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# PROBLEM SET #5

*Issued: Tuesday, Apr. 1, 2014*

*Due (at 9 a.m.): Wednesday Apr. 16, 2014*, in the EE C247B HW box near 125 Cory.

**1.** Suppose you would like to use the process flow outlined in Problem Set #3 to fabricate the suspended cross beam structure, which you have already seen in Problem Set #4. The structure is constructed entirely of doped polysilicon, i.e., the yellow and green layers are both doped polysilicon. Dimensions for most of the features are indicated in Figs. PS5.1-1 to PS5.1-3. The structure itself (in green) is meant to be 2 μm thick, and the interconnect layers beneath (in yellow) are meant to be in a thin doped polysilicon layer.

Use Cadence to generate a layout that achieves the structure of Figs. PS5.1-1 to PS5.1-3 using the process flow outlined in Problem Set #3. In addition, add a contact to the substrate ground plane with sufficient area to allow bond wiring to this contact. Also, add interconnect and a bond pad that allows the structure to be biased to a specific voltage during testing. Make sure the spacings for the bond pads are sufficient to allow wire bonding. Export your layout to a GDS file and email it to your GSI using 'HW5_layout_last name_first name' as the email title and GDS file name.

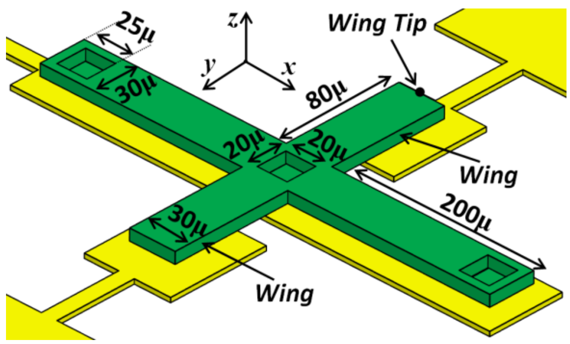



Fig. PS5.1-1: Zoom in of the polysilicon beam structure

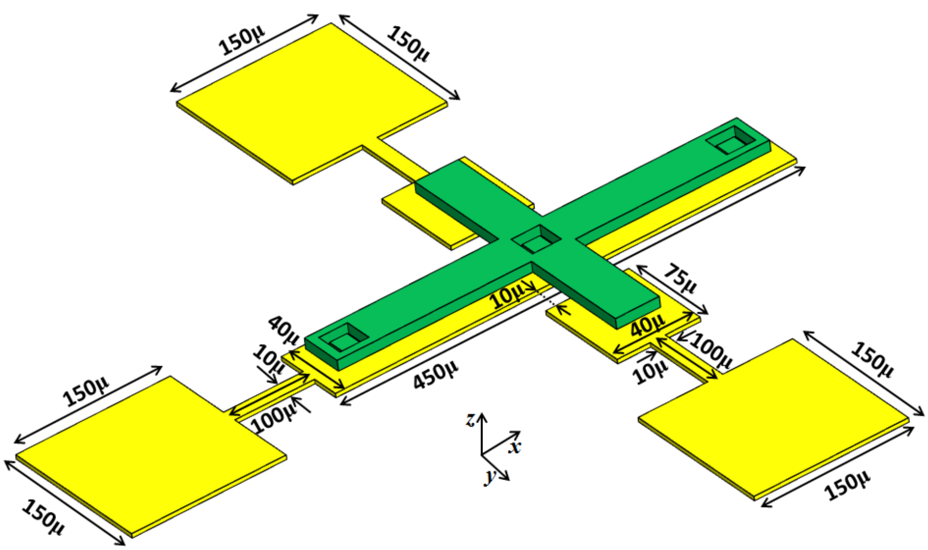



Fig. PS5.1-2: Wide-view schematic with electrode contact dimensions

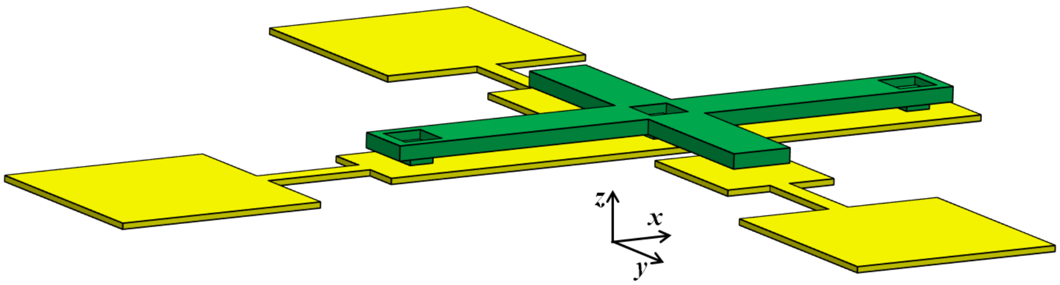



Fig. PS5.1-3: Side view showing anchor points

**2.** A clamped-guided beam of length $L$ is subjected to a concentrated load $F$ at the guided end and two equal and opposite axial forces $S$ as shown in Fig. PS5.2.

Derive that the equivalent $y$-direction stiffness $k_y$ at the guided end of the beam can be expressed as:

$$k_y^{-1} = \frac{pL - 2\tanh\left(\frac{pL}{2}\right)}{p|S|}, \text{when } S > 0 \text{ (tensile load)}$$

$$k_y^{-1} = \frac{-pL + 2\tan\left(\frac{pL}{2}\right)}{p|S|}, \text{when } S < 0 \text{ (compressive load)}$$

where $p = \sqrt{|S|/(EI_z)}$

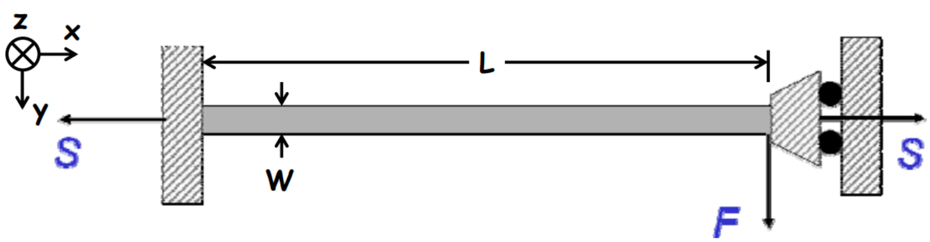
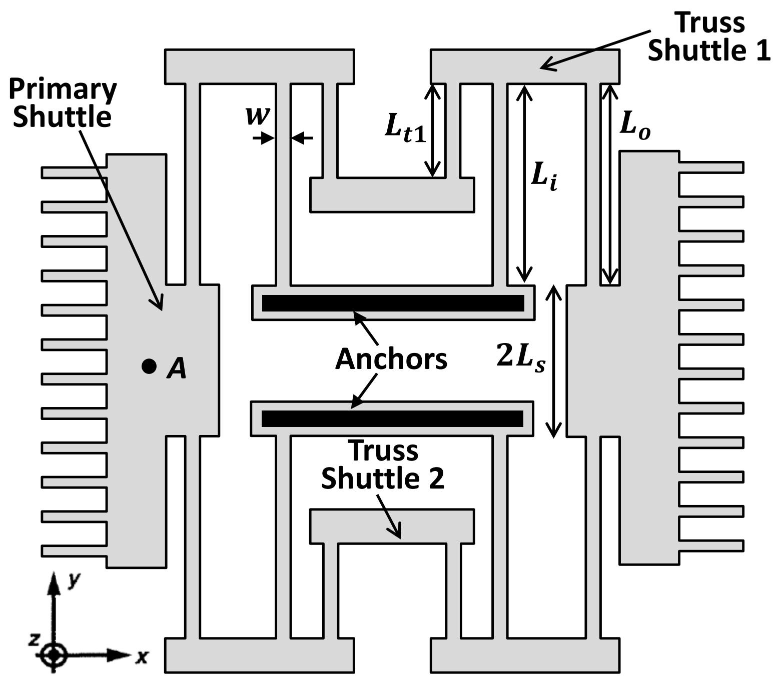



Fig. PS5.2

**3.** Fig. PS5.3-1 presents the top view of a micromechanical device constructed in a 2 μm-thick structural layer using the following two-mask surface micromachining process:

i. Deposit 2.0 μm of SiGe on a fused quartz (glass) wafer using LPCVD.
ii. Lithographically define and then etch anchor openings in SiGe (anisotropic).
iii. Deposit 2.0 μm of polysilicon using LPCVD @ 650°C.
iv. Lithographically define and then etch the polysilicon structure (anisotropic).
v. Etch SiGe completely using an $H_2O_2$ etch, releasing the structure (isotropic).

Data on the structural material used in this problem and on specific geometric dimensions are given in the box below, in Fig. PS5.3-1. For this problem, assume that all folding trusses and shuttles are rigid in all directions, including the vertical (i.e., $z$) direction. In addition, all suspension beam widths are 2 μm. Assume room temperature is 25°C.




<u>Structural Material Properties</u>
$E = 160$ GPa, $\rho = 2331$ kg/m$^3$, Poisson ratio, $\nu = 0.2$
<u>Geometric Dimensions</u>: (all beams width $w$)
$L_o = L_i = 50$ µm; $L_{t1} = 25$ µm; $L_s = 25$ µm
$w = 2$ µm, thickness, $h = 2$ µm

Fig. PS5.3-1

**(a)** Calculate the biaxial stress in the polysilicon layer due to linear thermal expansion before releasing the structure. For all of problem 3, you may assume all materials are isotropic and use the materials properties from *Senturia Table* 8.1, reproduced below.

| Material | $\rho_m$ kg/m$^3$ | $E$ GPa | $\nu$ | $\alpha_T$ µstrain/K | $\sigma_o$ MPa | Comment |
|---|---|---|---|---|---|---|
| Silicon | 2331 | page 193 | | 2.8 | | Cubic |
| $\alpha$-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 |

**(b)** Folded beam design usually can help release residual stress. Can the folded beams in this structure fully release the stress? Calculate the stress in the flexure beams $L_o, L_i$ and $L_{t1}$ after releasing the structure and identify whether the stress is compressive or tensile? Assume all shuttles and trusses are perfectly rigid.

**(c)** Calculate the static spring constant in $x$-direction at point $A$ on the primary shuttle of the micromechanical device.

**4.** Suppose a cantilever beam of length *L* is subjected to a linearly distributed load of intensity as shown in Fig. PS5.4.

**(a)** Derive an expression for the deflection *w* as a function of location *x*, i.e., get *w(x)*, by integrating the moment.

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

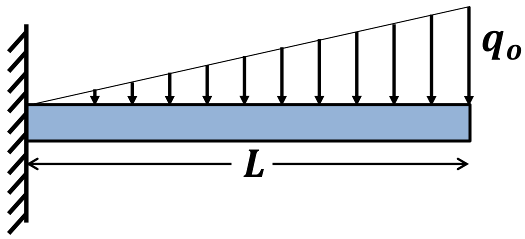



Fig. PS5.4