PROBLEM SET #4

Issued: Thursday, Oct. 6, 2011,

Due (at 7 p.m.): Tuesday, Oct. 18, 2011, in the EE C245 HW box in 240 Cory.

1. One method to estimate the tensile strain in a thin film is to fabricate ring and beam structures of varying radii, as shown in Figure 1. In this structure, a tensile strain applied to the anchors is converted to a compressive strain on the cross-beam. Here, the radius of the smallest structure with a buckled beam gives an upper limit on the tensile strain in the film. For this problem, assume the structure has the dimensions shown in Figure 2.

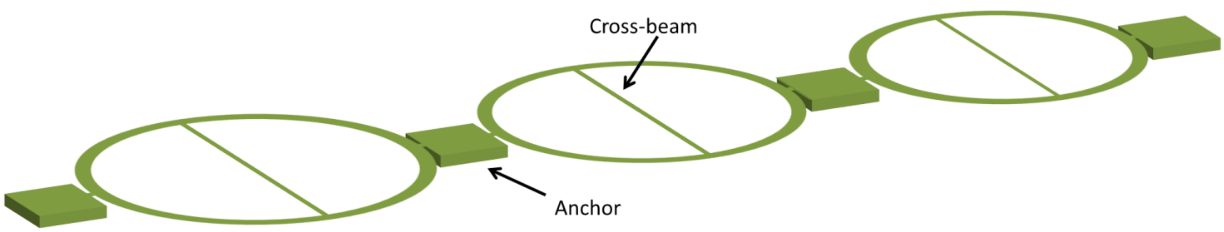


Figure 1 - Array of ring and beam structures

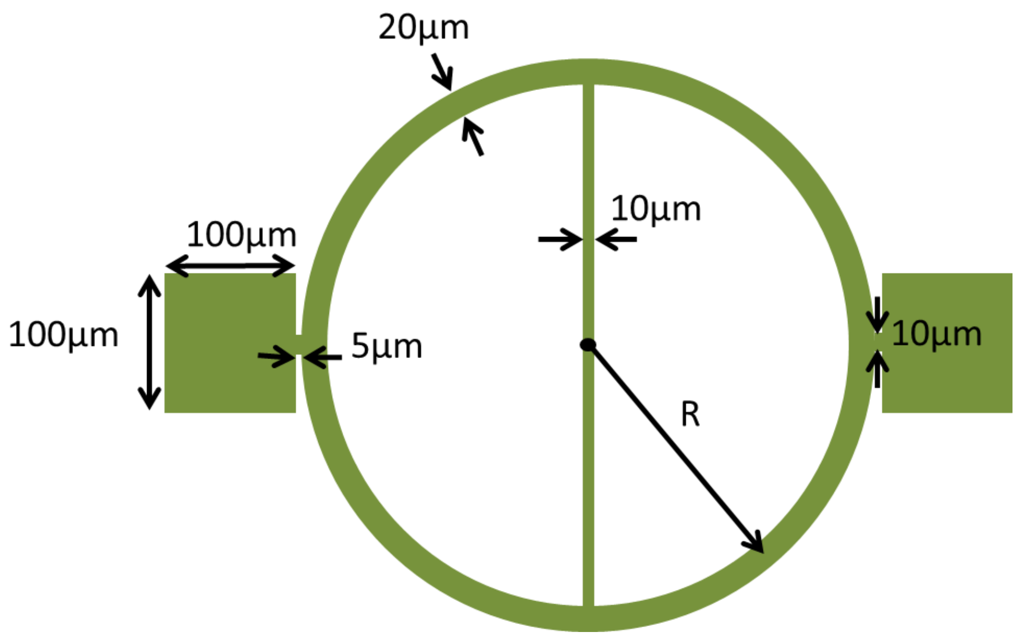


Figure 2 - Ring and beam structure dimensions

The structure illustrated in Figure 1 can be fabricated on a (100) Si wafer using the following one mask fabrication process:

i) Deposit 2.0 µm of SiO2 using LPCVD
ii) Deposit 2.0 µm of polysilicon using LPCVD
iii) Spin positive PR, expose using the pattern, then develop
iv) Etch polysilicon using reactive ion etching (anisotropic)
v) Etch SiO2 using a timed HF etch (isotropic)

(a) Assume that 49 wt. % hydrofluoric acid (which is the concentration straight out of an HF bottle) etches SiO_2 isotropically at 3.0 μm per min with infinite selectivity to polysilicon. Answer the following, rounding all answers to the nearest second.

i) Calculate the etch time needed to free the rings from SiO_2, i.e., at the instant there is a nonzero gap between the ring and the SiO_2 below. Note that there might still be oxide underneath the rings at the time in question, but the oxide will not be holding the rings in place, i.e., the rings are free to move.

ii) Calculate the etch time needed to remove all of the SiO_2 below the rings.

iii) Calculate the etch time needed to completely release the entire structure, including the anchors.

(b) In this device, tensile strain ε_0 can be determined using the following equation:

$$\varepsilon_0 = 2.575\left(\frac{h}{R_{cr}}\right)^2 \quad (1)$$

where h is the thickness of the device and R_{cr} is the critical radius of the buckled structure

i) Determine the minimum number of devices required to measure tensile strain between 0.05% and 0.5% with a maximum error of 5% due to the discrete nature of the structures. Assume radii can be fabricated to the nearest 0.5 μm.

ii) Using the results from (i), what is the radius of the largest unbuckled structure under 0.25% tensile strain?

iii) Will the beams of the buckled structures buckle laterally or out-of-plane? Explain your reasoning.

(c) Suppose the polysilicon film is under -0.25% compressive strain. Propose a structure that could be fabricated in the same process to measure this compressive strain. Draw the structure and give all necessary dimensions. (The drawing could be a layout, if you wish.)

2. You are given a polysilicon cantilever of length $L = 500$ µm, width $W = 50$ µm, and thickness $H = 2$ µm suspended 2 µm above a silicon substrate by a surface micro-machined polysilicon anchor, as shown in Figure 3. The beam is subjected to a uniform transverse load q_0. Assume material properties as given in Table 8.1 of *Microsystem Design*, reproduced in Figure 4.

(a) Provide an expression for the tip deflection under load q_0.

(b) Calculate the effective spring constant for this cantilever under load q_0. What is the resonant frequency of the cantilever under load q_0?

(c) For a load which produces a tip deflection of 1.5 um, determine the maximum stress in the beam. Where is this stress located?

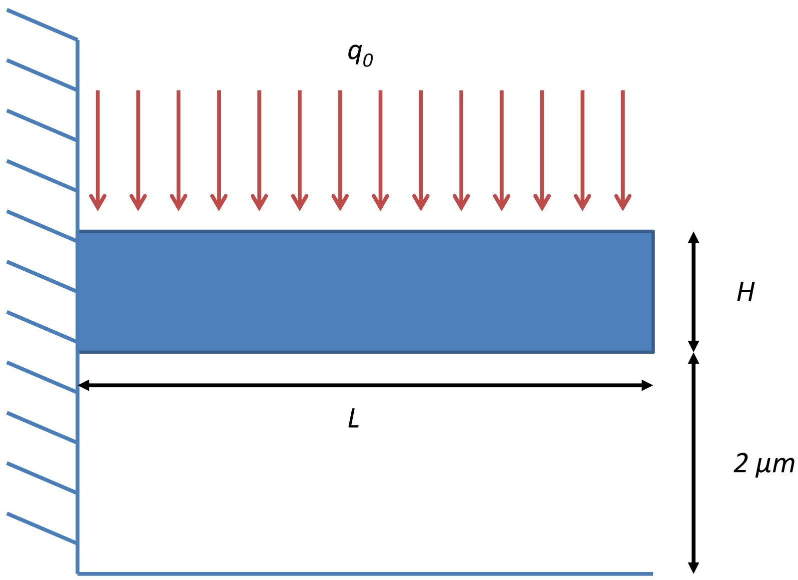


Figure 3 – Cantilever Beam for Problem 2

Table 8.1. Mechanical property data for selected microelectronic materials. (Sources: [52, 54, 55, 56])

Material	ρ_m kg/m^3	E GPa	ν	α_T µstrain/K	σ_o MPa	Comment
Silicon	2331	page 193		2.8		Cubic
α-Quartz	2648	page 573		7.4, 13.6		Hexagonal
Quartz (fused)	2196	72	.16	0.5		Amorphous
Polysilicon	2331	160	~0.2	2.8	Varies	Random grains
Silicon dioxide	2200	69	.17	0.7	-300	Thermal
Silicon nitride	3170	270	.27	2.3	+1100	Stoichiometric
	3000	270	.27	2.3	-50 – +800	Silicon rich
Aluminum	2697	70	~.3	23.1	varies	Polycrystalline

Figure 3 - Table 8.1 from *Microsystem Design*

3. Use the same cantilever as in Problem 2, except that a thin film of silicon-rich silicon nitride (i.e., low-stress silicon nitride) of thickness h = 50 nm has been deposited on the top of the beam at 900°C such that, at room temperature, there is a residual tensile stress of σ_r in the film. (Also, the load is no longer applied.) You may assume material properties as given in Table 8.1 of *Microsystem Design*, reproduced in Figure 4.

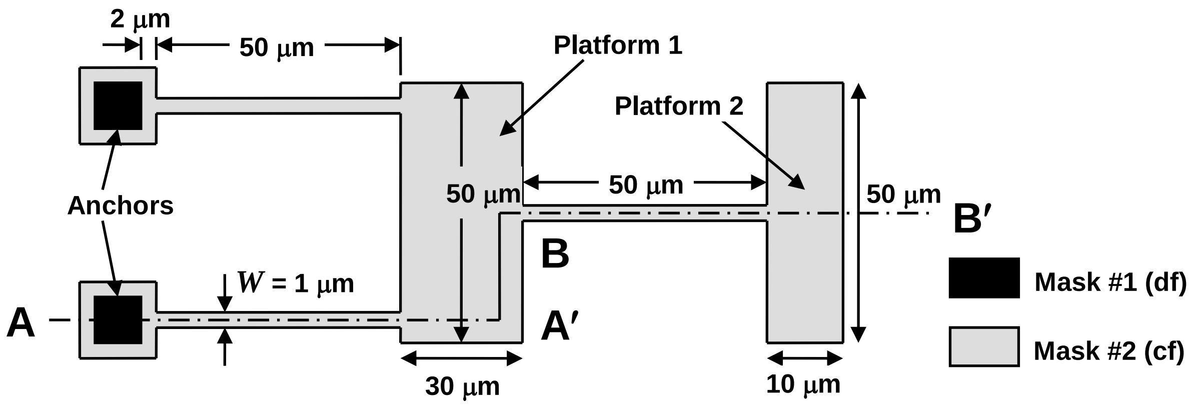
(a) Show that the axial contraction strain ε_{ax} in this case can be calculated as:

$$\varepsilon_{ax} = \frac{\sigma_r h}{\tilde{E}_0 h + \tilde{E}_1 H} \qquad (2)$$

where $\tilde{E}_0$ and $\tilde{E}_1$ are the biaxial moduli of the film and beam, respectively.

(b) Find an expression for tip deflection at the end of the cantilever. Assuming the residual tensile stress of the silicon nitride is 500 MPa, calculate the radius of curvature and the vertical deflection of the tip.

4. You are given the layout below along with the process traveler to follow. In the mask legend, cf = "clear field" and df = "dark field". In the process traveler, assume that all lithography steps use positive photoresist, and that all etch steps are 100% selective to the intended film. Also, assume that RIE etches are anisotropic, but any other type of etch has some degree of isotropy. Follow the instructions after the process traveler.



Polysilicon Structural Material Properties: Young's Modulus, E = 150 GPa; Density, ρ = 2,300 kg/m^3; Poisson ratio, ν = 0.226 Sheet Resistance = 10 Ω/□, Specific Heat, c_p = 0.77 J/(gm K), Thermal Conductivity, k = 30 W/(m K) Geometric Dimensions: provided in the figure

Process Traveler:

iv) Deposit 2 μm of LTO via LPCVD.
v) Deposit 500 nm of silicon rich nitride via LPCVD.
vi) Deposit 2 μm of LTO via LPCVD.
vii) Lithography via Mask #1.

viii) Etch oxide via RIE and stop on nitride.
ix) Remove photoresist.
x) Deposit 2 μm of *in situ*-phosphorous-doped polycrystalline silicon via LPCVD.
xi) Deposit 70 nm of dielectric X with 500 MPa of uniform axial compressive stress relative to the polysilicon layer after everything is cooled to room temperature.
xii) Deposit 2 μm of LTO via LPCVD.
xiii) Lithography via Mask #2.
xiv) Etch oxide via RIE and stop on the dielectric X film.
xv) Etch dielectric X via RIE and stop on the polysilicon.
xvi) Etch polysilicon via RIE and stop on oxide.
xvii) Remove photoresist.
xviii) Dip in HF until structures are fully released. (Note that HF does not attack dielectric X.)

Instructions:

(a) Draw the final cross-section along the A-A′ and B-B′ lines as one continuous cross-section. Label thicknesses and lengths, and justify any drawn bending of the structure with numerical proof of the amount of bending.

(b) Suppose you applied 2V between the anchors of the structure. With what time constant will platform 1 reach its final temperature? Provide an expression and a numerical value with units. Neglect the thermal conductivity and specific heat of dielectric X for this part.

(c) If the substrate is at 25°C, what is the final temperature on platform 1 with 2V applied between the anchors? Provide an expression and a numerical value in °C. Again, neglect the thermal conductivity and specific heat of dielectric X.