PROBLEM SET #2

Issued: Tuesday, February 14, 2017

Due: Tuesday, February 28, 2017, 10:00 a.m. in the EE C247B homework 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) 2min.; (b) 5min.; and (c) 6min.

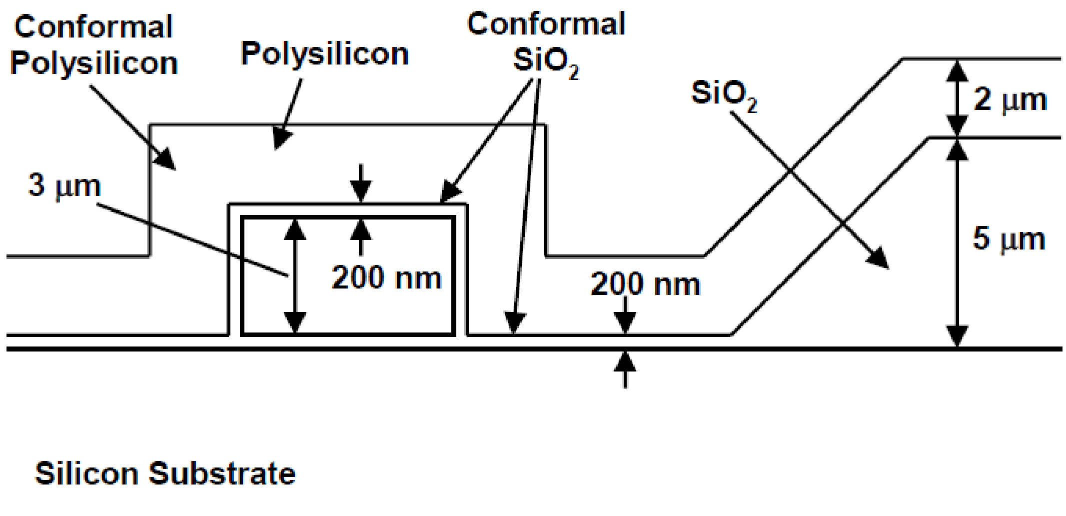

Fig. PS2.1

2. You have a *p*-type wafer, and you want to make a *p*-*n* junction at a depth of x_j = 500nm 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.

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

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 = 80min
- A polysilicon deposition, at temperature T_3 = 615°C, over a time period t_3 = 120min
- A rapid thermal anneal, at temperature T_4 = 1050°C, over a time period t_4 = 1min

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. You are given the layout below along with the process traveler to follow. In the layout each box corresponds to $1\mu m^2$. In the mask legend, cf = "clear field" and df = "dark field". In the process traveler, assume that all lithography steps use positive photoresist, except when otherwise indicated, and that all etch steps are 100% selective to intended film. Also, assume that RIE etches are anisotropic, but any other type of etch has some degree of isotropy. Follow the instructions after the process traveler.

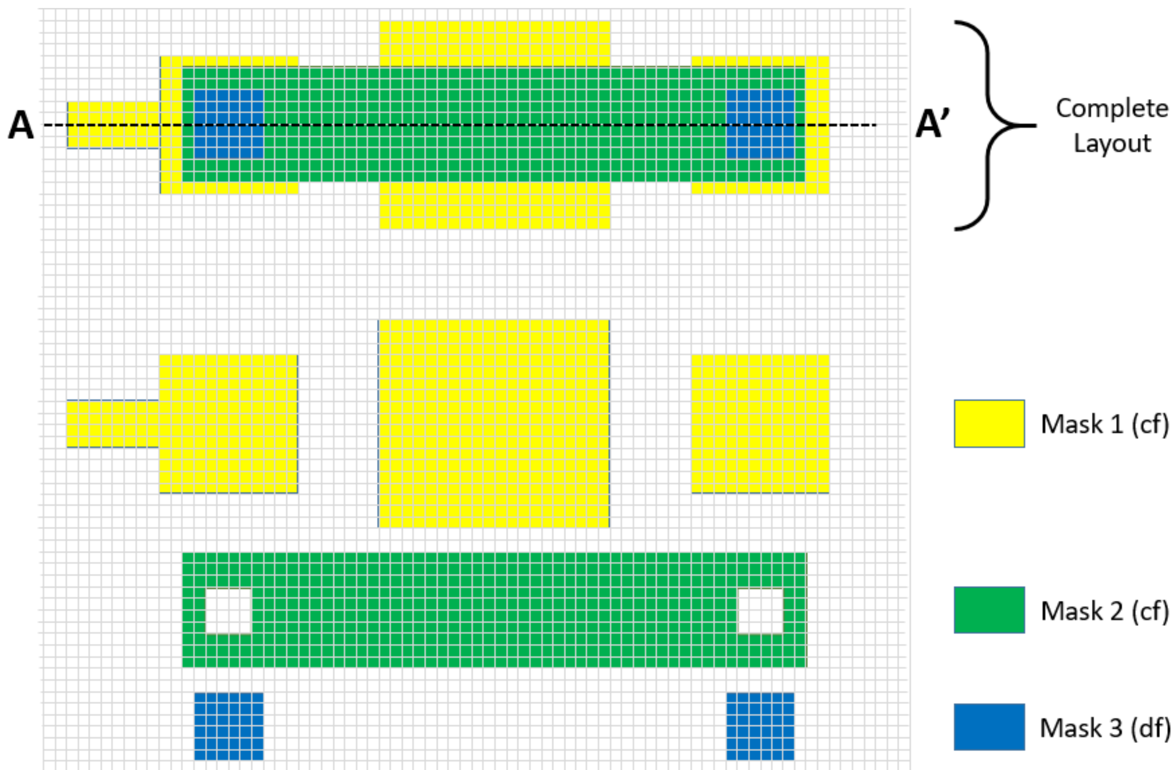

Fig. PS2.2

<u>Process Traveler:</u>

(i) Deposit 2µm of LTO via LPCVD.

(ii) Deposit 500nm of silicon rich nitride via LPCVD

(iii) Deposit 300nm of *in situ*-phosphorus-doped polycrystalline silicon via LPCVD at 610°C.

(iv) Lithography via Mask 1.

(v) Etch polysilicon via RIE and stop on nitride.

(vi) Remove photoresist.

(vii) Deposit 500nm of LTO via LPCVD.

(viii) Deposit 2µm of *in situ*-phosphorus-doped polycrystalline silicon via LPCVD at 610°C.

(ix) Deposit 2µm of LTO via LPCVD.

(x) Lithography via Mask 2.

(xi) Etch oxide via RIE and stop on polysilicon.

(xii) Etch polysilicon via RIE and stop on oxide.

(xiii) Remove photoresist.

(xiv) Lithography via Mask 3.

(xv) Etch oxide via RIE and stop when the etch reaches polysilicon or nitride on the substrate.

(xvi) Remove photoresist.

(xvii) Deposit 3µm of *in situ*-phosphorus-doped polycrystalline silicon via LPCVD at 610°C.

(xviii) CMP the polysilicon and stop on oxide.

(xix) Lithography via Mask 3 using a negative resist.

(xx) Etch polysilicon via RIE and stop on oxide.

(xxi) Remove photoresist.

(xxii) Dip in HF until structures are fully released.

Instructions:

(a) Draw the cross-section through step (xiii) along the AA' axis.

(b) Draw the final cross-section along the AA' axis.

4. *(This problem continues from Problem #1 of Homework #1)*

Suppose the gap spacing between the bottom of the cube and the substrate is also scaled by the same factor as the structural dimensions. Assuming the structure given in Fig. PS2.3 is released using a wet etch, after which it is immersed in DI water, then dried, at what scaling factor will pull-in of the cube to the substrate via stiction become a problem? Note that the total stiffness presented by the inner and outer beams to the cube in the vertical (i.e., z) direction is given by:

$$k_z = 4EW_bH^3\left(\frac{1}{L_{bi}^3 + L_{bo}^3}\right)$$

Starting dimensions and material properties for this structure are given in Table PS2.1.

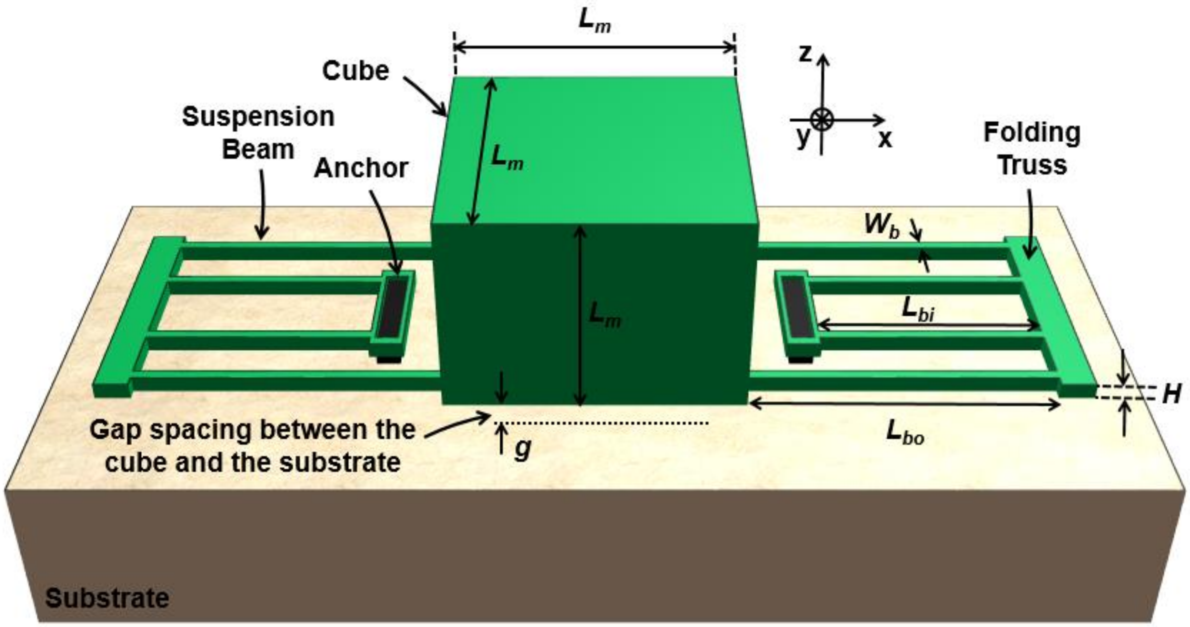

Fig. PS2.3

PARAMETER	VALUE	UNIT
Young's Modulus, *E*	150	GPa
Density, *ρ*	2,300	kg/m^3
Poisson Ratio, *v*	0.226	-
Inner Beam Length, L_{bi}	75	µm
Outer Beam Length, L_{bo}	100	µm
Beam Width, W_b	2	µm
Beam Thickness, *H*	5	µm
Cube Side Length, L_m	100	µm
Gap Spacing Between the Cube and the Substrate, *g*	5	µm
DI Water Contact Angle for Str. and Subs. Materials	85	°
Water-Air Interface Surface Tension	72.75×10^{-3}	N/m

Table PS2.1