PROBLEM SET #5

Issued: Tuesday, Oct. 19, 2010.

Due (at 7 p.m.): Thursday, Oct. 28, 2010, in the EE C245 HW box in 240 Cory.

1. Consider the ratioed folded beam flexure system shown in Figure 1 below. The device is to be fabricated using the following process with a clear field structure mask (blue) and a dark field anchor mask (green).

- Thermally grow 2 μm of SiO_2 on a (100) silicon wafer.
- Anisotroprically etch anchor holes in the SiO_2 using RIE and the anchor mask (green).
- Deposit 2 μm of polysilicon using LPCVD.
- Etch the polysilicon layer using RIE and the structure mask (blue).
- Release the structure by etching the SiO_2 in hydrofluoric acid (HF)

The result is illustrated in Figure 1 where the suspended structure is shown in blue and is attached to the substrate at the two anchor regions shown in green. The device is to be inspected under a microscope and probed using a sharp metal tip controlled by a micromanipulator.

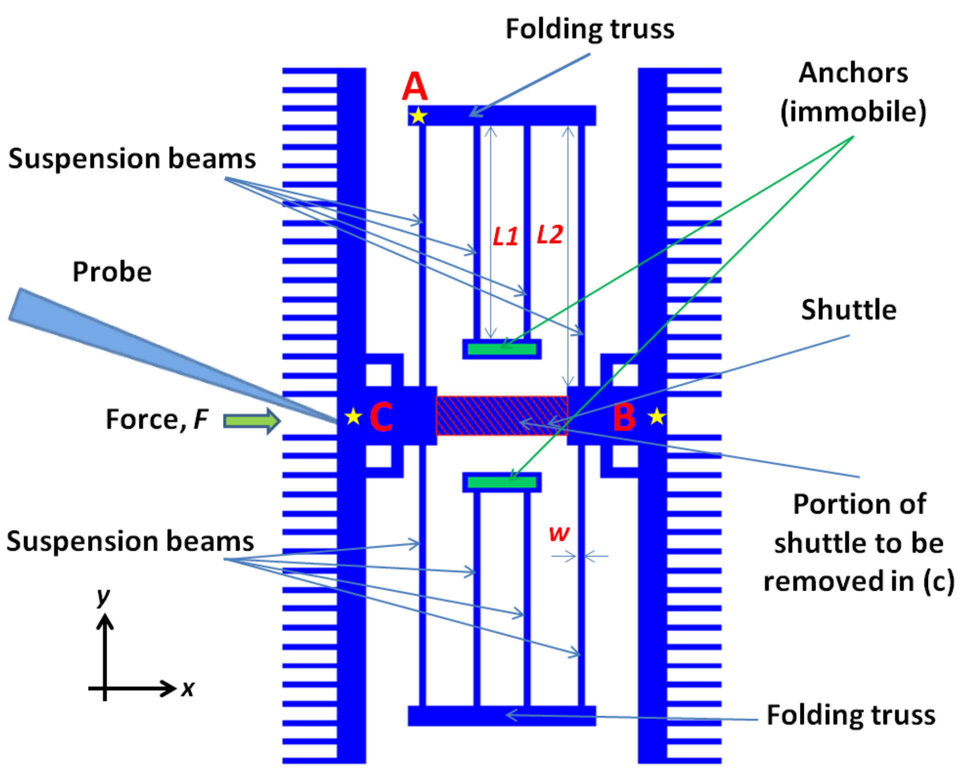

Figure 1. A ratioed folded beam flexure system and a probe.

(a) Derive the x-directed stiffness of the folded flexure at point A as a function of L_1 and L_2 in terms of the Young's modulus E, beam width w, and film thickness t, where L_1 and L_2 represent the inner and outer beam lengths respectively. You should assume that the suspension beams are the only elements of the structure that bend significantly.

(b) Suppose that $L_1 + L_2 = \gamma$, where γ is a fixed design parameter, i.e., $0 \le L_1 \le \gamma$, $L_2 = \gamma - L_1$. Find a ratio of L_1 to L_2 that yields an x-directed stiffness at point B equal to 1/3 the maximum stiffness attainable by varying L_1 and L_2 only. Note that the positions of the folding trusses and anchors are dependent on the values of L_1 and L_2, but these positions do not affect the solution to this problem.

(c) Suppose that the red shaded region of the structure is removed, $L_1 = 110$ μm and $L_2 = 90$ μm. The Young's modulus of polysilicon is 150 GPa and the beam width $w = 2.0$ μm. A force of 1 μN is applied at point C. Calculate the *x*-directed displacement of point B.

2. Suppose that the polysilicon cantilever illustrated in Figures 2 and 3 was fabricated using the process described in Problem 1. Before HF release, the cantilever had the stress profile shown in Figure 4. The Poisson's ratio of polysilicon, ν = 0.22. What point force *F* should be applied to the 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.

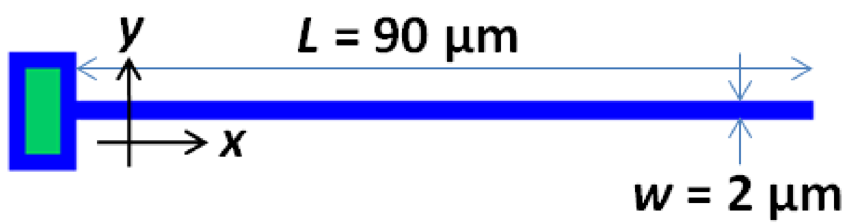

Figure 2. Layout view of a polysilicon cantilever

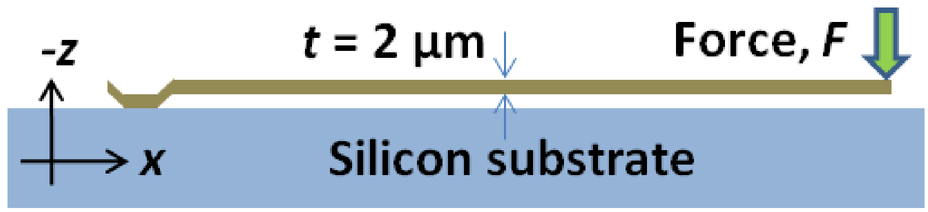

Figure 3. Cross-section of the cantilever after release but before bending (right).

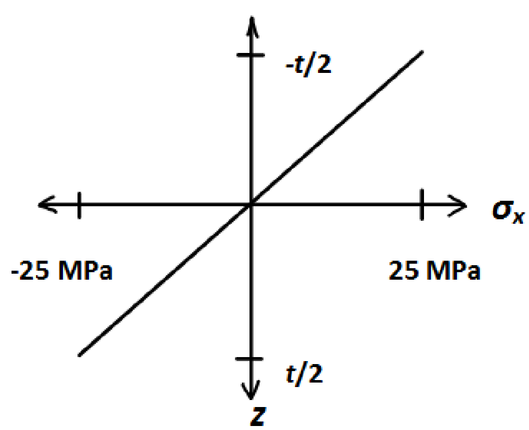

Figure 4. Stress profile in the cantilever before bending.

3. Consider a fixed-fixed beam of width W and height H under the loading conditions shown in Figure 5 below.

(a) Calculate the small-deflection stiffness of the beam by integration of the moment.

(b) Calculate the small-deflection stiffness of the beam using equivalent spring circuits.

(c) Calculate the large-deflection stiffness of the beam using virtual work principles. [Hint: Use a cosine trial function $\hat{w} = \frac{c}{2}\left(1 + \cos\frac{2\pi x}{L}\right)$, where c is the displacement at the center of the beam.]

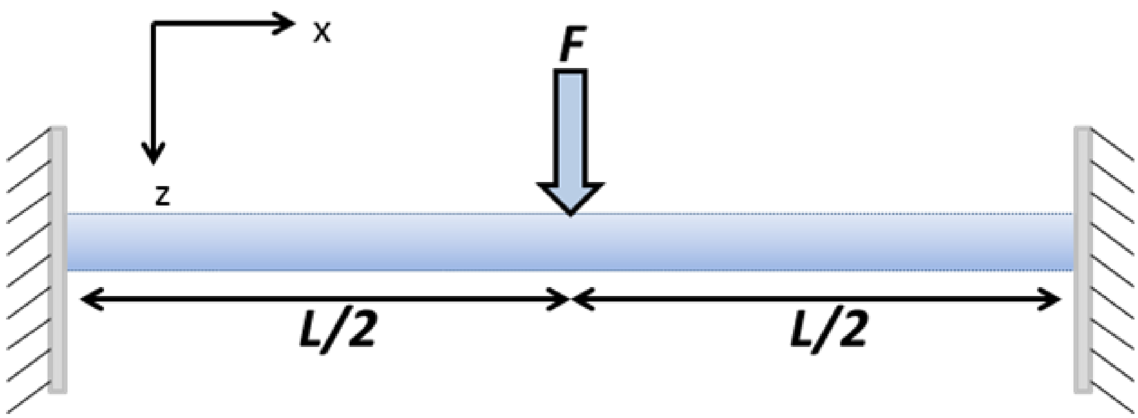

Figure 5. A fixed-fixed beam with a point load *F* applied at its center.