1) Bulk micromachining

- Describe how you proceed in order to wet-etch a 25 μm thick silicon diaphragm in a single crystal silicon wafer of thickness 400 μm. Surface is the 100 plane, primary flat is in <110> direction).
- Show how you calculate the dimensions of the mask opening resulting in a square diaphragm with side lengths 500 μm. For etching you use etchants TMAH or KOH.
- For the etch process, which material would you choose to protect the silicon from etching, outside the mask opening?
- Draw a sketch of the cross-section of the diaphragm in the wafer. Define the crystal planes in the drawing.
- Describe the RIE (reactive ion etching) dry etch process. Describe the wall angle of a typical RIE-etched channel.
- Draw a typical cross-section of an etched glass-cavity. Draw the protecting mask (gold mask) and the width and depth of the etched cavity for isotropic glass etch.

2) Micromachining

- Describe the main characteristics of surface micromachining and bulk micromachining. Give micro-element sensor or actuator examples for both technologies.
- Suggest a manufacturing process (layers, masks) for the aluminum beam of CoventorWare tutorial one.

3) Elasticity and beams

- Describe the meaning of Young's modulus and the Poisson ratio in Hooke's law. Draw the stress-strain curve for silicon. What are the mechanical / elastic advantages using silicon compared to e.g. a metal?
- The linear beam equation describes the bending and stresses in a beam for small deflections (say less than 10% of it's thickness).
- Define the constants / variables of the equation to the right. How do you proceed (boundary conditions etc.) to obtain the deflection function for a beam that is clamped in one end, and has a uniform force (e.g. from acceleration) over the beam?

$$\frac{d^4 w}{dx^4} = q / EI$$

4) Microfluidics

- Describe the capillary rise of a wetting liquid in a vertical capillary tube. Define the wetting angle. Which forces act on the water column?
- Describe the flow profile of a liquid flowing between two parallel plates or through a narrow pipe, pressure driven flow. The flow is stationary.

5) Stress and piezo-resistors

- Draw a beam that is fixed at one end, the beam is etched in n-type single crystalline silicon. The surface of the silicon wafer is (100). The crystal direction along the x beam axis is <110>.

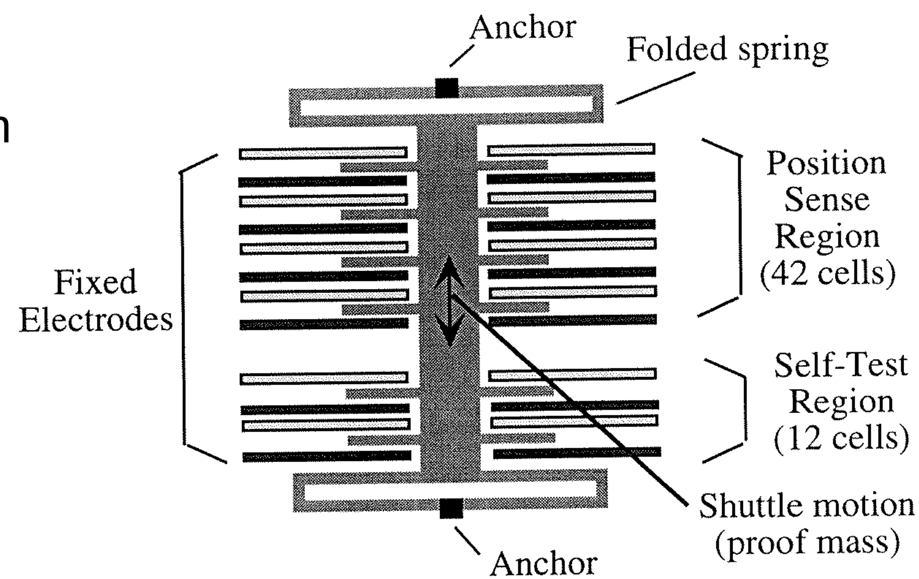
- Describe the stresses on a surface x=constant (i.e. stresses in a cross-section) of a beam bending due to e.g. a point force at the end of the beam.
- Where do you find the maximum stress?
- Where do you find the minimum stress?

- If you were to place one piezoresistor on this beam, where would you place it for maximum sensitivity (consider pros and cons)
- Describe how the piezoresistor is a resistor in an electrical circuit, doped in the silicon.
- What would be the change in resistance with stress for this piezoresistor, the gauge factor ($\Delta R/R$)?

6) Capacitive accelerometer

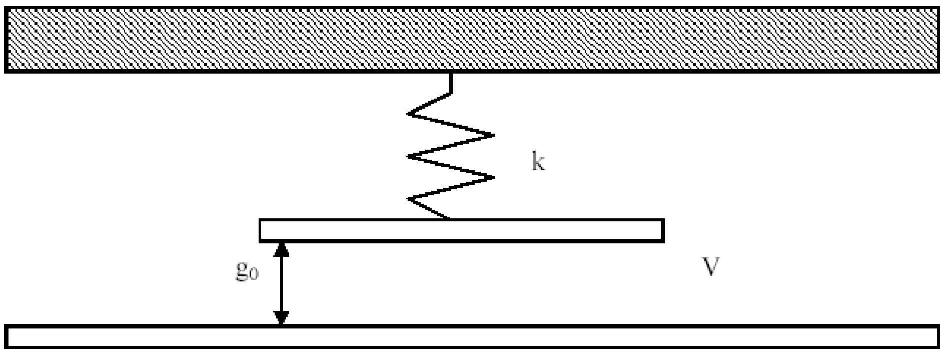
- The capacitance of a conducting beam (e.g. length 80 μm, width 10 μm, thickness 0.5 μm), placed 2 μm above an infinite electrode, in vacuum, can be found approximately using the parallel plate definition. Why is this capacitance different (larger or smaller?) from that found by the Coventor program?

- Describe the functioning of a capacitive surface-machine comb-accelerometer
- Which parts constitute the three electrodes of the differential capacitor?
- Which inertial / elastic / electrostatic forces act on the proof mass?
- What is self-test?



7) Forces and pull-in

- Consider a conducting plate that is suspended by a linear elastic spring. A small voltage (below pull-in voltage) is applied between the plate and an infinite electrode.
- Describe the forces that act on the plate and the position of the plate when the electric field is applied (use the parallel plate approximation and disregard the fringing electrostatic field).
- Explain the pull-in effect for the plate, spring, electrode system in the figure.
- In terms of the mechanical and electrostatic forces acting on the plate, what is the pull-in voltage / displacement of the plate? Show equations.
- Describe hysteresis when the voltage between the plate and the electrode is increased above the pull-in voltage and then decreased. You may add a thin dielectric layer in the figure.



8) Mirror

- Describe the functioning of the DLP pixel sketched
- Consider pure torsion, and a linear angular displacement with torsional force, explain roughly how the electrostatic forces change with the tilt angle
- Will there be a pull-in? Why?