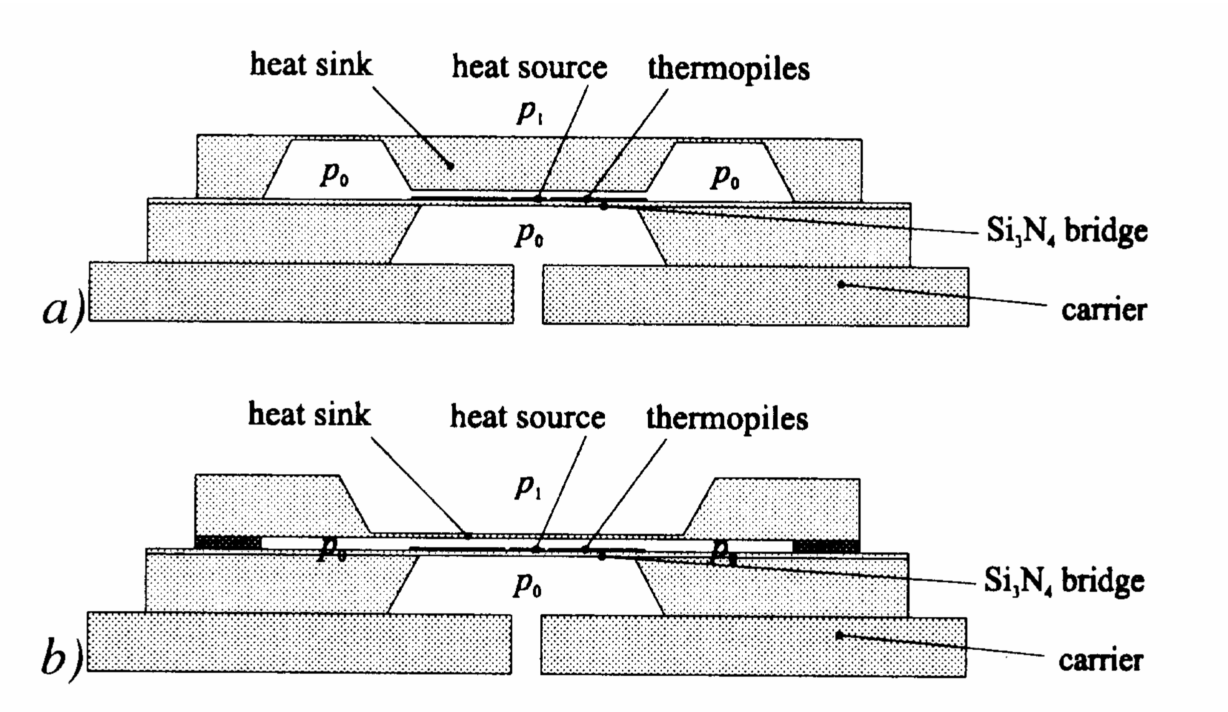
Microsystems technology S-129.3210 (5 ECTS)

Exam 11.05.2007 Ilkka Tittonen & Sami Franssila

Answer 4 out 6 questions. All questions 6 point max.

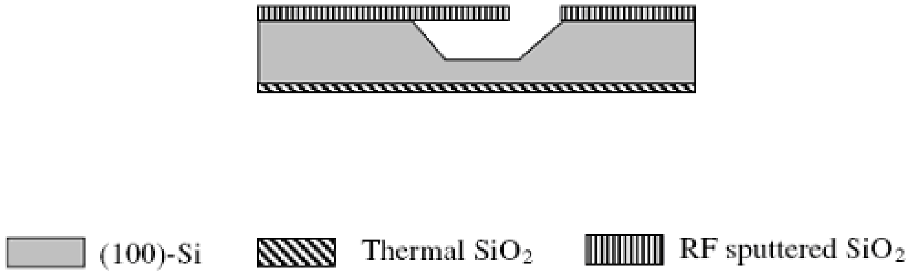
1. Explain the operating principle of a thermal pressure sensor shown below (2 p). Then choose one of the two designs a) or b), and explain its fabrication process step-by-step. Pay special attention to etching and bonding steps (4 p).



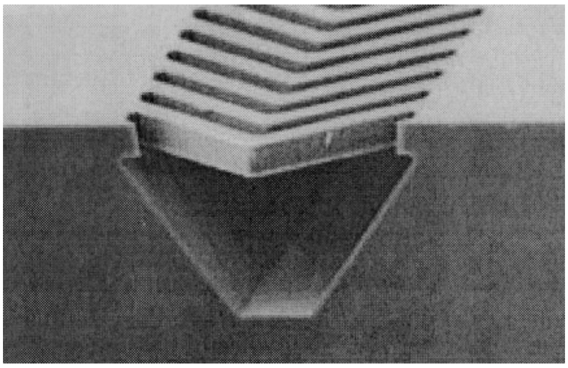
2. Explain shortly the difference between the two: (1 point each).
a) anodic bonding vs. fusion bonding
b) isotropic etching vs. anisotropic etching
c) anisotropic wet etching vs. anisotropic plasma etching
d) epitaxial wafer vs. bulk wafer
e) surface micromechanics vs. bulk micromechanics
f) photomask vs. etch mask

3. For the three devices below, list the main fabrication steps, and include a top view photomask(s), and explain how the etched shape and the photomask shape relate to each other. 2 points each

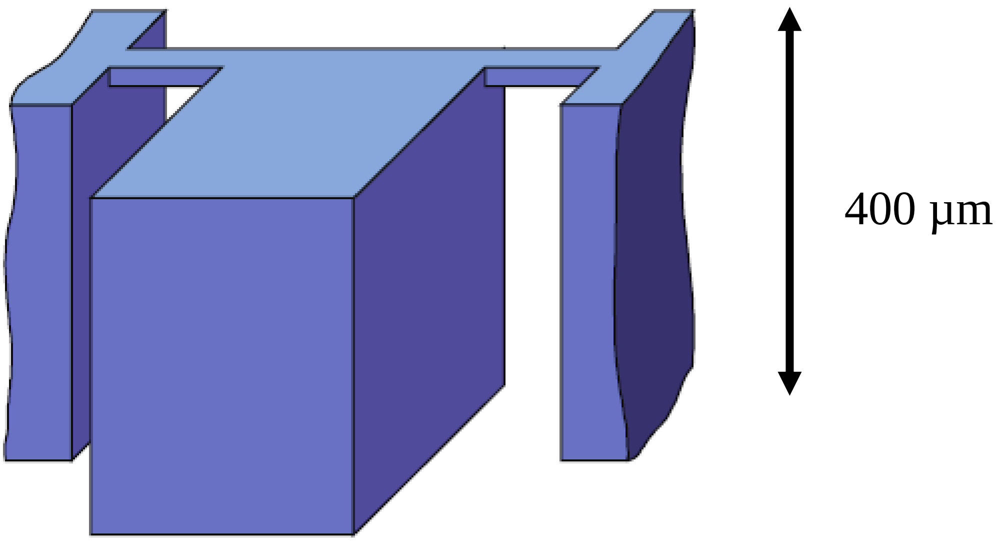
a) oxide cantilever



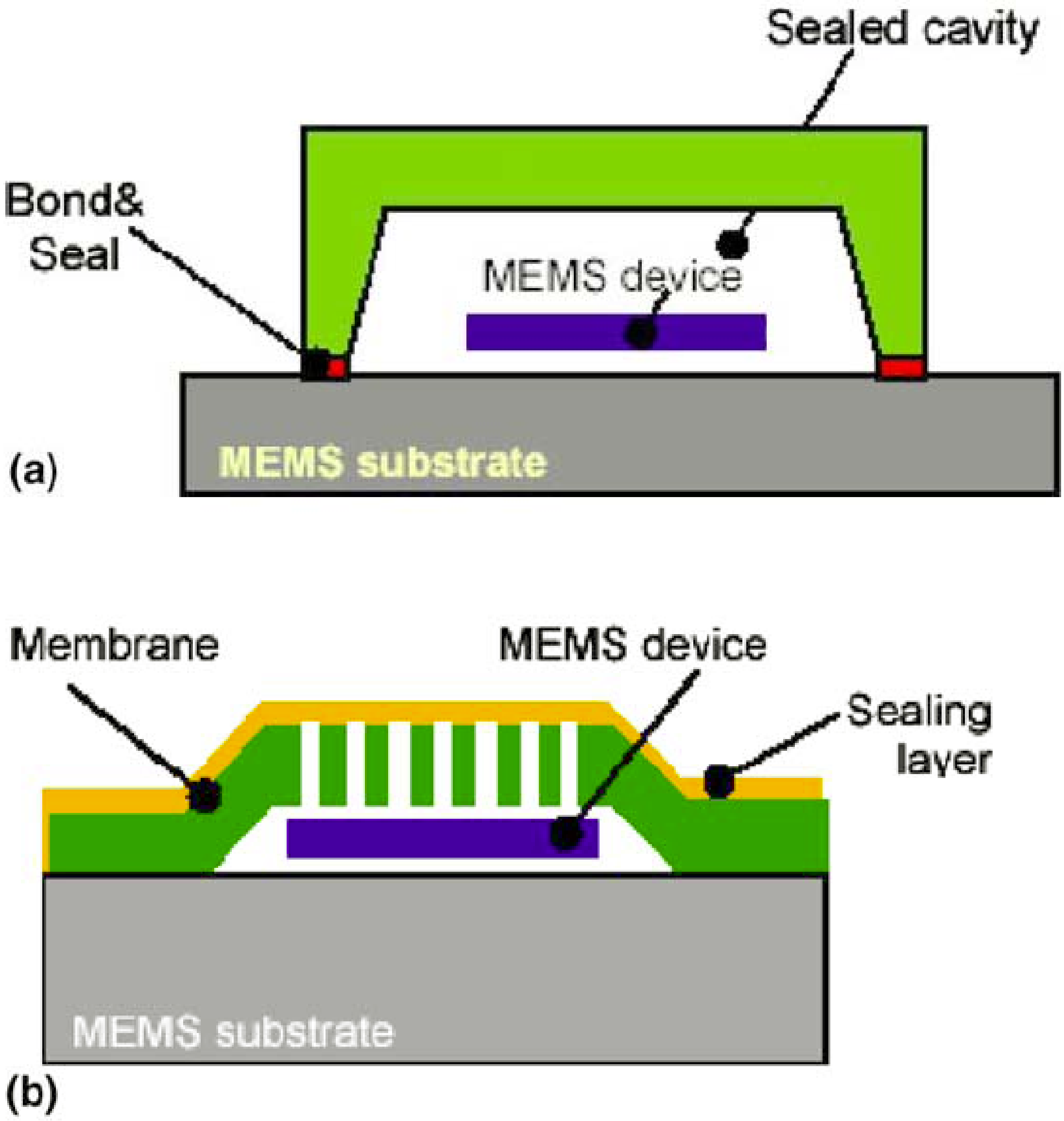
b) etched structures in silicon



c) torsion beam suspension



4. Compare the two methods shown below for packaging of MEMS devices. Discuss the fabrication, the cost, the strengths and weaknesses, possible applications etc.



A. Witvrouw et al. / Microelectronic Engineering 76 (2004) 245–257

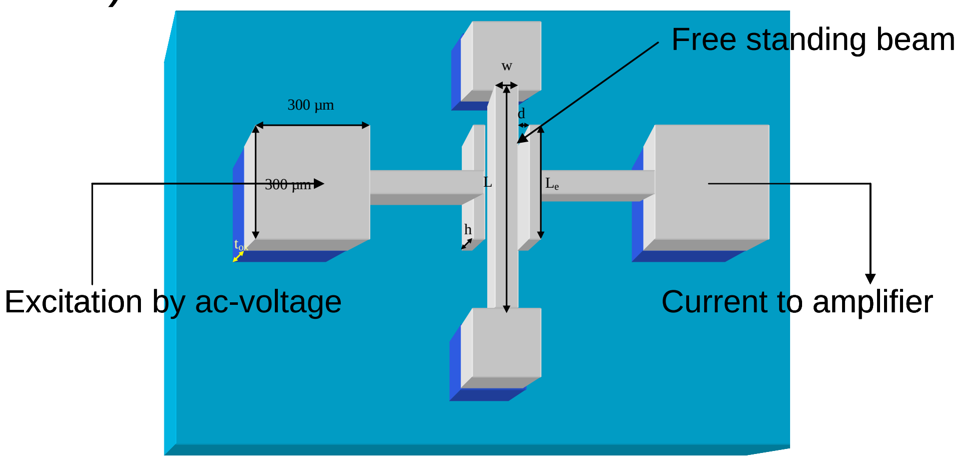
5. Answer wither true (T) or false (F) on the following statements. In addition, explain why the statement is true or false. (0.5p per correct choice of T or F, 0.5p per correct explanation)

a) For MEMS-devices, the electromechanical coupling constant gives the maximum amount of total electrical and mechanical energy of the system.
b) For MEMS-resonators, the mechanical non-linearity causes the spring softening effect that lowers the resonance frequency.
c) For MEMS-resonators, the electrical spring constant, k_e, is directly proportional to the coupling gap d.
d) When etching a <100> silicon wafer with thickness t using KOH, the minimum feature size on mask that can be etched through the wafer is $1.416 \cdot t$.
e) For photonic crystals, the only thing that determines the properties of the photonic band gap is the periodicity in the refractive index in the material.
f) Thickness variation in commercial silicon wafers is typically less than 0.1 %.

6. Capacitively coupled high-frequency micromechanical SOI resonator

a) Explain by using detailed calculations, why the DC-bias voltage is necessary for this device to work as a high-frequency resonator. (2 p.)

A)

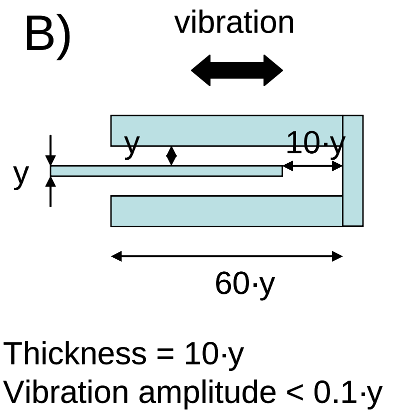


L	**100 µm**
L_e	75 µm
w	5 µm
d	1 µm
h	10 µm
t_{ox}	2 µm

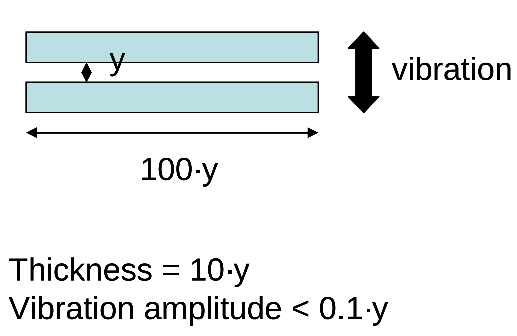
Key:	
	Device silicon
	Silicon dioxide
	Structural silicon

b) Calculate the electromechanical coupling constant for both systems in Figs. B and C when they are biased with a DC-voltage U_{DC}. Show by exact calculations that the capacitive non-linearity is smaller for comb-electrodes such as those in Fig. B compared with those in Fig. C. (2 p.)

B)



C)



c) Calculate the mechanical impedance for the system in Fig. A. Remember that you will need to use effective value for the mass (m_{eff}) instead of the value obtained by density times volume. Estimate the order for magnitude of feed-through and pad capacitances. The resonator is fabricated on an SOI-wafer. Assume that the quality factor of the resonator is Q = 2000 and that both electrodes are biased with a voltage U_{DC} = 100 V. (2 p.)

Equations and constants

Clamped-free beam (beam clamped at the one end while the other is free)

1^{st} resonance frequency: $$f_1 = 0{,}162\sqrt{\frac{E}{\rho}}\left(\frac{w}{L^2}\right)$$

spring constant: $$k = \frac{Eh}{4}\left(\frac{w}{L}\right)^3$$

Clamped-clamped beam (both ends clamped)

1^{st} resonance frequency: $$f_1 = 1{,}03\sqrt{\frac{E}{\rho}}\left(\frac{w}{L^2}\right)$$

spring constant: $$k = 16Eh\left(\frac{w}{L}\right)^3$$

Equivalent circuit values:

$$R_m = \frac{\sqrt{km_{eff}}}{Q\eta^2},$$

$$L_m = \frac{m_{eff}}{\eta^2},$$

$$C_m = \frac{\eta^2}{k}.$$

Current generated by moving beam in biased coupling gap: $$i = U\frac{\partial C}{\partial x}\dot{x}$$

Resonance frequency of a mass-spring-system: $$\omega_0 = \sqrt{\frac{k}{m}}$$

Coupling coefficient: $$\eta = U\frac{\partial C}{\partial x}.$$

Pull-in voltage: $$U_{pi} = \sqrt{\frac{8\cdot kd^2}{27\cdot C_0}}$$

Dielectric-constant of vacuum	$\varepsilon_0 = 8.85\cdot10^{-12}$ 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