PROBLEM SET #2

Issued: Friday, Feb. 13, 2015

Due (at 9 a.m.): Friday, Feb. 27, 2015, in the EE C247B HW box near 125 Cory.

1) The cross-section below is to be etched via reactive ion etching (RIE). For this problem, assume that the RIE etch is 100% anisotropic and that it etches polysilicon at the rate of 1 μm/min and has a silicon-to-oxide selectivity of 5:1. Draw cross-sections of the structure after etching for (a) 2 min.; (b) 5 min.; and (c) 6 min.

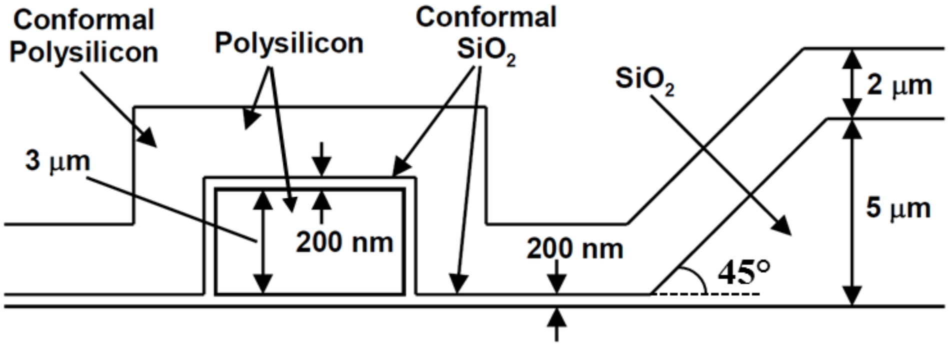

Fig. PS2.1

2) You have a p-type wafer, and you want to make a p-n junction at a depth of x_j = 500 nm by diffusing phosphorus from the front side.

(To motivate this problem, assume that you're making a single-crystal silicon membrane. At the end of your process, you will etch away the wafer from the back using a wet etchant that will stop on the p-n junction. The membrane thickness will equal the junction depth.)

a) The wafer is initially doped with gallium to a concentration $N_A = 10^{15}$ cm^{-3}. If you use $POCl_3$ to dope the wafer at temperature T_1 = 1000 ºC:

i) How long (t_1) would you need to keep the wafer in the diffusion furnace to achieve this junction depth?

ii) What is the sheet resistance?

b) Suppose that the above is not the only high-temperature step in your process and that you will also do the following afterwards:

Two LTO depositions (before and after the poly deposition), at temperature T_2 = 400 °C, over a total time period of t_2 = 80 min;

A polysilicon deposition, at temperature T_3 = 615 °C, over a time period t_3 = 120 min;

A rapid thermal anneal, at temperature T_4 = 1050 °C, over a time period t_4 = 1 min

i) Rank the four thermal steps from greatest effect on the phosphorus diffusion to least effect.

   ii) What is the new junction depth after these additional steps?

3) Figure PS2.2 presents the top view of an accelerometer constructed of 2 µm thick micro-crystalline diamond (MCD) with a proof mass area of 50 µm × 50 µm. The proof mass has 2 µm × 2 µm etch holes placed in a periodic pattern with a 10 µm pitch. The structure is released using XeF_2 etching and the cross-section A-A' before the release etch is given in Figure PS2.3, which also shows the thickness of the polysilicon sacrificial layer (1 µm) and the thickness of the protective Si_3N_4 layer (400 nm) as well as the silicon substrate. Assume that XeF_2 does not attack MCD, but it does attack the Si_3N_4 with an etch rate of 10 nm/min, and that when it etches it is 100% isotropic. Also assume that the XeF_2 etch rate is 200 nm/min for both polysilicon and single-crystal silicon.

- **a)** What would be the minimum etch time to free the structure if the structure did NOT have the etch holes?
- **b)** What is the minimum etch time to free the actual structure with the etch holes?
- **c)** Sketch the cross-section A-A' after 10, 30, and 60 and minutes of etching. Draw any curves accurately and provide numerical values for all dimensions needed to specify all breaks and corners. Assume that the anchor is large enough to hold the MCD proof mass for all given etching times. Also, note that the substrate is much thicker (>500 µm) than the deposited films so it won't be etched entirely during the release.
- **d)** What is the diameter of the hole opening at the surface of the substrate after 60 minutes of (total) etching?
- **e)** Discuss qualitatively the benefits of using etch holes.

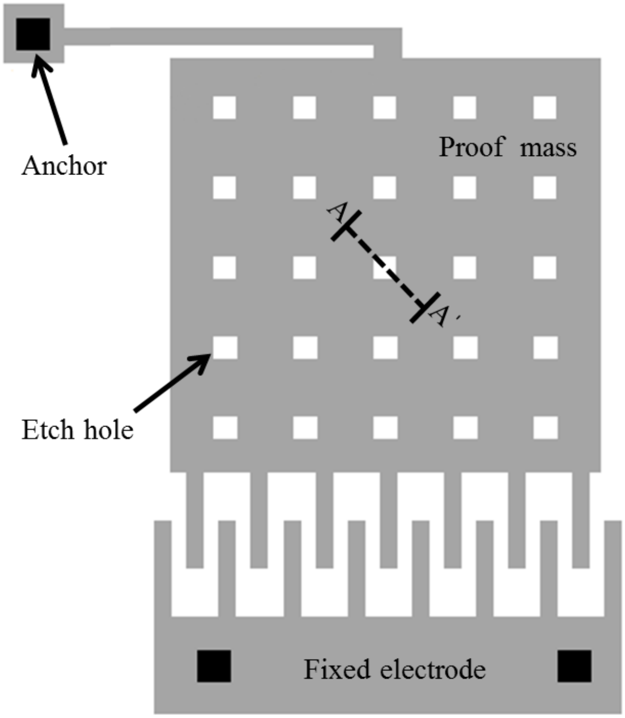

Fig. PS2.2

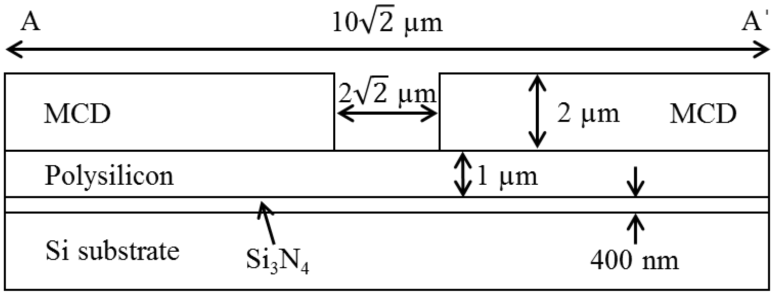

Fig. PS2.3

4) Figure PS2.4 presents the perspective view of a cube suspended 3 µm above the substrate by folded flexures anchored at the inner points indicated. The entire structure, including cube and all suspensions, is perfectly symmetrical and constructed of a single structural material, the properties of which are given in Table PS2.1. Also, as indicated in Table PS2.1, all suspension beam widths and thicknesses are 2 µm and 5 µm, respectively.

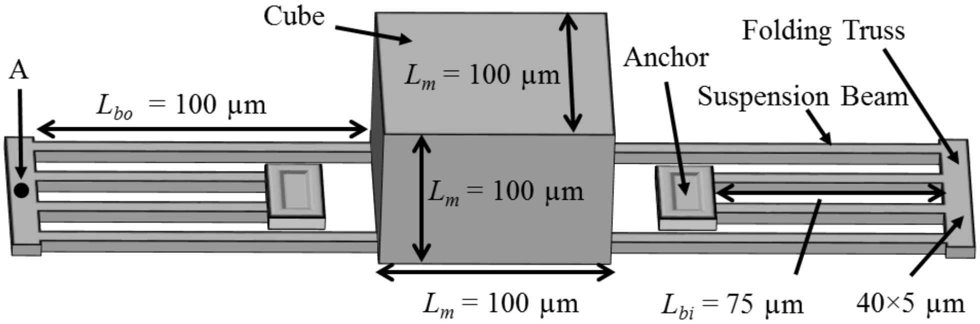

Fig. PS2.4

Young's Modulus	E	150 GPa
Density	ρ	2300 kg/m^3
Poisson ratio	ν	0.226
Suspension Beam Width	W	2 µm
Suspension Beam Thickness	h	5 µm
Specific Heat	c_p	0.77 J/(g·K)
Thermal Conductivity	k	30 W/(m·K)

Table PS2.1

a) If all structural dimensions were scaled by 0.01×, by what factor would the thermal time constant of the structure change? (Use the following convention: For a reduction, the scaling factor is less than one; for an increase, the scaling factor is greater than one).

b) Suppose a laser is directed at point A to deliver a power P_i to that location that achieves a temperature T_m on the cube. If all structural dimensions were scaled by 0.01×, by what factor would the input laser power need to be adjusted in order to maintain the same temperature T_m on the cube while still directed at point A?