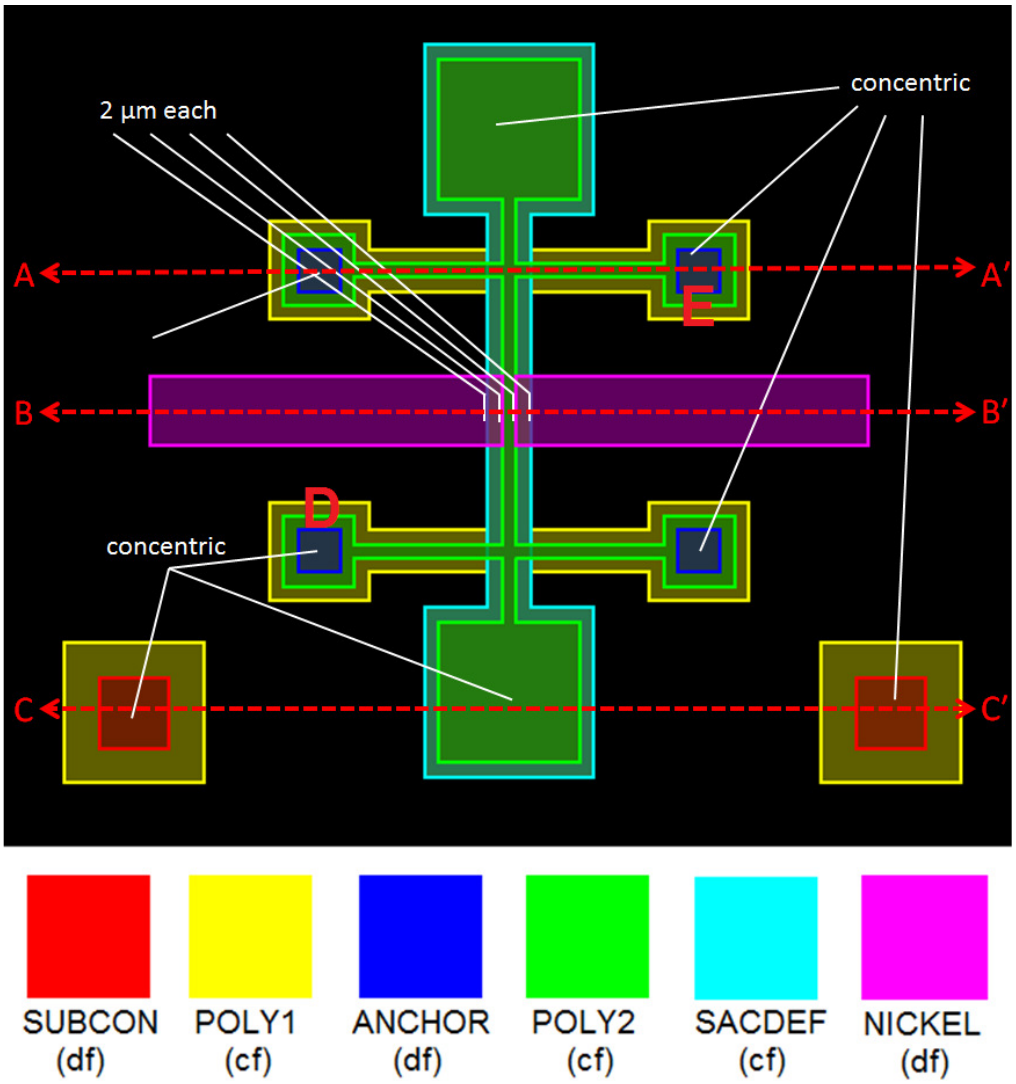
# PROBLEM SET #3

*Issued: Tuesday, Sept. 26, 2010*

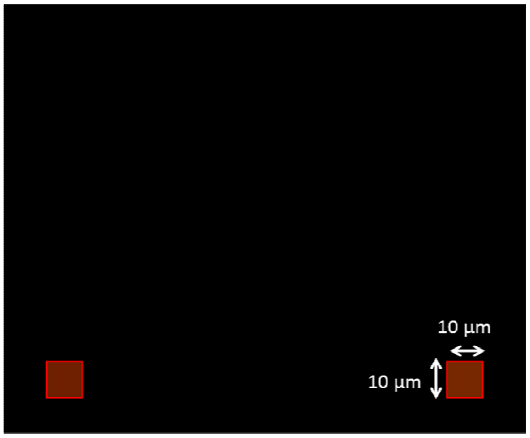
*Due (at 7 p.m.): Thursday, Oct. 7, 2010*, in the EE C245 HW box in 240 Cory.

**1.** The following pages comprise a surface micromachining process flow for a free-free micro-mechanical beam with end proof-masses (layout shown below). 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.).

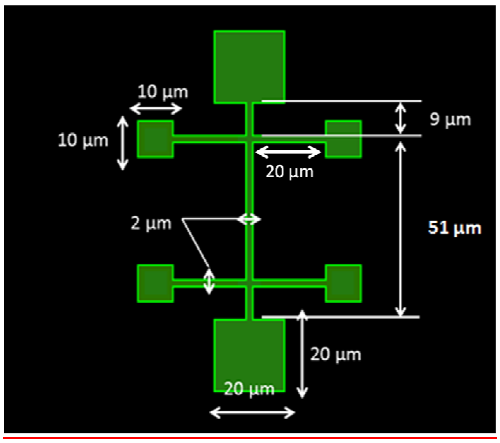



The background color of the layout editor is black. This is "field" for all masks.

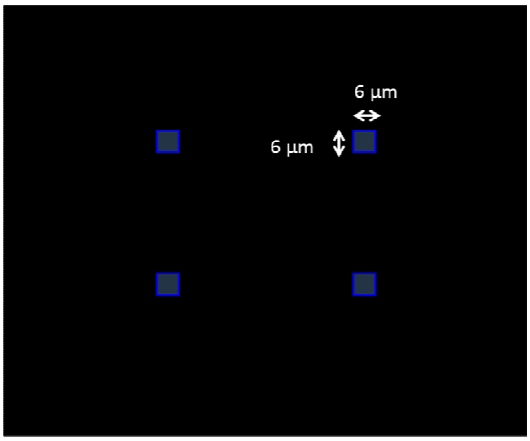
The six masks used in this process flow are shown below with dimensions.



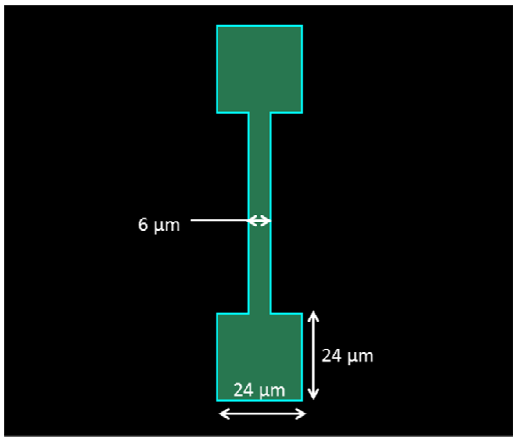

Mask 1: SUBCON (dark field)



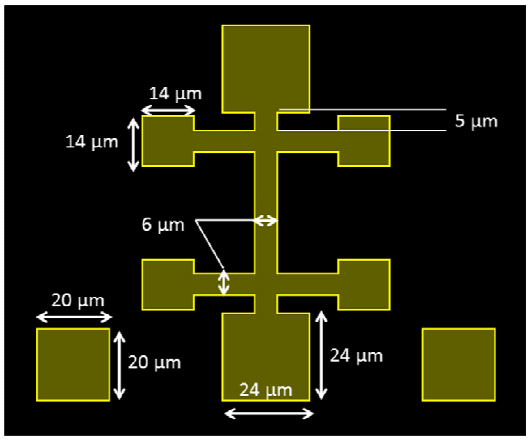

Mask 4: POLY2 (clear field)



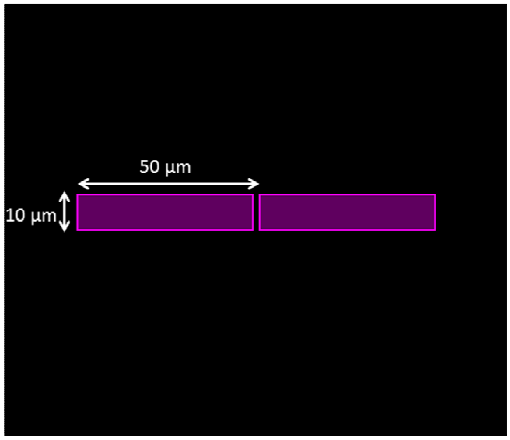

Mask 2: ANCHOR (dark field)




Mask 5: SACDEF (clear field)




Mask 3: POLY1 (clear field)




Mask 6: NICKEL (dark field)

Lateral Free-Free Beam Micromechanical Resonator with Sub-Micron Capacitive Gaps Process

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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)

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

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1.1 Strip oxide
Sink8 BHF, 1 minute

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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: PSGlF and PSGlB

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3.0 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

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4.0 Substrate Contact Mask: SUBCON (chrome-df)

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

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4.2 Etch nitride in Lam1.
$SF_6$ = 175 sccm, He = 50 sccm

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4.3. Etch in Lam2:
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
4.4. Wet dip in 10:1 BHF for 20 s to remove native oxide.
4.5 Remove resist, piranha clean wafers.

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5.0 Interconnect Polyl Deposition: target = 300 nm
Phosphorus-doped polysilicon deposition: Tystar16, 16VDPLYA
time = 2 hour 30 minutes, temp. = 650°C (~120 nm per hour)
Include etching controls: POLYlF, POLYlB

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

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

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6.2 Plasma etch poly-Si in Lam5 etcher, inspect
($Cl_2$/HBr at 300 Watts, 12 mTorr)

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

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7.0 Sacrificial PSG Deposition: target = 600 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 and PSG2B

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

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

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

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9.2 Etch in lam2:
For 1 µm oxide: etch as usual.
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
For both cases, overetch with 700 W recipe.

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9.3 Check contact using IV probe station.

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

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9.5 Remove resist, piranha clean wafers.

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10.0 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).

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11.0 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

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

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

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

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13.2 Etch oxide mask in lam2.

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

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13.4 Etch 2nd poly in lam5:
($Cl_2$/HBr at 300 Watts, 12 mTorr)

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

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14.0 Sacrificial High Temperature Oxide (HTO) Deposition:
target = 100 nm
Tystar17, Custom Recipe
Temperature = 835°C, Pressure = 600 mTorr
Flows (sccm): DCS = 100, $N_2O$ = 40
Time (100 nm) = 48 minutes (~21A/min)

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15.0 Sacrificial Oxide Definition Mask: SACDEF (chrome-cf)

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

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15.2. Etch in Lam2:
For 100 nm HTO: [press = 2.8 Torr, power = 350 W, gap = 0.38 cm, $CHF_3$ = 30 sccm, $CF_4$ = 90 sccm, He = 120 sccm, time = 10 sec.]
15.3. Wet dip in 20:1 BHF for 10 s to remove native oxide.
15.4 Remove resist, piranha clean wafers.

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16.0 Ni Seed Layer Definition Using Etchback

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16.1 Ni Evaporate: target = 40 nm
Edwardeb3
time (40 nm) = 400 secs (~ 0.1 nm per sec. )

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16.2 Spin thick PR, soft bake.
PR thickness: 10 µm

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16.3 $O_2$ Plasma etch PR in Ptherm etcher, inspect
Flows (sccm): $O_2$ = 100
Power = 150 Watts
time = 8 mins (1 µm/min)

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16.4 Etch Ni with Ni etchant
CH3COOH:HNO3:H2SO4=5:5:2 solution
time (40 nm) = 2 mins (~ 20 nm per 1 min)

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16.5 Remove resist:
technics-c, 10 min. 02 plasma B 300 W

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17.0 Ni Electrode Deposition Mask: NICKEL (chrome-df)

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17.1 Create PR mold for electroplating:
Spin, expose, develop, inspect, descum.
PR thickness: 5 µm

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17.2 Ni Electroplate:
current I = 3 mA
time (2.2 µm) = 67 mins (~33 nm per min)

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17.3 Remove resist:
technics-c, 10 min. 02 plasma B 300 W

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17.4 Remove Ni seed layer:
CH3COOH:HNO3:H2SO4=5:5:2 solution
time (40 nm) = 2 mins (~ 20 nm per 1 min)

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18.0 µStructure Release

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18.1 Piranha clean in sink8.

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18.2 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.

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18.3 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. Assume positive photoresist is used throughout the entire process.

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 |
| $CH_3COOH$+$HNO_3$+$H_2SO_4$ | Nickel | Photoresist | 5:1 |
| | | Oxide | 300:1 |
| | | Nitride | 300:1 |
| 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)** What is the electrical resistance through the structure between anchors D and E? Assume $\mu_n$ = 1200 cm$^2$/V·s in both the Poly1 and Poly2 layers and that the active dopant concentration of the in-situ phosphorous-doped polysilicon is $3\times10^{20}$ cm$^{-3}$. Use $1\times10^{21}$ cm$^{-3}$ for the solid solubility limit of phosphorus in polysilicon. Assume $E_A$ = 3.7 eV and $D_0$ = 10.5 cm$^2$/s for any diffusion steps.

**(c)** Suppose the center beam and proof masses comprise a ~~semi-~~rigid structure and are supported by an effective restoring stiffness of 1000 N/m by the horizontal anchored support beams. If the contact angle of water between the underside structure and the substrate $\theta_c$ = 30°, and the room-temperature surface tension of the water-air interface $\gamma_{la} = 72.75\times10^{-3}$ N/m, will the device be stuck down after drying in air?

**(d)** 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? [Hint: How can you know this if the contact angle is unknown?]

| **Liquid** | **Surface Tension, $\gamma_{la}$ (N/m)** | **Contact Angle, $\theta_c$ (°)** |
|---|---|---|
| Water | $72.75\times10^{-3}$ | 30 |
| Methanol | $22.70\times10^{-3}$ | Unknown |