PROBLEM SET #4

Issued: Wednesday, March 4, 2016

Due: Monday, March 14, 2016, 8:00 a.m. in the EE C247B homework box near 125 Cory.

1. This problem considers bending of a simple cantilever and several methods to counteract the stress induced vertical deflection.

(a) Consider the unreleased cantilever beam shown in Fig. PS4.1-1 with a given vertical stress gradient. Derive an expression for the moment due to this stress gradient immediately after releasing the structure.

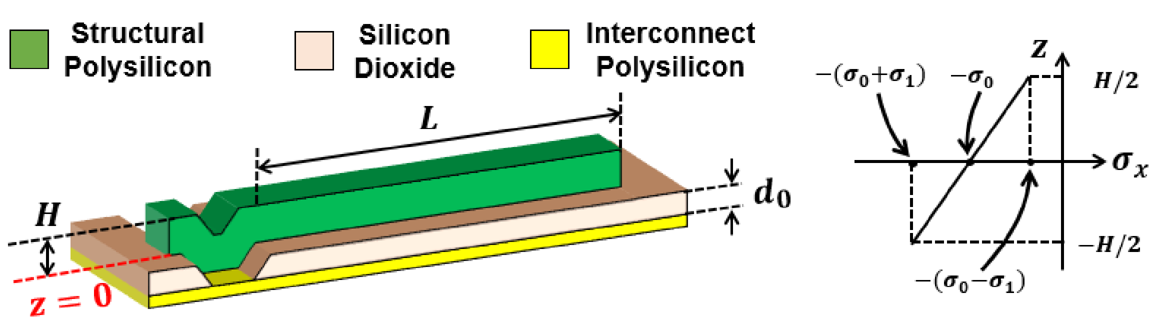

Fig. PS4.1-1

(b) Find an expression for and sketch the cantilever deflection profile (vertical displacement as a function of *x*) due to the given stress gradient. What is the tip deflection?

(c) How much force must be applied at the tip to counteract the stress so that $\theta = 0^o$? Is the cantilever perfectly flat now?

(d) Now, suppose you have decided to implant a thin layer of ions which creates a compressive stress and counteracts the bending. Given the information in Fig. PS4.1-2, what is the value of the compressive stress, σ_i required to zero out the tip deflection after releasing this structure? Is the cantilever perfectly flat now?

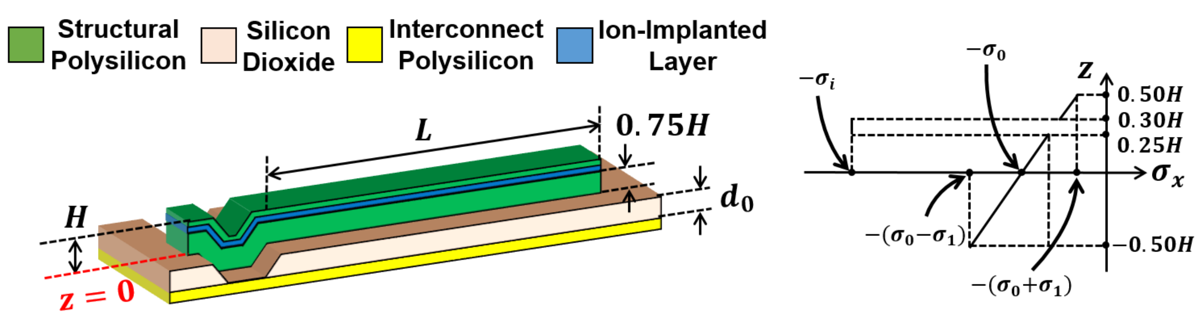

Fig. PS4.1-2

(e) Now, suppose that instead of implanting you have decided to suppress the vertical bending of the cantilever by depositing a thin film atop the structural polysilicon layer as shown in Fig. PS4.1-3. Here, the thermal expansion coefficient of the thin film α_c is larger than the thermal expansion coefficient of the structural polysilicon α_p. Assuming the film is stress-free at room temperature T_0 and the stress gradient of the structural polysilicon is as given in Fig. PS4.1-3, find the temperature T at which the cantilever beam tip deflection is zero after releasing this structure. Is the cantilever perfectly flat now?

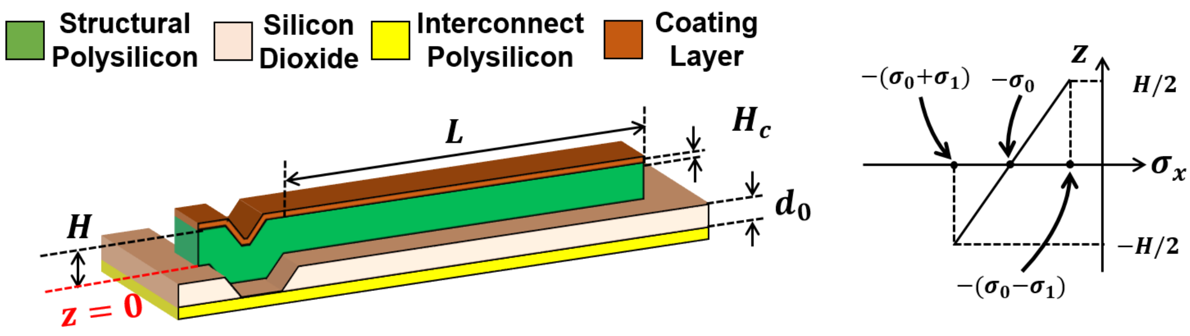

Fig. PS4.1-3

2. Throughout this problem following abbrevations are used.

NAME	ABB.	NAME	ABB.
Silicon	Si	**Hydrofluoric Acid**	HF
Silicon Dioxide	SiO_2	**Photoresist**	PR
Silicon Nitride	Si_3N_4	**Low Pres. Chem. Vapor Dep.**	LPCVD

Table PS4.2-1

One method to estimate the tensile strain in a thin film is to fabricate ring and beam structures of varying radii as shown in Fig. PS4.2-1. In this structure, a tensile strain applied to the anchors is converted to a compressive stress 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 Fig. PS4.2-1.

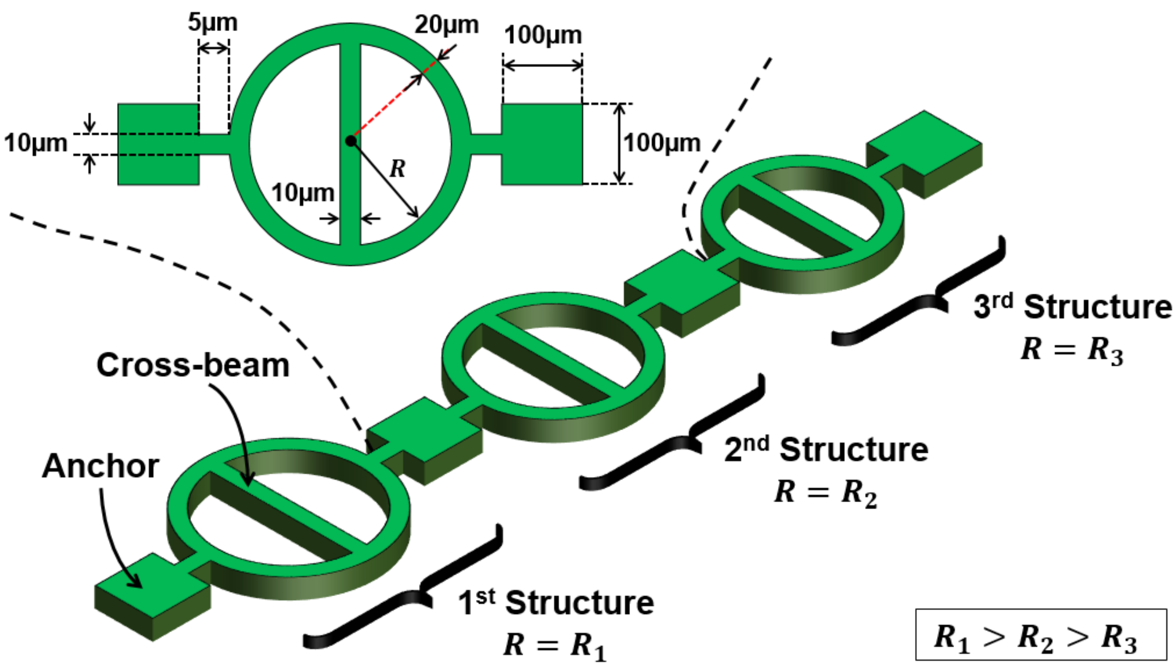

Fig. PS4.2-1

The structure illustrated in Fig. PS4.2-1 can be fabricated on a (100) silicon wafer using the following one-mask fabrication process:

i. Deposit 2.0μm of SiO_2 using LPCVD.
ii. Deposit 2.0μm of polysilicon using LPCVD.
iii. Spin positive PR, expose, develop.
iv. Etch polysilicon using anisotropic RIE.
v. Etch SiO_2 using a timed isotropic HF etch.

(a) Assume that 49% HF (which is the concentration straight out of an HF bottle) etches SiO_2 isotropically at 3.0μm/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 can be determined using the following equation:

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

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

i. What is the radius of the largest unbuckled structure under 0.25% tensile strain?

ii. 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.

3. Fig. PS4.3-1 presents the top view of a shuttle mass suspended 3μm above a substrate by a triple-folded beam suspension and achieved via a surface micromachining process with a 2μm-thick structural layer and using a 3μm-thick oxide as a sacrificial layer that etches in HF at the rate of 1μm/min. Data on the structural material used in this problem is given in Table PS4.3-1. Also, assume that all folding trusses are rigid in all directions including the vertical, i.e. *z* direction.

PARAMETER	VALUE	UNIT
Young's Modulus	150	GPa
Density	2300	kg/m^3
Poisson Ratio	0.226	-
DI Water Contact Angle for Structural and Substrate Materials	85°	-
Water-Air Interface Surface Tension	$72.75x10^{-3}$	N/m

Table. PS4.3-1

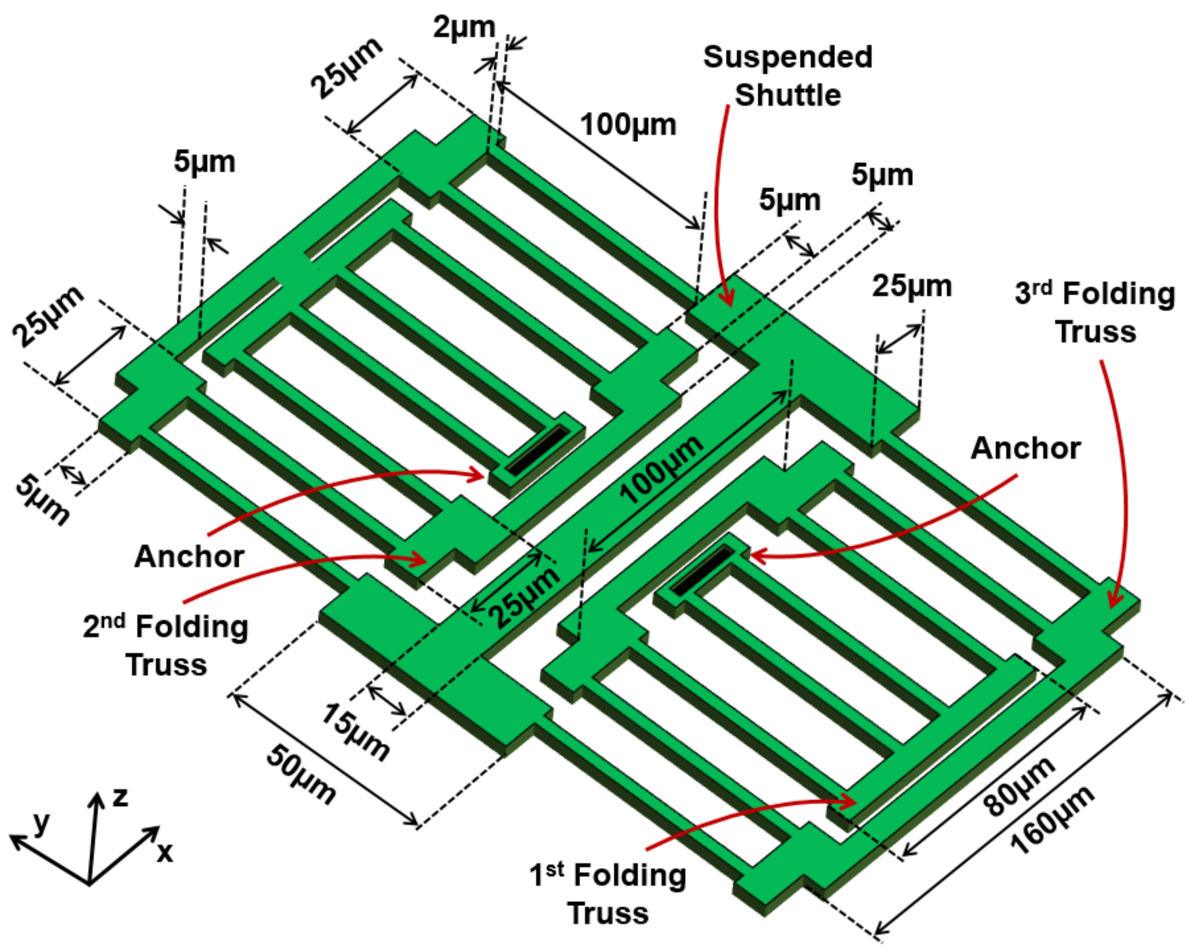

Fig. PS4.3-1

(a) Write an expression for the static spring constant in the x-direction at a location on the shuttle and calculate its numerical value with units.

(b) Write an expression for the static spring constant in the z-direction at a location on the shuttle and calculate its numerical value with units.