIGA, CMOS, MUMPS?

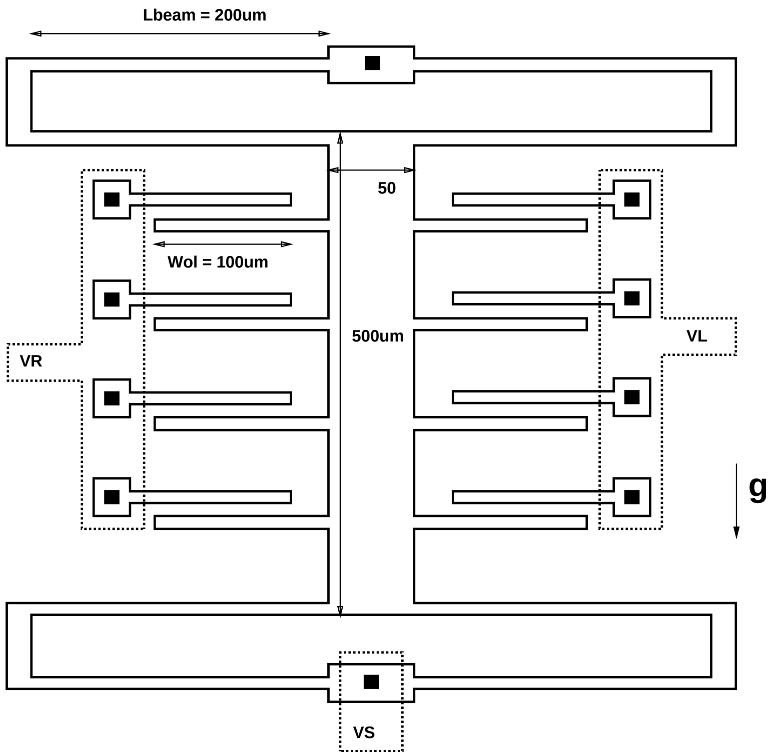
   (d) You need to design an array of structures with different resonant frequencies to test new theories on viscous damping. Which standard process do you choose: LIGA, CMOS, MUMPS?

3. (25 points) In the Orbit 2 micron CMOS process, assume that all etch steps have perfect selectivity (no etching) to the material that they are intended to stop on, and that they etch all other materials at the same rate. Assume that all etch steps use a 100% overetch.

Using these assumptions draw the five cross sections (aa through ee) shown below. Use the grid on the following page. **Label your cross sections with layer names and vertical dimensions.** You may assume that all of the layout geometry has dimensions much larger than the film thicknesses, so that you can ignore edge effects and lithography problems.



4. (30 points) You have designed an accelerometer in the MCNC/MUMPS process using layer ply1 ($2\mu m$ thick). The proof mass is 50x500 microns, the support springs are 200 microns long and 2 microns wide, and you have variable capacitor fingers with an overlap of 100 microns and a nominal gap of 2 microns. (I drew 8 fingers - you can use 10 if it makes your calculations nicer.)



(a) Calculate the total spring constant of the support spring system.

(b) Calculate the resonant frequency of the device. Neglect the mass of the springs and comb fingers if you want to.

(c) Calculate the deflection of the device under its own weight (a 1 g acceleration).

(d) Assuming that I connect VR and VL together and apply a voltage between them and VS, what voltage will I need to apply to bring the proof mass back to its rest (0 g) position while it is in a 1 g field?

(e) Calculate $C_{sense}(z)$, the capacitance of the comb fingers as a function of position of the proof mass (in the direction of g in the figure).

(f) Assume that you have a circuit which gives you a voltage from your capacitance change, and that the voltage is given by:

$$V_{out} = \frac{\Delta C}{C_{amp} + C_{sense}(2\mu m)} V_x \tag{2}$$

Where V_x is the sensor excitation voltage, and $\Delta C = C_{sense}(z) - C_{sense}(2\mu m)$. If C_{amp} is 1 pF and V_x is 1 Volt, what is the sensitivity of the sensor in volts per g?

(g) If your sensor/amplifier system has a total of 1 μV of noise in the frequency band of interest, what is the resolution or noise equivalent acceleration of the system?

(10 points)

5. The resistance of a polysilicon resistor is influenced by both temperature and strain.

   (a) Write a simple equation for the resistance as a function of strain and temperature.

   (b) Imagine an N-type polysilicon resistor fixed firmly in a material with zero coefficient of thermal expansion (this is a fairly good model of an unreleased resistor in CMOS). Write a simple equation for the strain as a function of temperature.

   (c) Combine the two equations above to get a formula for resistance as a function of temperature alone.

   (d) Give reasonable estimates for the physical constants involved, and calculate the *net* temperature coefficient of resistance for the resistor.