Test MEMSDesign
(191211300)

Module/course code: 191211300
Date: April 15th 2016
Time: 13:45 – 16:15 *(+25% for students who may use extra time)*
Coördinator: Dr. ir. Niels Tas
Instructors: Dr. ir. Remco Wiegerink, Dr. ir. Niels Tas

Type of test:
- Closed book

Allowed aids during the test:
- (Scientific) calculator

Additional remarks:
- 5 Questions
- Determines for 1/3 the final grade of the course

Name:________________________

St. nr:________________________

Question 1: Sensors (25 points)

a). What does it mean that silicon is a "brittle" material? Is this an advantage or disadvantage?

b). Silicon force sensors are usually meant for relatively small loads due to the limited thickness of a silicon wafer. Sketch how it is possible to realize a sensor for large loads, i.e. in the order of 100N or larger.

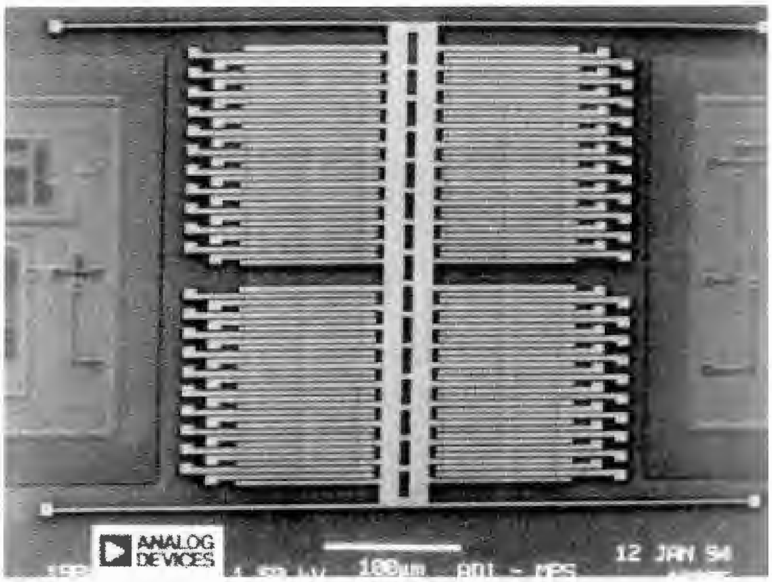
c). Mention 3 readout principles that are commonly used in silicon microsensors to detect a mechanical deformation. Explain in a few sentences how these readout principles operate.

d). In an acceleration sensor we have basically 3 parameters to play with: the size of the proof mass M, the spring constant K, and the damping D.

What should we do to obtain a large bandwidth?

What should we do to minimize thermal noise?

The photograph shows an Analog Devices sensor with so-called transverse comb structures. How can these structures be used for 1) readout of the proof mass position, 2) tuning of the spring constant, and 3) electrical force feedback?



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e). Most angular rate sensors are based on the structure of a tuning fork. Make a simple drawing of a tuning fork and indicate the directions of:

- the "drive mode"
- the "sense mode"
- the rotational velocity that is measured.

Question 2: Actuators (15 points)

a.) Explain which physical effect is practically limiting in increasing the force of all types of electrostatic actuators operated in air, by increasing the drive voltage. Explain the physical background of the limiting effect.

b.) For a given maximum electric field strength in the actuator gap(s), what can you do to increase the force for a given maximum chip area?

c.) Please explain why we typically use folded flexures to construct a linear guidance for linear electrostatic actuators? Please also give a design rule (a rough indication is enough) when their use becomes really necessary.

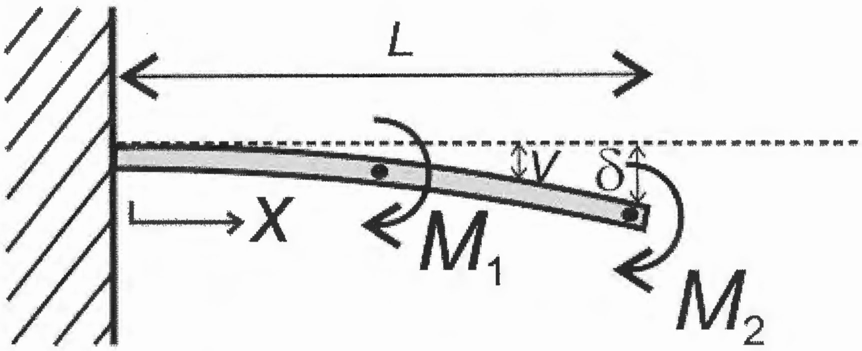
Question 3: Adhesion and Friction (15 points)

a.) For small body forces and relative large contact areas, surfaces adhesion may play an important role in friction. Please explain what role. It would be nice if you can first explain the physical background of the classical Amontons friction law and then add the effect of adhesion.

b.) What can you do to reduce adhesion in case unwanted contact may occur between micro-parts in a MEMS device (mention minimal three measures).

Question 4: Mechanics (25 points)

Consider a (prismatic) cantilever beam of length L, loaded at the tip by a torque M_2, and at $x = L/2$ by a torque M_1.



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a.) Calculate the reaction forces / moments (acting from the support on the beam)

b.) Draw the shear force and bending moment diagrams (the internal shear force and bending moment as a function of the distance x to the support) for both torques acting simultaneously.

c.) Please explain where along the beam you expect the maximum curvature (if both torques have the same sign).

d.) Please calculate the tip deflection δ as a function of M_1 and M_2 (acting simultaneously). You may assume small deflections. The flexural rigidity of the beam in the direction of the deflection is $E \cdot I$ where E is the Young's modulus and I is the moment of inertia of the cross sectional area of the beam.

Question 5: Fluidics and Surface Tension (20 points)

a.) Consider a small (< 0.1 mm) water droplet in air. Is the pressure in the droplet lower, higher or equal to the pressure of the surrounding air? Please explain.

b.) Now the same question as in a) for a small air bubble in water. Can you give the physical law needed to explain your answers?

c.) Please explain what you expect for the pressure of water just behind the convex meniscus of a partially filled hydrophobic nanochannel (the "empty" part contains air at a pressure of 1 bar). Can you give an order of magnitude estimation of the pressure that you expect?

d.) Does it take more, or less time to fill a micro/nanochannel by capillary action when it becomes smaller in the cross section (same length). Please explain.