PROBLEM SET #4

Issued: Wednesday, March 11, 2015

Due (at 9 a.m.): Wednesday, March 18, 2015, in the EE C247B HW box near 125 Cory.

1) Suppose you fabricated the free-free beam structure below using the same masks and a similar process flow given in Problem Set #3:

- Deposit 400 nm of polysilicon using LPCVD
- Spin positive PR, expose using POLY1 mask, then develop
- Etch polysilicon using RIE (anisotropic)
- Deposit 2 μm of PSG using LPCVD
- Spin positive PR, expose using ANCHOR mask, then develop
- Etch PSG using RIE (anisotropic)
- Deposit 1.6 μm of polysilicon using LPCVD (at 650 °C)
- Spin positive PR, expose using POLY2 mask, then develop
- Etch polysilicon using RIE (anisotropic)
- Release structure using a timed HF etch (isotropic)

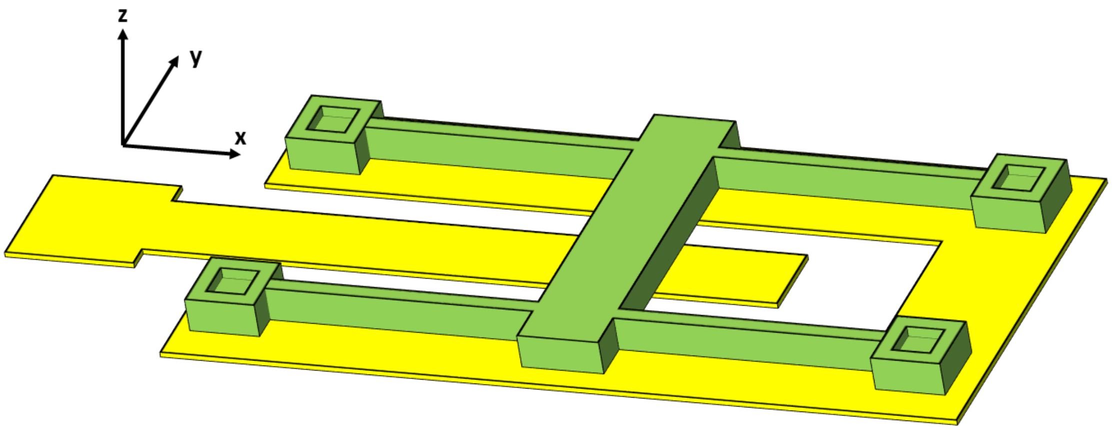

Fig. PS4.1-1 Polysilicon free-free beam structure of PS3

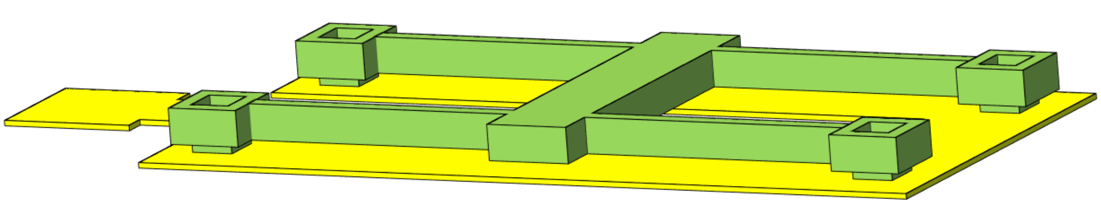

Fig. PS4.1-2 Side view showing anchor points

a) Assume the structure is dipped in %49 HF long enough to release the four support beams but not long enough to release the free-free beam (i.e. the free-free beam is still attached to the substrate with the sacrificial layer underneath). Using the material properties given in the table below, determine if the support beams will buckle after dipping in %49 HF. Show your work and clearly state the reasons behind your conclusion.

Material Properties	**Si Substrate**	**Polysilicon**
Young's Modulus [GPa]	160	150
Thermal Expansion Coeff. [10^{-6}/℃]	2.6	2.2
Poisson Ratio	0.17	0.23

b) Suppose you also fabricated a separate clamped-free beam (shown in Fig. PS4.1-3) having the same geometry as one of the support beams (i.e., L=40 µm, W= 2 µm). Assuming that the deposited polysilicon film has a vertical stress gradient as shown in Fig PS4.1-4, where σ_x is proportional to $z^{1/3}$ with σ_1= 10^7 Pa at location $z = H/2$, how high above the substrate is the tip of this cantilever be after release?

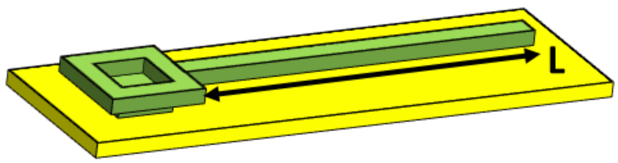

Fig. PS4.1-3

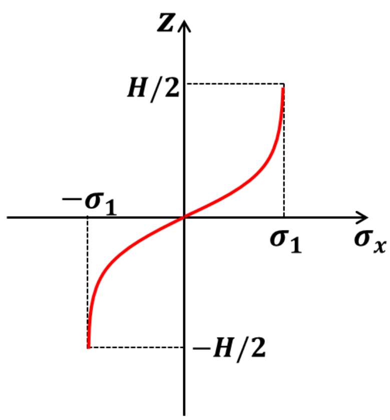

Fig. PS4.1-4 Stress gradient in polysilicon cantilever

c) What point force F should be applied to the cantilever tip after release so that the deflection at the tip is zero? Explain why the cantilever will not be perfectly flat even when a point load is applied at the tip.

d) One method to measure the stress gradient in a thin film entails measuring the radius of curvature by directing a laser beam onto the surface of the film and measuring the angle θ between the wafer surface and the laser beam directed straight down. Suppose you can also use such system to measure the stress gradient in the cantilever, as illustrated in Fig. PS4.1-5. Write an expression of the angle θ as a function of location x and Find the angle θ_{max} at the tip of the cantilever as a function of the maximum stress σ_1 in the film.

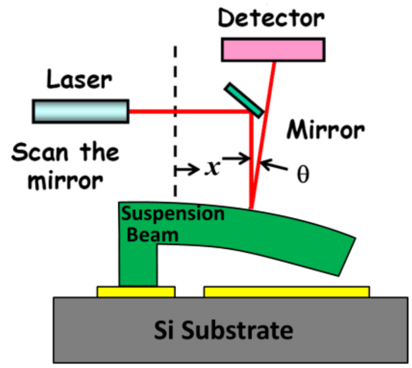

Fig. PS4.1-5

2) Fig. PS4.2 presents top view of a 2 µm-thick polysilicon structure suspended 2 µm above the substrate except for the anchoring locations indicated as the darkly shaded regions. Key dimensions for the beams and data on the structural material used in this problem are given in the box below the figure. Assume that all folding trusses and shuttles are rigid in all directions.

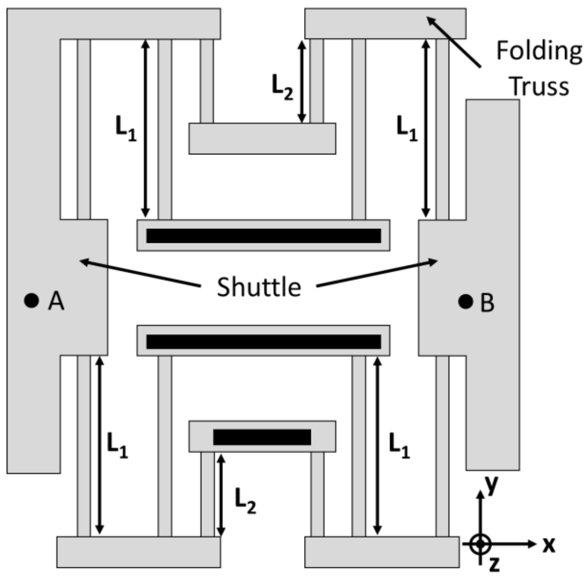

Fig. PS4.2

Structural Material Properties:

E = 150 GPa, ρ = 2330 kg/m^3, Poisson ratio = 0.2

Geometric Dimensions:

L_1 = 30 µm, L_2 = 10 µm,

width of all beams = w = 2 µm

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

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

c) If point *A* moves X_A = 1 μm in the *x*-direction due to a force applied at *A*, how much does point *B* move? Provide an expression for X_B in terms of X_A and spring constants, and calculate a numerical value.

3) Suppose a cantilever beam of length *L* is subjected to a uniform load of intensity *q* and a concentrated load *P* at the free end of the beam as shown in Fig. PS4.4.

a) Derive an expression for the deflection *w* as a function of location *x*, i.e., get *w*(*x*), using the principle of virtual work.

b) Determine the deflection at the free end and the spring constant if *q*=*P*/*L*.

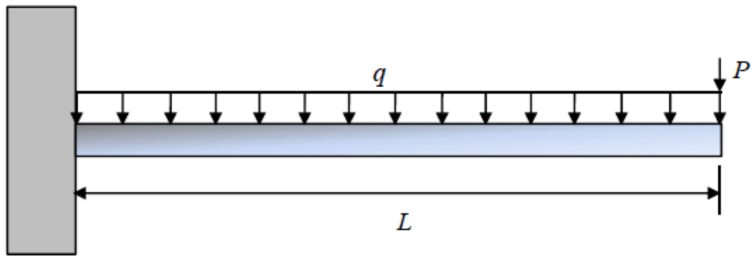

Fig. PS4.4