

PROBLEM SET #3

Issued: Monday, March 2, 2015

Due (at 9 a.m.): Wednesday, March 11, 2015, in the EE C247B HW box near 125 Cory.

- 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.).

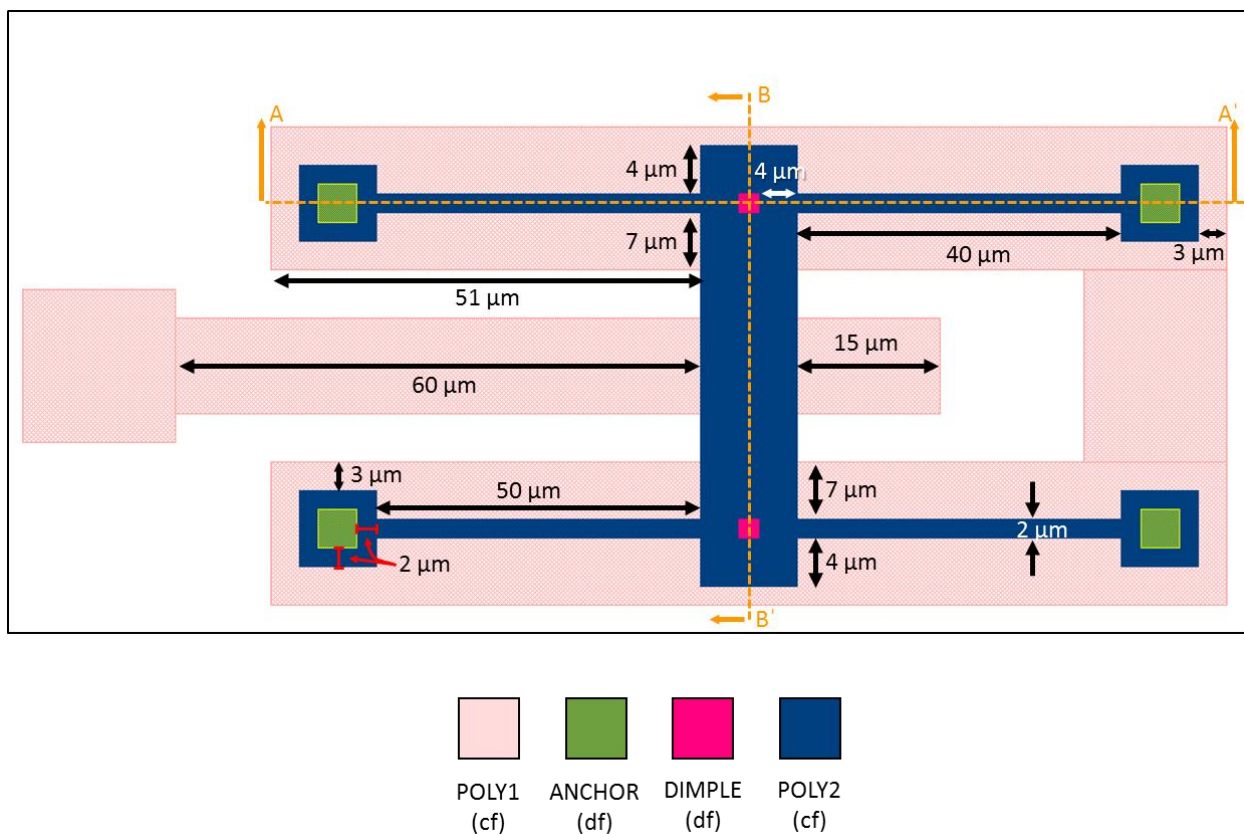
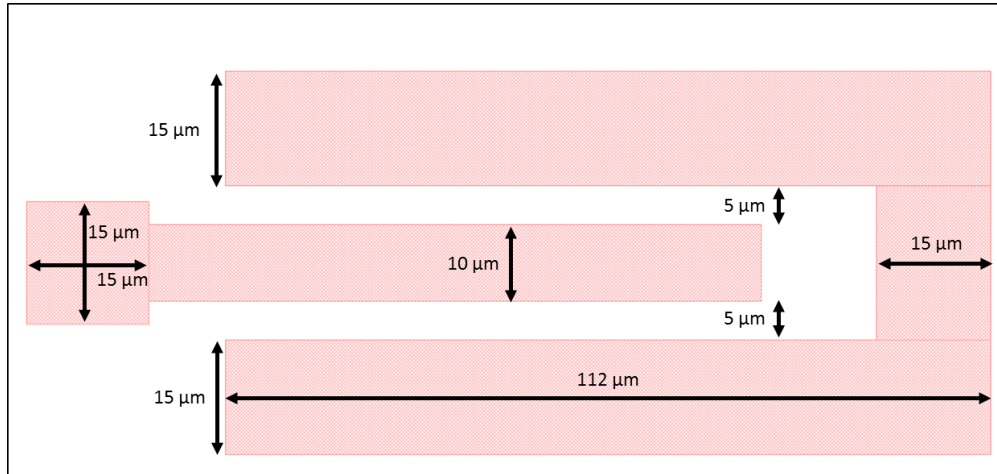


Figure PS3.1

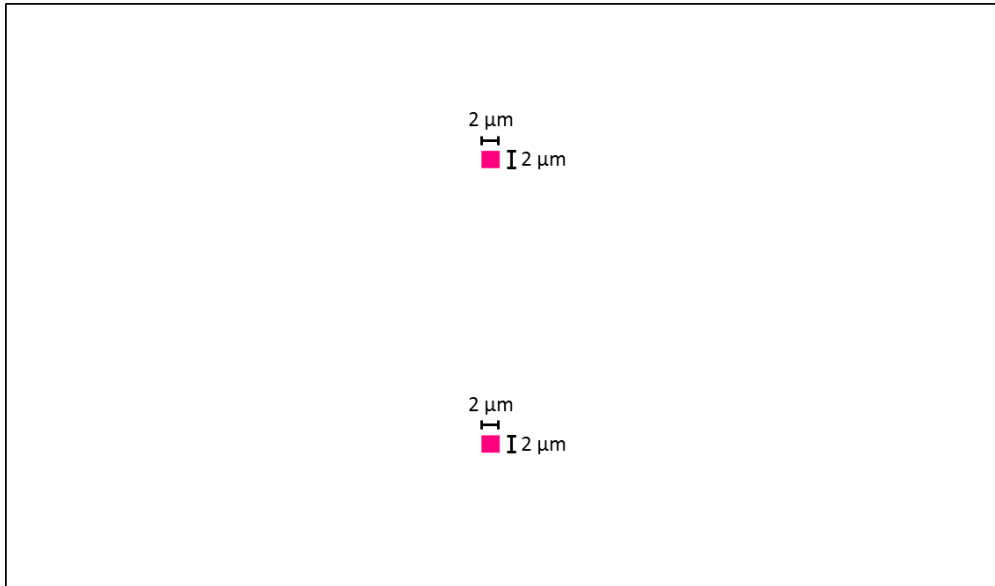
The four masks used in this process flow are shown below with dimensions. The background color of the layout editor is white. This is the “field” for all masks.



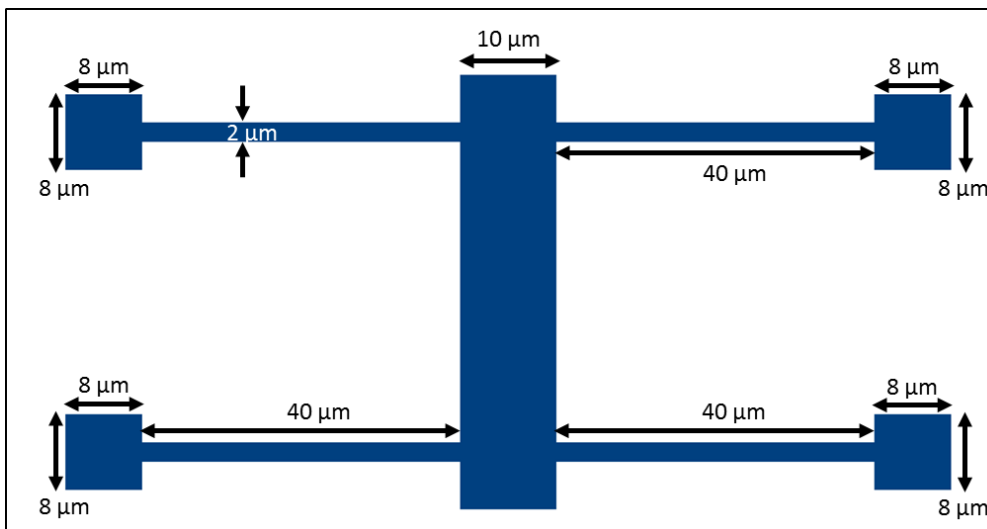
Mask 1: POLY1 (clear field)



Mask 2: ANCHOR (dark field)



Mask 3: DIMPLE (dark field)



Mask 4: POLY2 (clear field)

Free-Free Beam Surface Micromachining Process

(Cl₂/HBr at 300 Watts, 12 mTorr)

0.0 Starting Wafers: 8-12 ohm-cm, n-type, (100) prime or just n-type test wafers.

Control Wafers:

PSG1F, PSG1B (Si) NIT1F, NIT1B (Si)

POLY1F, POLY1B (tylanll ctrl.)

PSG2F, PSG2B (Si) POLY2F, POLY2B (Si)

PSG3F, PSG33 (81)

1.0 Wafer POCl₃ doping

Tystar13, recipe 13POCL3A

Flows (slm): N₂: 5, POCl₃ (in N₂): 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): SiH₄ = 60, PH₃ = 10.3 (entered), O₂ = 90

time (2μm) = 1 hour 40 minutes (~1000 Å per 5 min.)

Include etching controls: PSG1F and PSG1B

3.0 PSG Densification

RTA in Heatpulse1: 30 secs @ 950 °C

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: NIT1F and NIT1B

5.0 Interconnect Poly1 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: POLY1F, POLY1B

6.0 Interconnect Poly1 Definition Mask: POLY1 (emulsion-cf)

6.1 Spin, expose, develop, inspect, descum, hard bake.

PR thickness: 1.1 μm

6.2 Plasma etch poly-Si in Lam8 etcher, inspect

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

7.0 Sacrificial PSG Deposition: target = 2 μm

Tystar12, 12VDLTOA

Flows (sccm): SiH₄ = 60, PH₃ = 10.3 (entered), O₂ = 90

time (2 μm) = 1 hour 40 minutes (~1000 Å per 5 min.)

Include etching controls: PSG2F and PSG2B

8.0 Sacrificial PSG Densification

RTA in Heatpulse1: 30 secs @ 950 °C

(also do PSG2 ctrls)

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

9.1 Spin, expose, develop, descum, hard bake.

PR thickness: 1.1 μm

9.2 Etch in lam6:

For 1 μm oxide: etch as usual.

For 2 μm oxide: [press = 2.8 Torr, power = 350W, gap = 0.38 cm, CHF₃ = 30 sccrn, CF₄ = 90 sccrn, He = 120 sccrn, time = 1 min.], [power = 0, same gases, time = 1 min.] 3X

For both cases, overetch with 700 W recipe.

9.3 Check contact using IV probe station.

9.4 Wet dip in 5:1 BHF for 10 secs.

9.5 Remove resist, piranha clean wafers.

10.0 μStructure Dimple Photo Mask: DIMPLE (chrome-df)

10.1 Spin, expose, develop, descum, hard bake.

PR thickness: 1.1 μm

10.2 Wet dip in 5:1 BHF for 1 min.

10.3 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 ctrls).

12.0 PSG Mask Deposition: target = 500 nm

Tystar12, 12VDLTOA
Flows (sccrn): SiH₄ = 60, PH₃ = 10.3 (entered),
O₂ = 90
time = 25 minutes (~1000 A per 5 min.)
Include etching controls: PSG3F and PSG3B

13.0 Thermal Anneal

Heatpulsel: 60 min. @ 1000°C in 50 l/sec N₂

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:
(Cl₂/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 (~3.6 μm per min.).
(Etch for whatever time is needed to remove
all exposed oxide, including oxide under-
neath structures)
Slowly agitate, rinse.
Spin dry or N₂ 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 RIE 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. Note that, step 10.2 is a timed-etch that doesn't etch the entire film. 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
%49 wt. HF (release)	Oxide ER = 3.6 μm/min	Nitride	250:1
5:1 BHF (consider only for step 10.2)	Oxide ER = 400 nm/min	Nitride	450:1

- (a) Draw cross-sections with clearly labeled dimensions and thicknesses for the structure along the A-A' and B-B' lines in the layout (i) before step 11.0 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 (again, for only RIE etches). 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) Suppose a mistake in lithography results in a 3-μm misalignment for the ANCHOR mask such that the anchor areas shift to the left in the direction of the line A-A'. Draw the cross-section along line A-A' before step 15.0 of the process. How will this affect the device operation and what potential issues can this cause?
- (c) For the rest of this problem, suppose that during the fabrication you skipped the dimple lithography step so there are no dimples underneath the resonator structure. Suppose the total z-direction restoring stiffness of suspension beams can be approximated by the expression

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

where subscript i corresponds to each suspension beam, E is the material Young's modulus, 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 resonator (free-free beam) during drying is 30° . Will the resonator be stuck down after drying in air? To simplify this problem, ignore the stiffness of the resonator and the effect of surface tension of the beams and only consider the resonator when determining sticking forces. Also, assume that the room-temperature surface tension of a water-air interface is 72.75×10^{-3} N/m.

- (d) Assuming the contact angle and surface tension numbers of part (c), 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.
2. Suppose the layout shown in Figure PS3.2 is used to fabricate a clamped-free beam using a single mask process whose details are given below:
- i. Deposit $2 \mu\text{m}$ of LTO.
 - ii. Deposit $2 \mu\text{m}$ of undoped polysilicon.
 - iii. Ion implant with phosphorus.
 - iv. Do lithography: Spin and expose photoresist with the single mask layer shown in Figure PS3.2.
 - v. Etch the polysilicon using RIE. Assume that the etch is completely anisotropic with an infinite selectivity of polysilicon to oxide.
 - vi. Remove photoresist.
 - vii. Dip the wafer in 5:1 buffered hydrofluoric acid (BHF) for 10 minutes, where the etch rate of LTO in BHF is 700 nm/min .

Assume for this problem that the undoped polysilicon film is completely stress free after deposition and before the ion implantation. Also assume that there is no stiction.

- (a) Draw the final cross-section of the structure after release along A-A'.
- (b) If the implanted phosphorus is 10 nm deep with a uniform axial compressive stress of 400 MPa , how far above the surface of the wafer will the tip of the beam be once the structure is released?

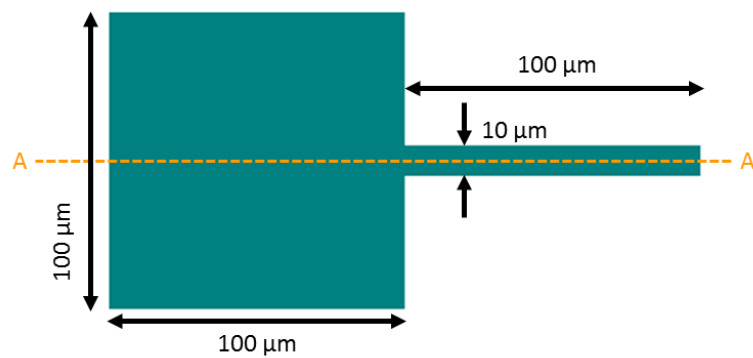


Figure PS3.2