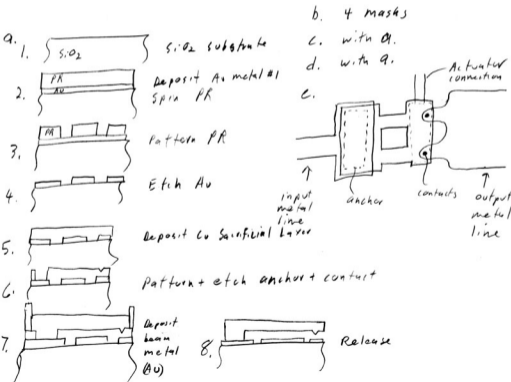


10' Problem 1: (25)

- 9 a. Sketch a process flow to fabricate a cantilever-based microswitch using cross-sections from the side of the cantilever beam. Show the use of photoresist in patterning layers at least once in your sequence of cross-sectional views. The finished device should have 3 or 4 terminals; one or two actuator terminals and the two terminals for the switched signal (one of the actuator terminals may be common with one of the signal terminals).
- 2 b. How many masks are required by your process?
- 7 c. Describe each process step.
- 3 d. Identify all materials used.
- 4 e. Sketch a top view of the finished switch, showing the connections for the actuator and signals.



Problem 2. Using the Deal-Grove model for silicon oxidation, determine the time required to grow a 1 micron oxide using wet oxidation on a wafer that already is covered with a 0.5 micron oxide at 920 and 1100 °C. (You want to end up with a total thickness of 1 μm .)

Temperature	A (μm)	B ($\mu\text{m}^2/\text{hr}$)	B/A ($\mu\text{m}/\text{hr}$)	T _{DG} (hr)
920	0.05	0.203	0.406	0
1100	0.11	0.510	4.64	0

$$\text{First find } \tau_{DG} = \frac{x_i^2}{B_{OC}} + \frac{x_i}{(B_{OC}/A_{OC})}$$

$$\text{at } 920, \tau_{DG} = \frac{(0.5)^2}{0.203} + \frac{0.5}{0.406} = 2.46$$

$$\text{at } 1100, \tau_{DG} = \frac{(0.5)^2}{0.510} + \frac{0.5}{4.64} = 0.60$$

τ_{DG} (or t) for 1 μm

$$920: \tau_{DG} = \frac{1}{0.203} + \frac{1}{0.406} = 7.39$$

$$1100: \tau_{DG} = \frac{1}{0.510} + \frac{1}{4.64} = 2.18$$

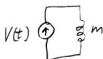
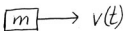
Process time is the time to grow 1 μm - time to grow 0.5 μm :

$$920: t = 7.39 - 2.46 = 4.93 \text{ hr}$$

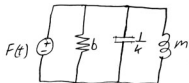
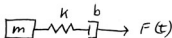
$$1100: t = 2.18 - 0.60 = 1.58 \text{ hr}$$

Problem 3. Find electrical equivalent circuits for the following systems:

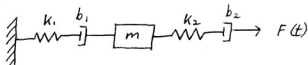
a.



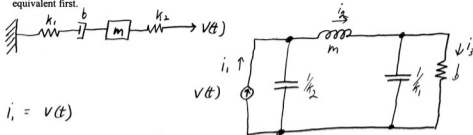
b.



c.



Problem 4. Find a set of state equations (first-order differential equations in the state variables) for the following system. You can work directly with the system or transform it to an electrical equivalent first.



$$i_1 = v(t)$$

$$\textcircled{1} \quad k_2 \int (i_2 - i_1) dt + m \frac{di_2}{dt} + k_1 \int (i_2 - i_3) dt = 0$$

$$\textcircled{2} \quad k_1 \int (i_3 - i_2) dt + b i_3 = 0$$

$$\text{from } \textcircled{1} \quad k_2 i_2 - k_2 i_1 + m \frac{d^2 i_2}{dt^2} + k_1 i_2 - k_1 i_3 = 0$$

$$\text{from } \textcircled{2} \quad k_1 i_3 - k_1 i_2 + b \frac{di_3}{dt} = 0$$

$$\left. \begin{aligned} x_2 &= i_2 \\ x_3 &= i_3 \\ x_1 &= \dot{x}_2 \end{aligned} \right\} \text{substitute}$$

$$k_2 x_2 - k_2 v(t) + m \dot{x}_1 + k_1 x_2 - k_1 x_3 = 0$$

$$k_1 x_3 - k_1 x_2 + b \dot{x}_3 = 0$$

state equations:

$$\dot{x}_2 = x_1$$

$$\dot{x}_1 = \frac{k_1}{m} x_3 + \frac{k_2}{m} v(t) - \frac{k_2}{m} x_2 - \frac{k_1}{m} x_2$$

$$\dot{x}_3 = \frac{k_1}{b} x_2 - \frac{k_1}{b} x_3$$

Problem 5. Give answers to the following questions:

- a. Give an example of a successful microfluidic MEMS product.

Ink jet print head.

- b. Give examples of two successful MEMS products that use the electrical and mechanical domains.

Accelerometer

Gyroscope

pressure sensor

- c. Give an example of a MEMS product that uses (at least) the electrical and thermal domains.

Ink jet print head

IR imager

- d. Explain why the electrostatic actuator has a snap down instability in the voltage controlled mode but not in the charge controlled mode.

The force can be shown to be a function of charge, independent of gap. Charge - control, force is a constant - no instability because the spring force increases. In the voltage control mode, the force increases with decreasing gap, without bound, so that as the gap becomes smaller, the electrostatic force eventually increases faster than the spring force and the actuator snaps down.

- e. Considering the electromechanical electrostatic actuator, why is it difficult to drive the actuator in the charge controlled mode?

1. The capacitance of the actuator is small - difficult circuit.
2. The capacitance of the circuit, wires, leads, is relatively large and charge can be transferred from these capacitances to the actuator.

- f. Considering an electrostatic actuator, describe electrical and mechanical methods to increase the damping of the motion.

Mechanical - Small gap, high pressure - air damping

Electrical - The damping is in the resistance - a large source resistance.