# Microsystems technology S-129.3210 (5 ECTS)

Exam January 8th , 2006, Hall S5, 9-12 hoursIlkka Tittonen & Sami Franssila

***Answer 4 out 6 questions.***

**1.** Explain step-by-step the fabrication process of the microvalve shown below. Estimate dimensions, identify materials and describe processes used. Remember to keep track what is taking place on wafer backside when top side is being processed and vice versa

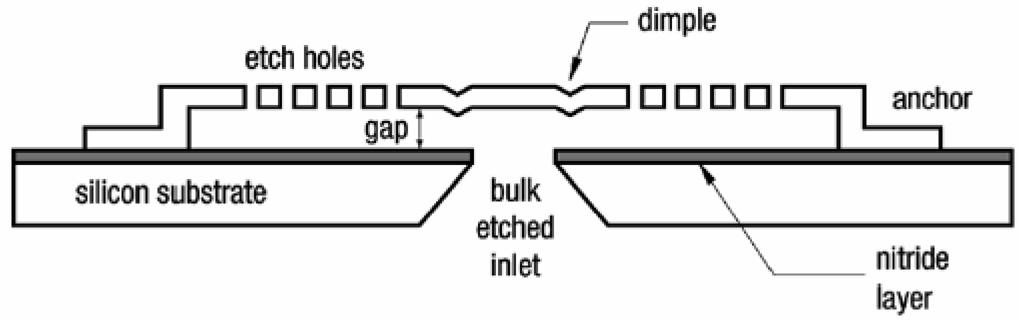
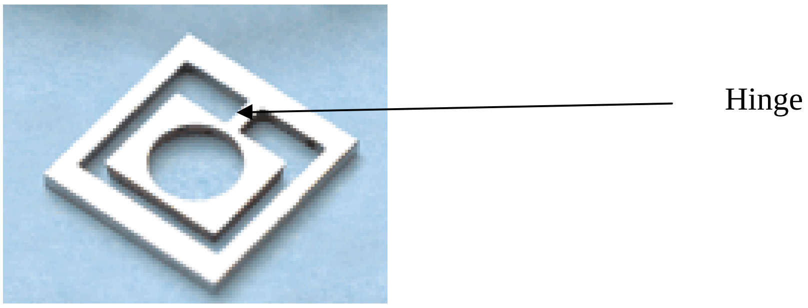


Fig. 1. Microvalve cross section. Note that the gap height dimension is exaggerated for clarity.

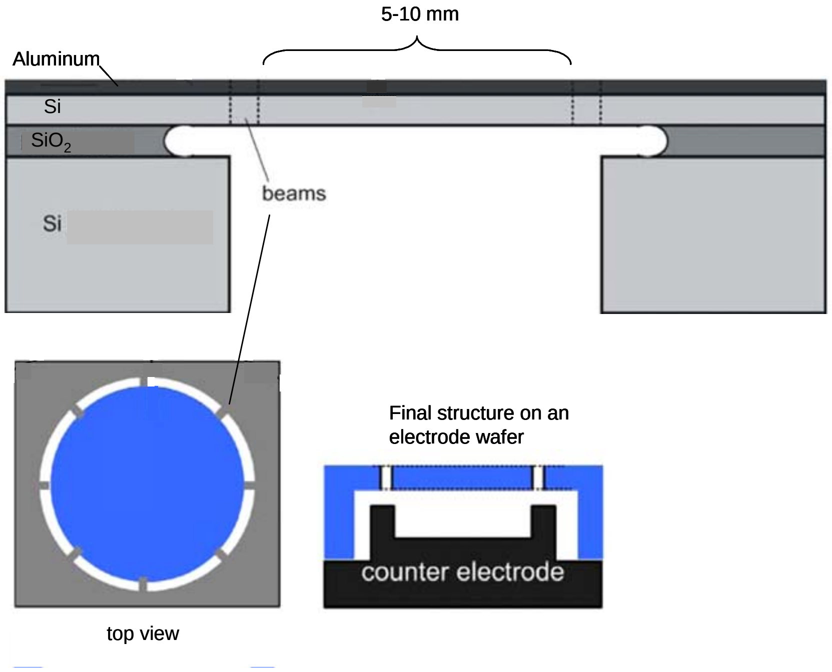
From: J. Collier et al, J.MEMS 13 (2004), 912

**2.** a) Assuming that the microgenerator shown below is made by wet etching of bulk silicon, explain the crystal planes relevant to etching. Also draw a top view picture of the mask that was used in etching, and indicate important xy-plane dimensions assuming 380 µm wafer thickness (3 p)
b) Assuming that all silicon processing techniques are available and the hinge is 10 µm thick while all other parts are 380 µm thick, explain step-by-step the fabrication of the device (which lithography steps, which etching steps, draw mask figures, .... (3 p)



Innos/Perpetum

**3.** a)



Design a process that could be used to fabricate the mirror shown in the figure (you can ignore the fabrication of the electrode wafer). Draw some cross section figures of intermediate process steps. How and why are the different steps performed? In what kinds of applications this mirror could be useful?

b) What are photonic crystals and for what can they be used? Explain and draw examples of 1D, 2D and 3D photonic crystals. Describe the difficulties related to fabrication of photonic crystals.

**4.** Answer if the following statements are true (T) or false (F). (1p each)

a) Finite-element modelling is a very good method to estimate damping in micromechanical systems
b) Young's modulus is approximately 130 MPa for silicon
c) Native oxide grows on the clean silicon surface in a few hours time when exposed to air.
d) For MEMS-resonators, the electrical spring constant, $k_e$, is directly proportional to the coupling gap $d$.
e) The growth of oxide layers on the surfaces of a silicon component causes shear stresses that may bend the whole device.
f) Silicon is not piezoelectric material

**5.** a) Compare given materials generally for MEMS-applications in terms of cost and processability. Give examples of fabrication methods available to process and/or grow given materials. Also comment on factors/effects you should pay attention to when using (two or more of the mentioned) materials together in a fabrication of a single device (for example if you use Al-electrodes on silicon or use $SiO_2$ to protect silicon or so...). (4p)

b) Compare material parameters concerning the suitability (pros and cons when compared to other materials: Mechanical and electrical properties, Actuation (and possibly read-out), Fabricational aspects etc…) of the material for a device when the device to be fabricated is i) High-frequency resonator ii) (Contact-Shunt-) Switch. (2p)

The materials are:
I) Silicon (Si)
II) Quartz ($SiO_2$)
III) Diamond (Di)
IV) Aluminium (Al)

You may need the following numbers to back-up your claims.

| | |
|---|---|
| Dielectric-constant of vacuum | $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m |
| Relative dielectric-constant of silicon | $\varepsilon_{Si} = 11.9$ |
| Relative dielectric-constant of silicon-dioxide | $\varepsilon_{SiO2} = 3.9$ |
| Relative dielectric-constant of diamond | $\varepsilon_{Di} = 5.7$ |
| Young's modulus of silicon | $E_{Si(100)} = 130$ GPa |
| Young's modulus of quartz | $E_{SiO2} = 73$ GPa |
| Young's modulus of diamond | $E_{Di} = 1035$ GPa |
| Young's modulus of aluminium | $E_{Al} = 70$ GPa |
| Density of silicon | $\rho_{Si} = 2330$ kg/m$^3$ |
| Density of quartz | $\rho_{SiO2} = 2650$ kg/m$^3$ |
| Density of diamond | $\rho_{Di} = 3500$ kg/m$^3$ |
| Density of aluminium | $\rho_{Al} = 2700$ kg/m$^3$ |

**6.** Recall that the electrostatic energy is $E = {}^1\!/_2 CU^2$. One major application area of micromechanics is to create very small size capacitors. A clock signal can be obtained by locking an external signal to the mechanical resonance of the capacitor. Assume that you have a movable micromechanical bridge and a stationary electrode so that the capacitance between them is $C = \varepsilon_0 \frac{A}{d_0 - x}$, where $x$ is the displacement from the equilibrium distance $d_0$. Very often in micromechanics mechanical motion is obtained by applying a voltage over the capacitor.

a) Show/calculate how an external voltage of the type $U = U_{dc} + U_{ac} \sin \omega t$ (Voltage that contains both a static DC-component and also a dynamic ac-component) causes motion. Discuss the role of the ac- and DC-voltage amplitudes. Are they both needed? If yes then why and when? (4p)
b) What is the effect caused by the pull-in voltage? How is it related to the given applied voltage $U = U_{dc} + U_{ac} \sin \omega t$? (2p)