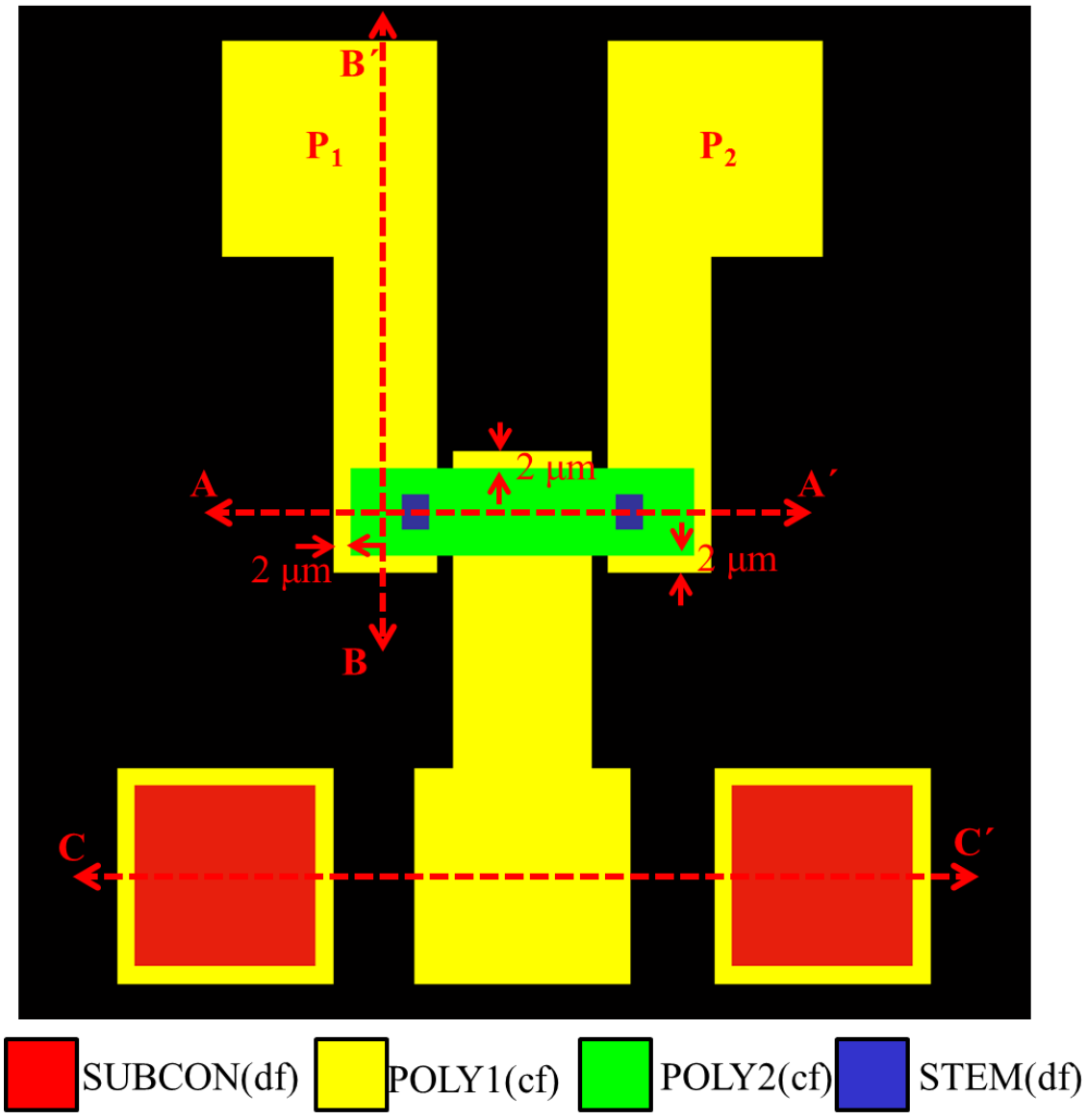
PROBLEM SET #3

Issued: Tuesday, Sept. 27, 2011

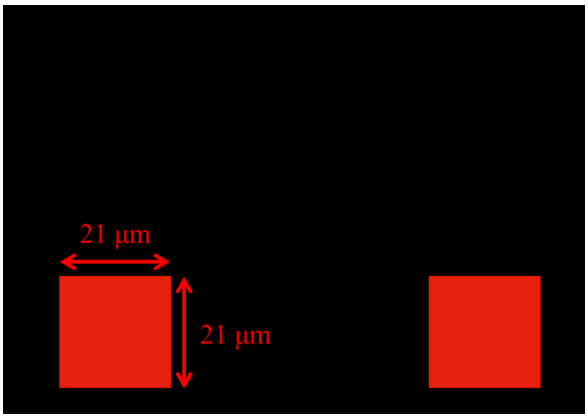
Due (at 7 p.m.): Thursday, Oct. 6, 2011, in the EE C245 HW box in 240 Cory.

1. The following pages comprise a surface micromachining process flow for a free-free micromechanical beam. 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 recipe information (i.e. film thicknesses, etch times, doses, temperatures, etc.).

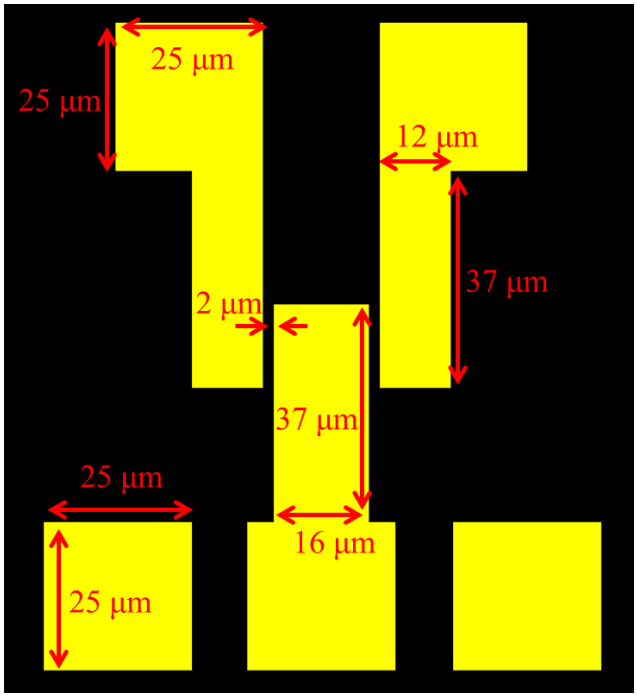


The background color of the layout editor is black. This is "field" for all masks.

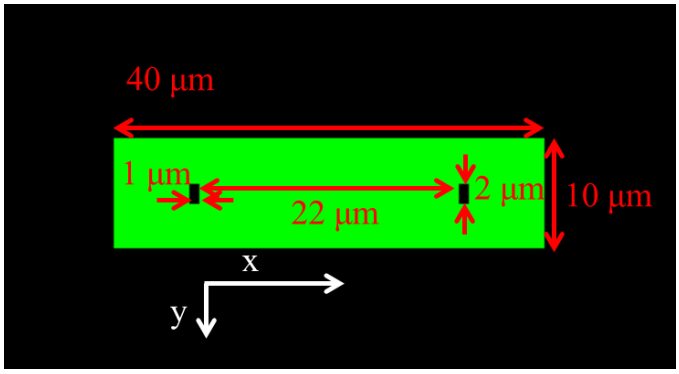
The four masks used in this process flow are shown below with dimensions.



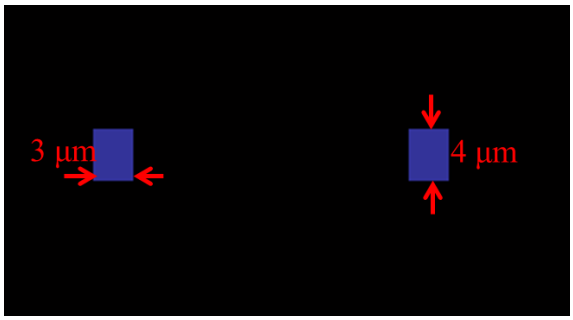
Mask 1: SUBCON (dark field)



Mask 2: POLY1 (clear field)



Mask 3: POLY2 (clear field)



Mask 5: STEM (dark field)

Self-Aligned Free-Free Beam Micromechanical Resonator w/ Sub-Micron Vertical Electrode-to-Resonator Gaps Process

---

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 (Si)
PSG2F, PSG2B (Si)
POLY2F, POLY2B (Si)
PSG3F, PSG3B (Si)
POLY3F, POLY3B (Si)

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 PSGl 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 A per 5 min.)
Include etching controls: PSG1F and PSG1B

3.0 PSG Densification
RTA in Heatpulsel: 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 Substrate Contact Mask: SUBCON (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 = 350 nm
Phosphorus-doped polysilicon deposition: Tystar16, 16VDPLYA
time = 3 hours, temp. = 650°C (~120 nm per hour)
Include etching controls: POLY1F, POLY1B

7.0 Interconnect Polyl Definition Mask: POLY1 (emulsion-cf)

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

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

8.0 Sacrificial PSG Deposition: target = 300 nm
Tystar12, 12VDLTOA
Flows (sccm): SiH_4 = 60, PH_3 = 10.3 (entered) , O_2 = 90
time (200 nm) = 30 minutes (~100 nm per 5 min.)
Include etching controls: PSG2F, PSG2B

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

10.0 μStructure Poly2 Deposition: target = 2 μm
Phosphorus-doped polysilicon deposition: Tystar16, 16SUPLYA
time = 16 hours, temp. = 650°C
Include etching controls: POLY2F, POLY2B

11.0 PSG Mask Deposition: target = 800 nm
Tystar12, 12VDLTOA
Flows (sccrn): SiH_4 = 60, PH_3 = 10.3 (entered), O_2 = 90
time = 40 minutes (~1000 A per 5 rnin.)
Include etching controls: PSG3F, PSG3B

12.0 Thermal Anneal
Heatpulsel: 60 min. @ 1000°C in 50 l/sec N_2
(also do PSG3 ctrls)

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

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

13.2 Etch oxide mask in lam6.

13.3 (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)

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

14.0 μStructure Anchor Photo Mask: STEM (chrome-df)

14.1 Spin, expose, develop, descum, hard bake.
PR thickness: 6 μm
Positive PR

14.2 Wet etch in 5:l BHF (~600 nm per min.) in sink8.
Etch for 1 minute
Slowly agitate, rinse.
Spin dry.

14.3 Remove resist, piranha clean wafers.

15.0 Stem-filling poly Deposition: target = 2 μm
Phosphorus-doped polysilicon deposition: Tystar16, 16SDPLYA
time = 16 hours, temp. = 650°C
Include etching controls: POLY3F, POLY3B

16.0 Stem-filling poly mask: STEM (chrome-df)

16.1 Spin, expose, develop, inspect, descum, hard bake.
PR thickness: 8 μm
Negative PR

16.2. Etch poly in lam8:
(Cl_2/HBr at 300 Watts, 12 mTorr)

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

16.4 Remove resist, piranha clean wafers.

17.0 μStructure Release

17.1 Piranha clean in sink8.

17.2 Wet etch in 5:l BHF (~600 nm per min.) in sink8.
(Etch for whatever time is needed to remove all exposed oxide, including oxide underneath structures)
Slowly agitate, rinse.
Spin dry or N2 gun dry.

17.3 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	Photoresist	1:1
		Oxide	2:1
		Silicon	1:3
$CF_4 + CHF_3$ + He	Oxide	Photoresist	3:1
		Nitride	4:1
		Silicon	4:1
Cl_2 + HBr	Silicon	Photoresist	1:1
		Oxide	100:1
		Nitride	1:2
HF (release)	Oxide	Stoichiometric Nitride	250:1

(a) Draw the cross-section of the structures along the A-A', B-B', and C-C' lines in the layout: (i) before step 15.0 of the process; and (ii) at the end of the process. Here, you should get the thickness dimensions correct (to within 100 nm or 20%, whichever is finer). 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) After the deposition in step 15, the nominal film thickness measured from control wafers POLY3F and POLY3B is found to be 2.1 μm. It is known that the Lam8 etches polysilicon at a rate of 200nm/minute. Based on this information, how long should the etch in step 16.2 be performed to etch 2.1 μm of polysilicon with a 30% overetch? Do any issues arise from etching for this amount of time? If so, how can the process be modified to correct these issues?

(c) 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 the bond pads P_1 and P_2 (where a probe tip might be placed in contact).

(d) Suppose the beam structure has an effective restoring stiffness of 1,500 N/m at its midpoint, and for the purposes of this problem, suppose you can use this number to represent the total restoring stiffness of the beam. Suppose also that if the beam bends, the sacrificial gap varies according to the following shape function:

$$g(x,z) = g_0 - z(\sin^2(\frac{x\pi}{22\mu m})) \text{ ; for } 0 \leq x \leq 22 \text{ μm and } 0 \leq z \leq g_0$$

where z is the downward displacement of the beam towards the substrate at its midpoint, and g_o is the initial gap spacing of the unperturbed beam. If the contact angle of water between the underside

of the beam and the substrate (and underlying electrode) is $\theta_c = 30^o$, and the room-temperature surface tension of the water-air interface is $\gamma_{la} = 72.75\times10^{-3}$ N/m, will the device be stuck down after drying in air? Consider only stiction forces under the 22 μm section (what we'll call the active area) between the anchors, and lump all the stiction force over the active area into a single force at the midpoint of the beam.

(Note that the lumping of the force and stiffness to a single point is a simplifying assumption, needed mainly because you are not yet equipped to do the problem more correctly. Later in the course, you will learn how to solve problems like this more accurately.)

(e) Assuming the same $g(x)$ function as in part (d), 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?