PROBLEM SET #3

Issued: Thursday, Feb. 20, 2014

Due (at 9 a.m.): Wednesday Mar. 5, 2014, in the EE C247B HW box near 125 Cory.

1. The following pages comprise a surface micromachining process flow for a MEMS device. No details are spared in this flow; even equipment names are given, as are diagnostic steps used to verify select process steps. Furnace program names (for equipment in the UC Berkeley Nanolab) are also given. These details are included to present a more realistic situation. In doing this problem, you must sift through the extraneous information and concentrate on the relevant information (i.e. film thicknesses, etch times, doses, temperatures, etc.).

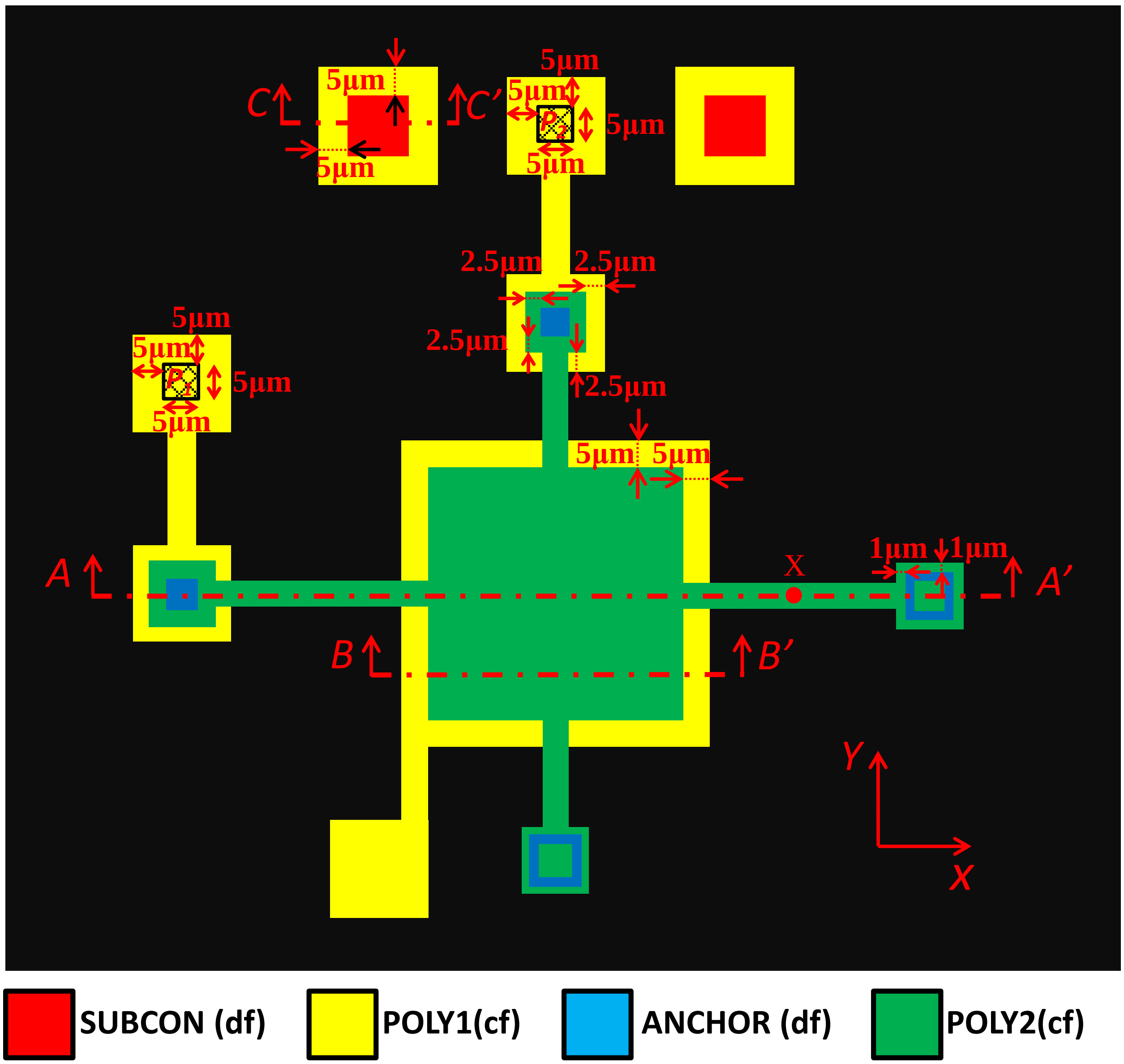
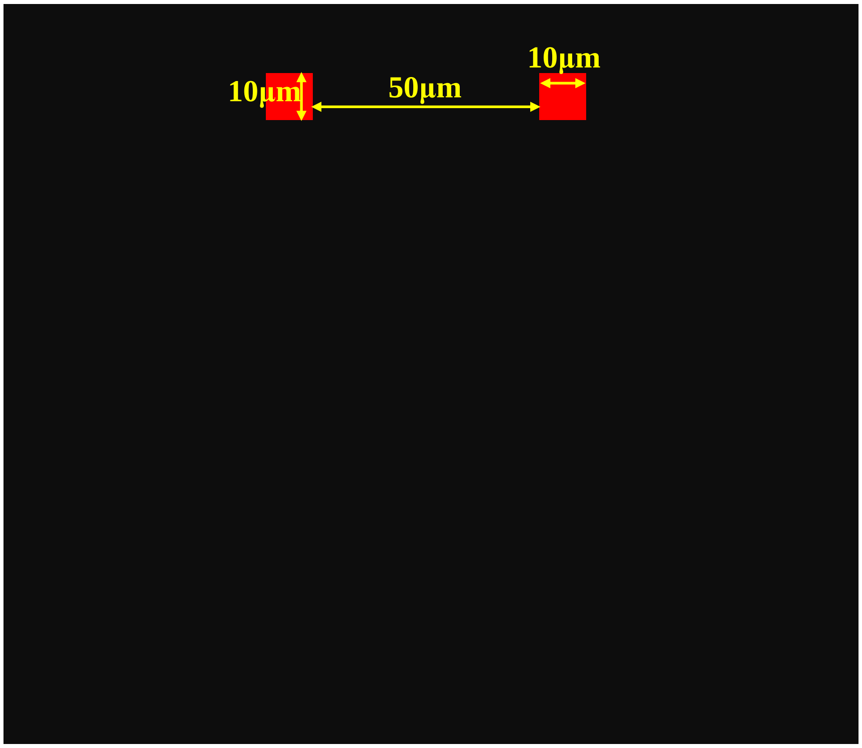
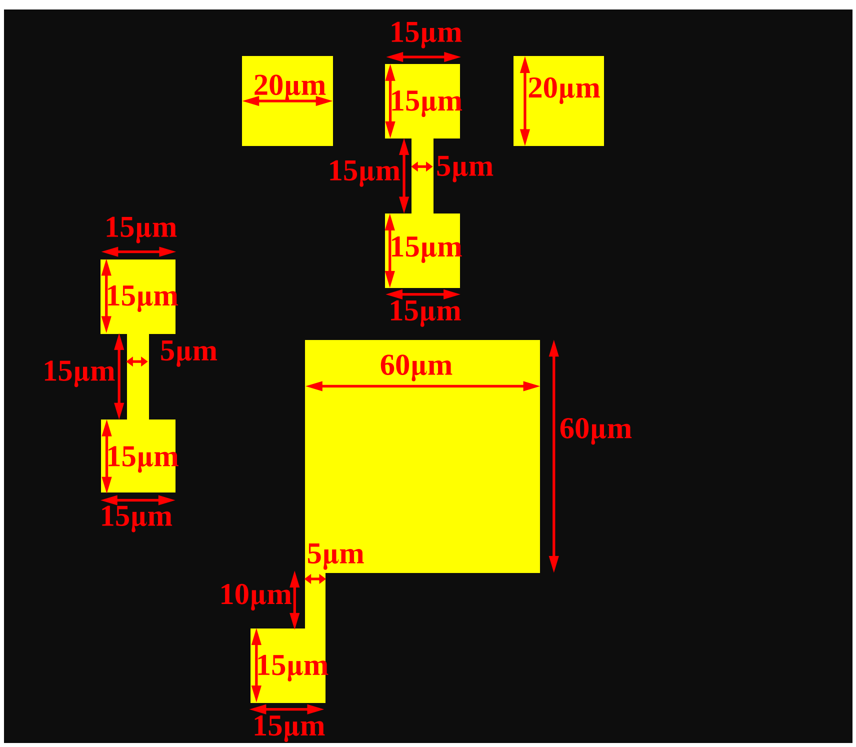


Figure PS3.1-1

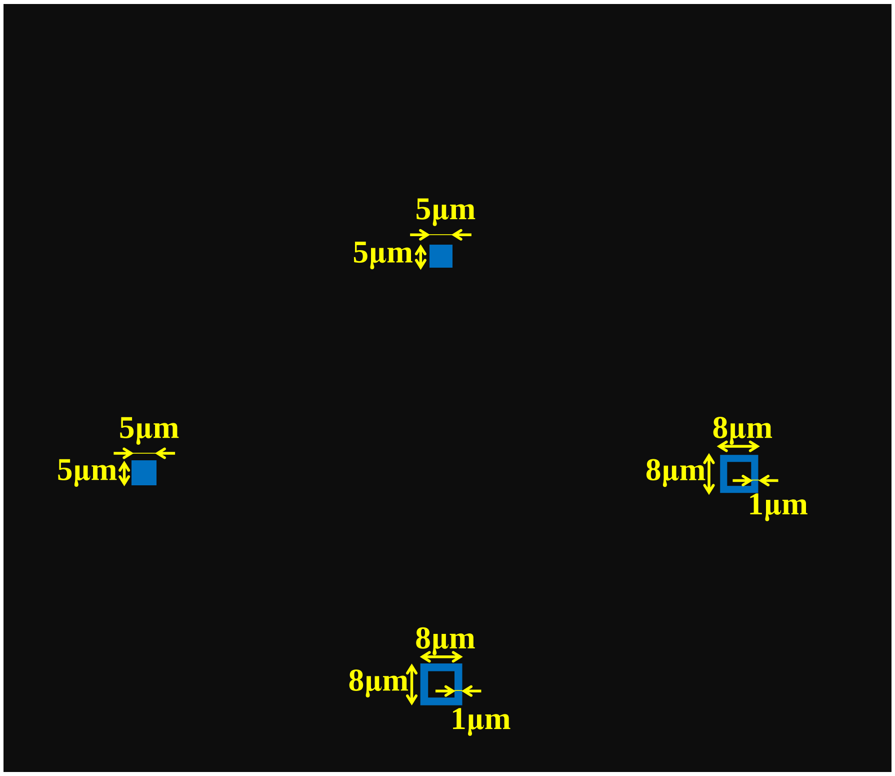
The four masks used in this process flow are shown below with dimensions. The background color of the layout editor is black. This is the “field” for all masks.



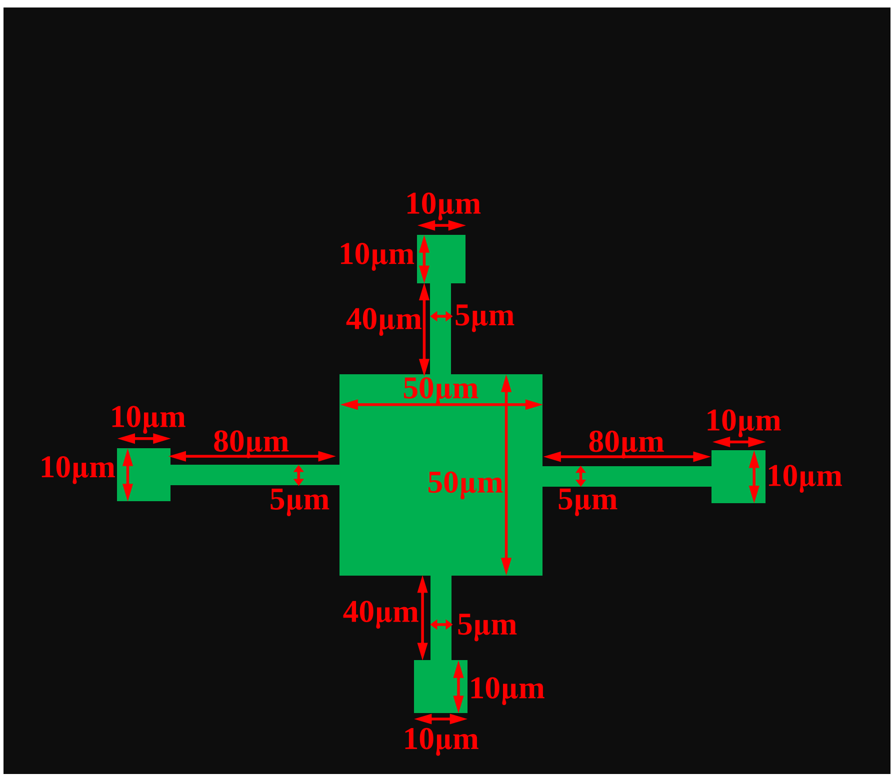
Mask 1: SUBCON (dark field)



Mask 2: POLY1 (clear field)



Mask 3: ANCHOR (dark field)



Mask 4: POLY2 (clear field)

Underside Capacitive-Gap Surface Micromachining Process

0.0 Starting Wafers: 8-12 ohm-cm, n-type, (100) prime or just n-type test wafers.
Control Wafers:
PSGlF, PSGlB (Si) NITlF, NITlB (Si)
POLYlF, POLYlB (tylanll ctrl.)
PSG2F, PSG2B (Si) POLY2F, POLY2B (Si)
PSG3F, PSG33 (81)

1.0 Wafer $POCl_3$ doping
Tystar13, recipe 13POCL3A
Flows (slm): N_2: 5, $POCl_3$ (in N_2): 1
Time = 1 hour

1.1 Strip oxide
Sink8 BHF, 1 minute

2.0 PSG Deposition: target = 2 μm
(immediately after n+ diffusion)
Tystar12, recipe 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time (2μm) = 1 hour 40 minutes (~1000 Å per 5 min.)
Include etching controls: PSGlF and PSGlB

3.0 PSG Densification
RTA in Heatpulse1: 30 secs @ 950 ^oC
Also do PSG1 ctrls

4.0 Nitride Deposition: target = 300 nm
Deposit stoichiometric nitride:
Tystar17, STDNITA.017
temp. = 800 °C, Flows (sccm): SiH2C12 = 25, NH3 = 75
time = 1 hr. 22 min., (~220 nm per hour)
Include etching controls: NITlF and NITlB

5.0 Substrate Contact Mask: Sub.Con. (chrome-df)
5.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.6 μm
Positive PR

5.2 Etch nitride in Centura-Mxp.
SF_6 = 175 sccm, He = 50 sccm

5.3. Etch oxide in Lam6:
For 2 μm oxide: [press = 2.8 Torr, power = 350 W, gap = 0.38 cm, CHF_3 = 30 sccrn, CF_4 = 90 sccrn, He = 120 sccrn, time = 1 min.], [power = 0, same gases, time = 1 min.] 3X

5.4. Wet dip in 10:1 BHF for 20 s to remove native oxide.

5.5 Remove resist, piranha clean wafers.

6.0 Interconnect Polyl Deposition: target = 400 nm
Phosphorus-doped polysilicon deposition:
Tystar16, 16VDPLYA
time = 3 hour 20 minutes, temp. = 650°C (~120 nm per hour)
Include etching controls: POLYlF, POLYlB

7.0 Interconnect Polyl Definition Mask: PolySi1 (emulsion-cf)

7.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.1 μm

7.2 Plasma etch poly-Si in Lam8 etcher, inspect
(Cl_2/HBr at 300 Watts, 12 mTorr)

7.3 Remove PR, piranha clean wafers along with PSG2F and PSG2B.

8.0 Sacrificial PSG Deposition: target = 2 μm
Tystar12, 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time (2 μm) = 1 hour 40 minutes (~1000 Å per 5 min.)
Include etching controls: PSG2F and PSG2B

9.0 Sacrificial PSG Densification
RTA in Heatpulsel: 30 secs @ 950 °C
(also do PSG2 ctrls)

10.0 μStructure Anchor Photo Mask: ANCHOR (chrome-df)

10.1 Spin, expose, develop, descum, hard bake.
PR thickness: 1.1 μm

10.2 Etch in lam6:
For 1 μm oxide: etch as usual.
For 2 μm oxide: [press = 2.8 Torr, power = 350W, gap = 0.38 cm, CHF_3 = 30 sccrn, CF_4 = 90 sccrn, He = 120 sccrn, time = 1 min.], [power = 0, same gases, time = 1 min.] 3X
For both cases, overetch with 700 W recipe.

10.3 Check contact using IV probe station.

10.4 Wet dip in 5:l BHF for 10 secs.

10.5 Remove resist, piranha clean wafers.

11.0 μStructure Poly2 Deposition: target = 2 μm
Undoped polysilicon deposition: Tystar16, 16SUPLYA
time = 16 hours, temp. = 650°C
Include etching controls POLY2F and POLY2B (tylanll cntrls).

12.0 PSG Mask Deposition: target = 500 nm
Tystar12, 12VDLTOA
Flows (sccrn): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time = 25 minutes (~1000 A per 5 rnin.)
Include etching controls: PSG3F and PSG3B

13.0 Thermal Anneal
Heatpulsel: 60 min. @ 1000°C in 50 l/sec N_2

14.0 μStructure Poly2 Definition Mask: POLY2 (emulsion-cf)
Align to Poly1 interconnect

14.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 1.6 μm

14.2 Etch oxide mask in lam6.

14.3 (optional) Remove resist:
technics-c, 10 min. 02 plasma B 300 W

13.4 Etch 2nd poly in lam8:
(Cl_2/HBr at 300 Watts, 12 mTorr)

14.5 If haven't already removed resist, remove resist.
Technics-c, 10 min. 02 plasma B 300 W

15.0 μStructure Release

15.1 Piranha clean in sink8.

15.2 Wet etch in 49% wt. HF (~2 μm per min.).
(Etch for whatever time is needed to remove all exposed oxide, including oxide underneath structures)
Slowly agitate, rinse.
Spin dry or N_2 gun dry.

15.3 Piranha clean in sink8 for 10 min. Follow with standard deionized water (DI) rinses. No HF dip. Spin dry or N2 gun dry.

For etch steps, if the etch uses a plasma or RIE process, assume perfect anisotropy. Also, assume that any etch time is determined by first calculating the time needed to etch through the nominal film thickness based on the nominal etch rate, then adding a 30% overetch to remove any small remaining spots of material. Assume that after you develop your photoresist, it has a sidewall angle of 90°. Also assume that the photoresist will have the given thickness in the field regions and have a perfectly flat upper surface.

When considering etches in this problem, assume the following selectivities (estimated from Kirt Williams', "Etch Rates for Micromachining Processing"). As a reminder, the definition of selectivity is $S_{A/B} = ER_A/ER_B$.

Etchant	Layer A	Layer B	Selectivity $S_{A/B}$
SF_6+He	Nitride ER = 50 nm/min	PR	1:1
		Oxide	2:1
		Silicon	1:3
CF_4+CHF_3+He	Oxide ER = 450 nm/min	PR	3:1
		Nitride	3:1
		Silicon	4:1
Cl_2+HBr	Silicon/Polysilicon ER = 350 nm/min	PR	1:1
		Oxide	100:1
		Nitride	1:2
HF (release)	Oxide ER = 2 μm/min	Nitride	250:1

(a) Draw cross-sections with clearly labeled dimensions and thicknesses for the structure along the A-A′, B-B′ and C-C′ lines in the layout (i) after step 10.0 of the process; and (ii) before step 15.0 of the process. Here, you should get the thickness dimensions correct (to within 100 nm or 20%, whichever is finer) and calculate the etching times based on the nominal thickness of the layers and 30% overetch. Draw the length (horizontal) dimensions using a compressed scale. If any structures completely detach from the wafer, please show this clearly in the final sketch.

(b) If the wafer is immersed in HF too long, something very bad happens. What is this? What is the longest time that the wafer can be immersed in HF before this happens? Is this enough to completely release the structure?

(c) Suppose the amount of time available in HF under the restriction of part (b) is insufficient to release the structure. Propose a design change that would allow complete release with only this much time in HF.

(d) Suppose you made a mistake in lithography, so that mask POLY2 is misaligned to mask ANCHOR by 5 μm to the right in x-direction. Draw the cross-section along line A-A' before step 15.0 of the process. How will this affect the device?

(e) Suppose the total z-direction restoring stiffness at the "proof mass end" of suspension beams can be approximated by the expression

$$k_z = \sum_i EW_i \left(\frac{H_i}{L_i}\right)^3$$

where subscript i corresponds to each suspension beam, E is the material Young's Modules, W_i, H_i, L_i are the width, thickness, and length of the suspension beam, respectively. Assume the contact angle of water underneath the proof mass during drying is $30°$. Will the proof mass be stuck down after drying in air? To simplify this problem, ignore the effect of surface tension of the beams and only consider the proof mass when determining sticking forces. Also, assume that the room-temperature surface tension of a water-air interface is 72.75×10^{-3} N/m.

(f) Assuming the contact angle and surface tension numbers of part (e), what is the minimum sacrificial oxide thickness that you can use and still end up with a structure that is not stuck to the substrate after release.

(g) Assume the structure is to be immersed in methanol instead of water prior to drying. Will the device be stuck down after drying in air from methanol?

Liquid	**Surface Tension, γ_{la} (N/m)**	**Contact Angle, θ_c(°)**
Water	72.75×10^{-3}	30
Methanol	22.70×10^{-3}	Unknown

(h) Assume the sheet resistance of the interconnect polysilicon (i.e., POLY1) is 20 Ω/□, and that of the polysilicon structural material (i.e., POLY2) is 5 Ω/□. Calculate the total resistance between the centers of bond pads P_1 and P_2, as indicated in the pattern filled area in Fig. PS3.1-1 (where probe tips might be placed in contact).

(i) Now suppose a step-function voltage V_{in} is suddenly applied between bond pads P_1 and P_2. With what time constant will the proof mass reach its steady-state temperature after the step voltage is applied? Suppose the anchors of suspension beams are fixed rigidly to a large isolation substrate which is kept at room temperature i.e. 25°C. Assume the thermal characteristics of polysilicon layer are the same as single-crystalline silicon, i.e., specific heat is 0.77 J/g·K, and thermal conductivity is 30 W/m·K.

(j) What is the steady-state temperature at point X (in the middle of the suspension beam) if the final step function value of V_{in} is 2V? Assume the substrate is kept at 25 °C.